# Dillingham, Alaska Wind Resource Report
# Woodriver Road Site

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Photo © Doug Vaught


## *Summary Information*

Winds measured in Dillingham were consistent with the State wind resource map and are acceptable for wind power development in the community. Because of the structural mass and complexity of the State EMS tower used as the test platform, the wind shear and turbulence were higher than is likely true. Because a successful wind power project has the potential to lower the electrical power generation costs in Dillingham, installation of a 40 or 50 meter meteorological tower nearby may yield better data.

*Meteorological Tower Data Synopsis*

| | |
|---|---|
| Wind power class | Class 3 – Fair |
| Average annual wind speed (33 meters) | 5.99 m/s |
| Maximum wind gust (2 sec. average) | 31.3 m/s, 4/21/05 |
| Mean wind power density (50 meters) | 375 W/m$^2$ (calculated) |
| Mean wind power density (33 meters) | 289 W/m$^2$ (measured) |
| Weibull distribution parameters | k = 1.85, c = 6.64 m/s |
| Roughness Class | 3.06 (forest) |
| Power law exponent | 0.235 (high wind shear) |
| Turbulence Intensity | 0.110 (moderate) |
| Data start date | April 22, 2004 |
| End data date | July 13, 2006 |

*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 | 2255 |
| Site Description | Dillingham Woodriver Road, on State EMS tower |
| Latitude/longitude | N 59° 03.700’ W 158° 28.350’ |
| Site elevation | 38 meters |
| Datalogger type | NRG Symphonie |
| Tower type | State EMS communications tower |


*Tower Sensor Information*

| Channel | Sensor type | Height | Multiplier | Offset | Orientation |
|---|---|---|---|---|---|
| 1 | NRG #40 anemometer | 33 m | 0.765 | 0.35 | East |
| 2 | NRG #40 anemometer | 19 m | 0.765 | 0.35 | Northwest |
| 7 | NRG #200P wind vane | 33 m | 0.351 | 172 | North |
| 9 | NRG #110S Temp C | 2 m | 0.136 | -86.383 | N/A |

## *Data Quality Control*

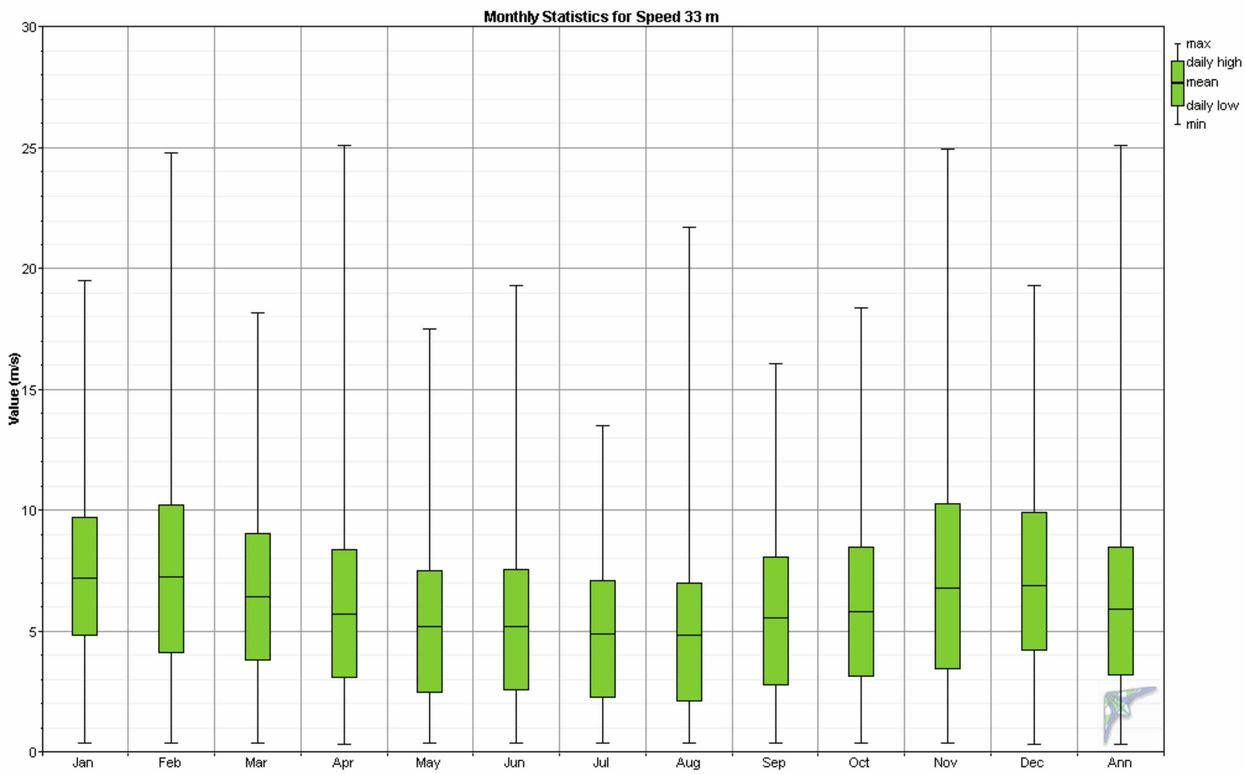
Data was filtered to remove presumed icing events that yield false zero wind speed data. Data that met the following criteria were filtered: wind speed < 1 m/s, wind speed standard deviation = 0, and temperature < 3 °C. Note that data recovery during the months of May through October was nearly 100%, but during the months of November through April some data was filtered, with November 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; all other analyses in this report are from the synthesized data set.

| | | 33 m anemometer | | 19 m anemometer | | Wind vane | | Temperature | |
|---|---|---|---|---|---|---|---|---|---|
| Year | Month | Records | Recovery Rate (%) | Records | Recovery Rate (%) | Records | Recovery Rate (%) | Records | Recovery Rate (%) |
| 2004 | Apr | 1,140 | 93.7 | 1,140 | 93.7 | 1,081 | 88.8 | 1,217 | 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 | 4,443 | 99.5 | 4,443 | 99.5 | 4,464 | 100 | 4,464 | 100 |
| 2004 | Nov | 4,152 | 96.1 | 4,050 | 93.8 | 3,759 | 87.0 | 4,320 | 100 |
| 2004 | Dec | 3,650 | 81.8 | 3,497 | 78.3 | 2,294 | 51.4 | 4,464 | 100 |
| 2005 | Jan | 4,359 | 97.6 | 4,225 | 94.6 | 3,822 | 85.6 | 4,464 | 100 |
| 2005 | Feb | 4,032 | 100 | 4,014 | 99.6 | 3,742 | 92.8 | 4,032 | 100 |
| 2005 | Mar | 4,385 | 98.2 | 4,345 | 97.3 | 4,395 | 98.5 | 4,464 | 100 |
| 2005 | Apr | 4,258 | 98.6 | 4,258 | 98.6 | 4,217 | 97.6 | 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 | 4,464 | 100 | 4,464 | 100 | 4,415 | 98.9 | 4,464 | 100 |
| 2005 | Nov | 2,200 | 50.9 | 2,159 | 50.0 | 2,115 | 49.0 | 4,320 | 100 |
| 2005 | Dec | 4,233 | 94.8 | 3,002 | 67.2 | 3,650 | 81.8 | 4,464 | 100 |
| 2006 | Jan | 4,244 | 95.1 | 4,151 | 93.0 | 4,464 | 100 | 4,464 | 100 |
| 2006 | Feb | 3,946 | 97.9 | 3,912 | 97.0 | 3,978 | 98.7 | 4,032 | 100 |
| 2006 | Mar | 4,464 | 100 | 4,464 | 100 | 4,407 | 98.7 | 4,464 | 100 |
| 2006 | Apr | 4,320 | 100 | 4,320 | 100 | 4,320 | 100 | 4,320 | 100 |
| 2006 | May | 4,464 | 100 | 4,464 | 100 | 4,464 | 100 | 4,464 | 100 |
| 2006 | Jun | 4,320 | 100 | 4,320 | 100 | 4,320 | 100 | 4,320 | 100 |
| 2006 | Jul | 1,782 | 100 | 1,782 | 100 | 1,782 | 100 | 1,782 | 100 |
| All data | | 112,920 | 96.6 | 111,074 | 95.0 | 109,753 | 93.9 | 116,903 | 100 |

## ***Measured Wind Speeds***

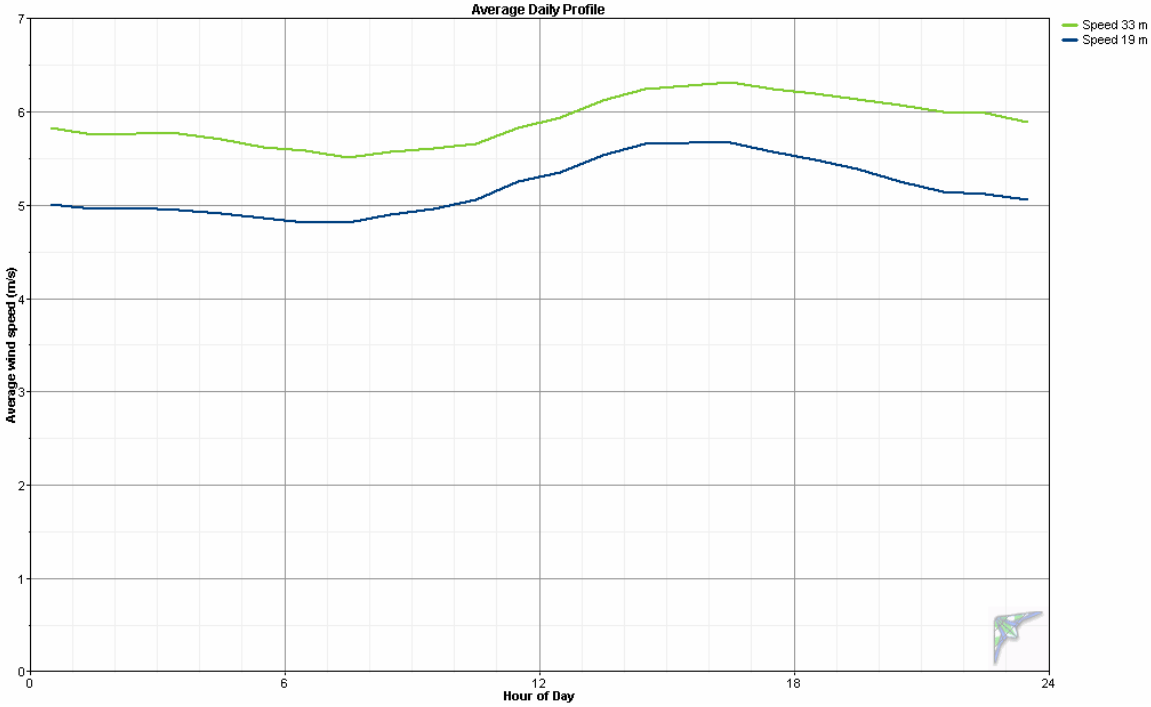
The 33 meter (Channel 1) anemometer annual wind speed average for the reporting period is 5.90 m/s and the 20 meter (Channel 2) anemometer wind speed average is 5.18 m/s.

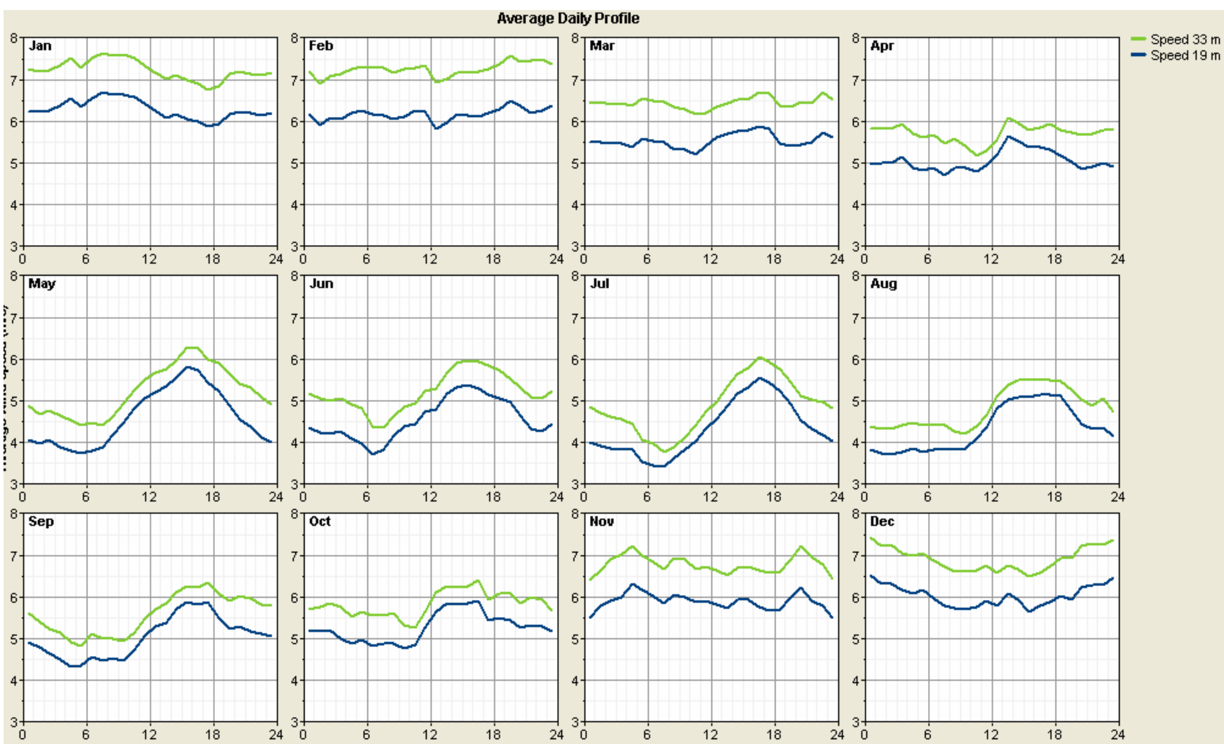
| | 33 m speed | | | | | 19 m speed | | | |
|---|---|---|---|---|---|---|---|---|---|
| Month | Mean (m/s) | Max (m/s) | Std. Dev. (m/s) | Weibull k | Weibull c (m/s) | Mean (m/s) | Max (m/s) | Weibull k | Weibull c (m/s) |
| Jan | 7.23 | 19.5 | 3.916 | 1.869 | 8.107 | 6.29 | 17.6 | 1.682 | 6.995 |
| Feb | 7.25 | 24.8 | 4.023 | 1.886 | 8.174 | 6.17 | 22.8 | 1.891 | 6.950 |
| Mar | 6.44 | 18.2 | 3.411 | 1.947 | 7.249 | 5.54 | 16.3 | 1.925 | 6.223 |
| Apr | 5.71 | 25.1 | 3.103 | 1.919 | 6.435 | 5.06 | 19.7 | 1.918 | 5.690 |
| May | 5.22 | 17.5 | 2.698 | 1.993 | 5.874 | 4.59 | 15.9 | 1.990 | 5.166 |
| Jun | 5.21 | 19.3 | 2.699 | 2.015 | 5.879 | 4.56 | 16.1 | 1.995 | 5.132 |
| Jul | 4.88 | 13.5 | 2.242 | 2.287 | 5.492 | 4.33 | 12.2 | 2.321 | 4.866 |
| Aug | 4.82 | 21.7 | 2.577 | 1.944 | 5.431 | 4.33 | 20.3 | 1.929 | 4.881 |
| Sep | 5.58 | 16.1 | 2.908 | 1.999 | 6.290 | 5.03 | 14.7 | 2.065 | 5.665 |
| Oct | 5.84 | 18.4 | 3.199 | 1.874 | 6.559 | 5.27 | 17.3 | 1.935 | 5.943 |
| Nov | 6.78 | 24.9 | 3.961 | 1.709 | 7.559 | 5.89 | 21.6 | 1.742 | 6.597 |
| Dec | 6.92 | 19.3 | 3.511 | 2.007 | 7.763 | 6.03 | 16.6 | 1.962 | 6.754 |
| Annual | **5.99** | 25.1 | 3.290 | 1.850 | 6.636 | **5.26** | 22.8 | 1.857 | 5.830 |




*Daily Wind Profile*

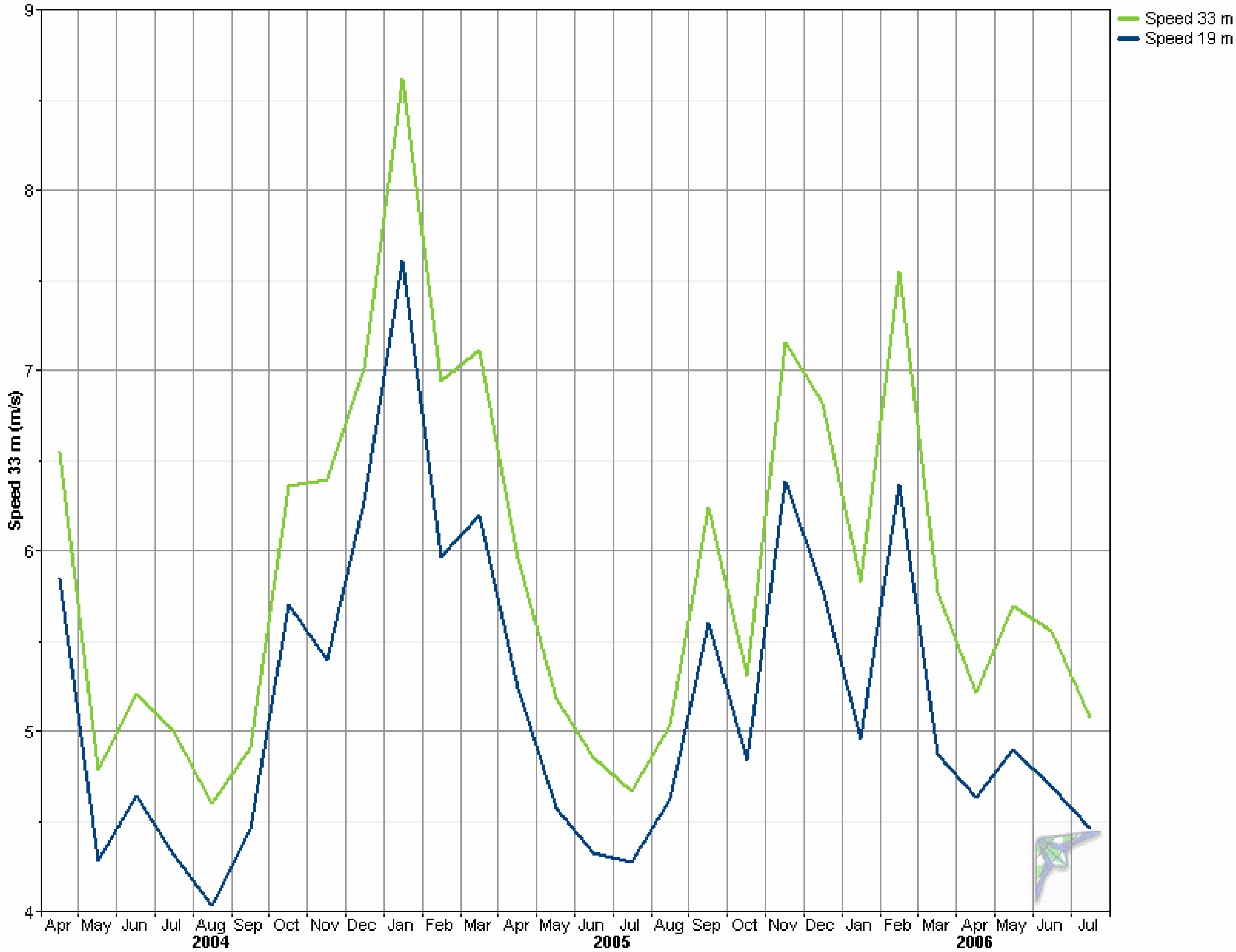
The daily wind profile indicates that the lowest wind speeds of the day occur in the morning hours of 5 to 9 a.m. and the highest wind speeds of the day occur during the afternoon and evening hours of 2 to 6 p.m. The daily variation of wind speed is minimal on an annual basis but is more pronounced on a monthly basis.

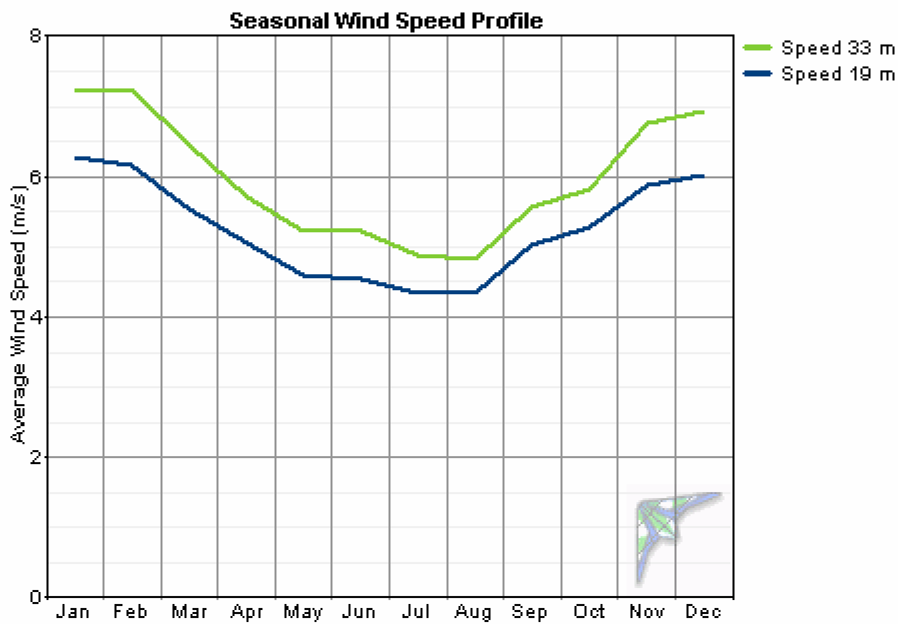


*Time Series of Wind Speed Averages*

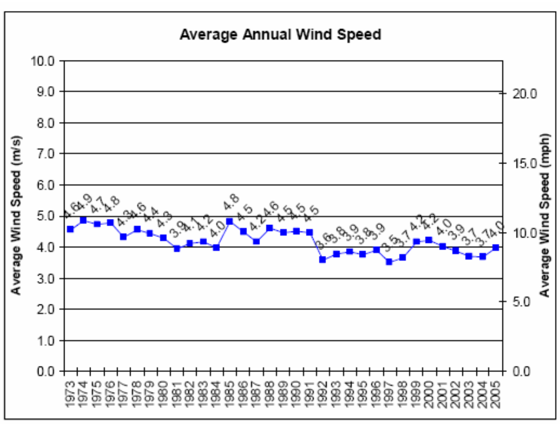
As expected, the highest winds in Dillingham occur during the fall through spring months with relatively light winds during the summer months of May through August. The second graph indicates typical daily wind speed variation during winter months, while the third graph shows measured monthly wind speeds for the entire measurement period (data not combined).





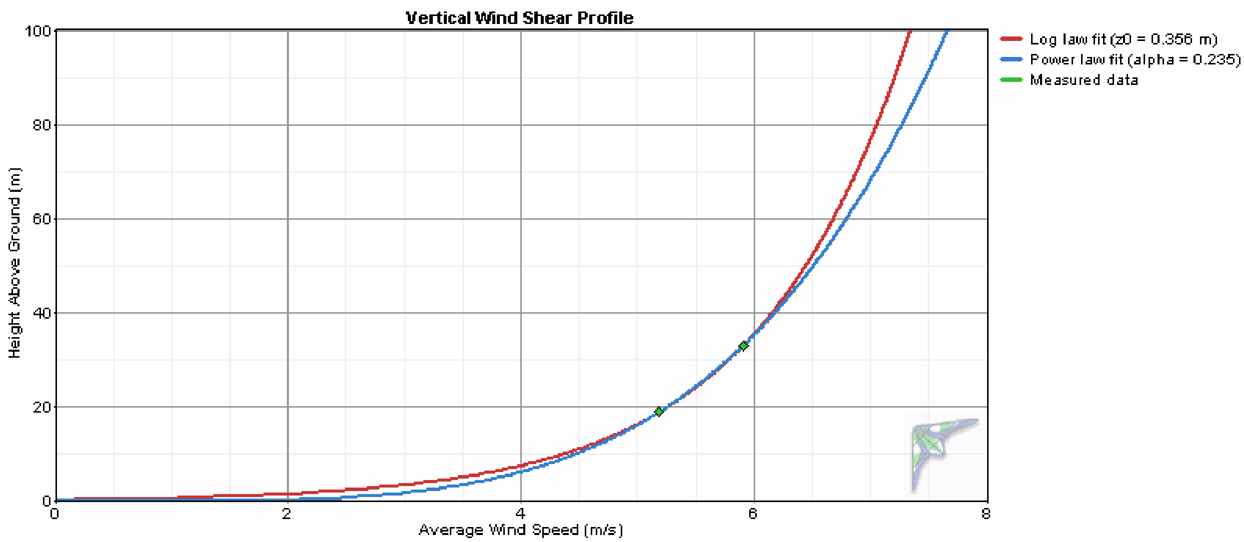

*Long-term Data Comparison*

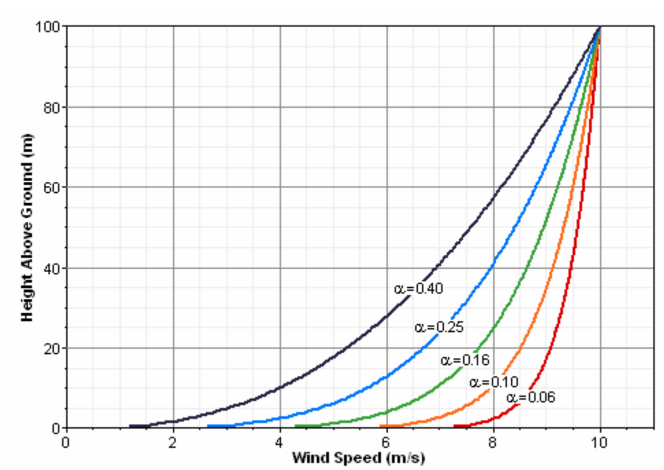
The graph below of average annual wind speed for the nearby Dillingham airport indicates that 2004 and 2005 experienced possibly low average annual wind speeds when compared to data over the past thirty-two years, although in comparison to the past ten years, the 2004/05 wind speeds recorded at the airport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

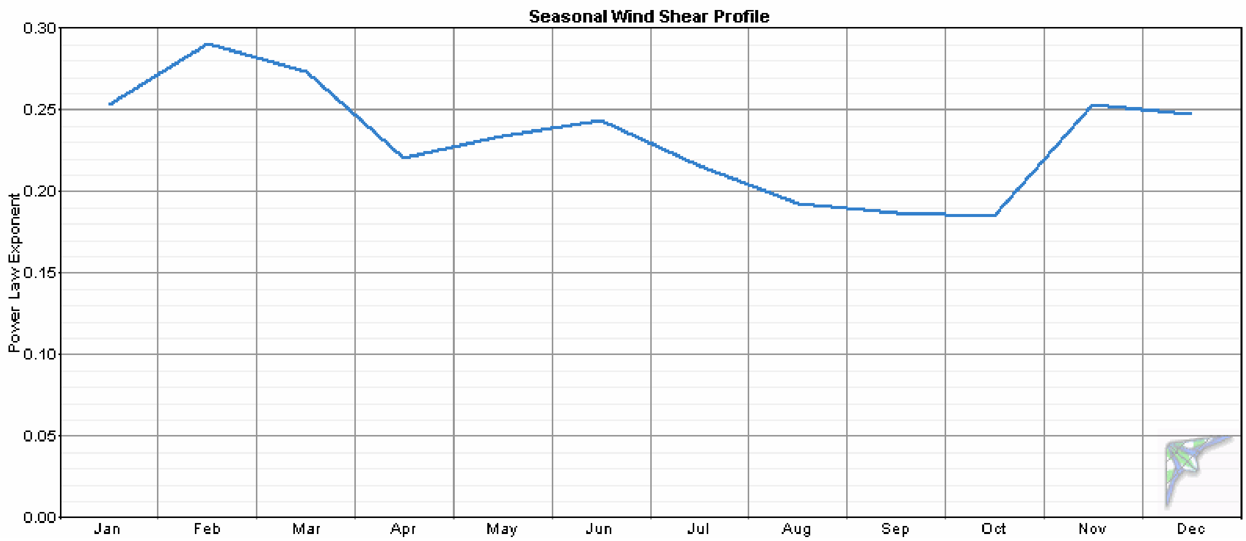


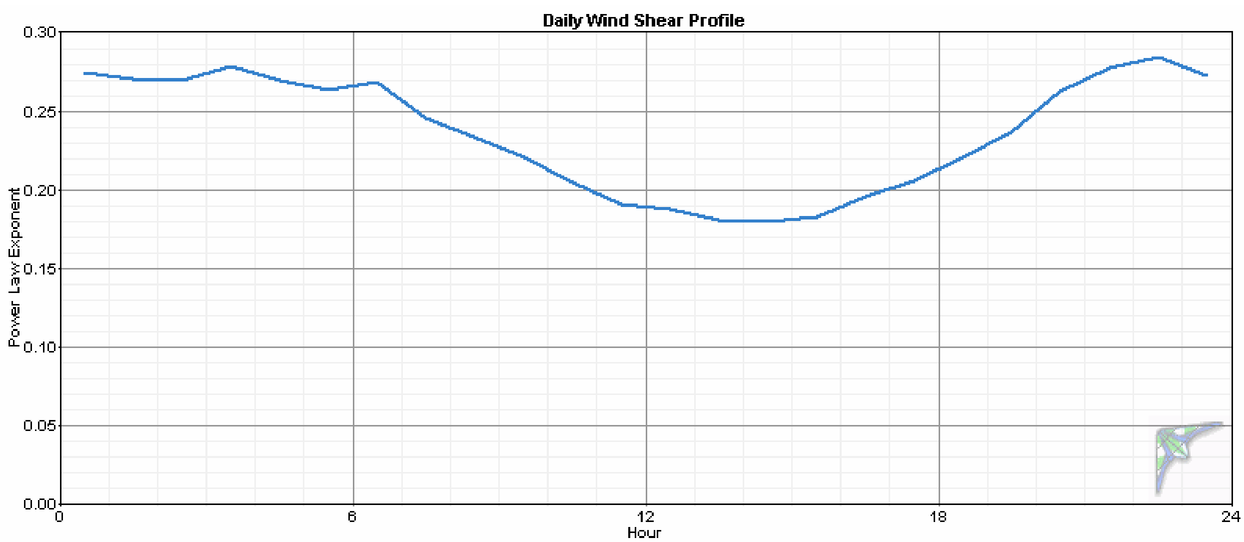
## *Wind Shear Profile*

The power law exponent was calculated at 0.235, indicating relatively high wind shear at the Dillingham test site.  Wind shear however very likely negatively affected by the structure of the State EMS tower on which the sensors were placed.  From certain wind directions, shading occurred which placed the 19 meter anemometer in a tower shadow compared to the higher anemometer.  A meteorological tower, preferably 40 or more meters in height, 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 particular data set may overestimate the wind resource at heights greater than 33 meters.



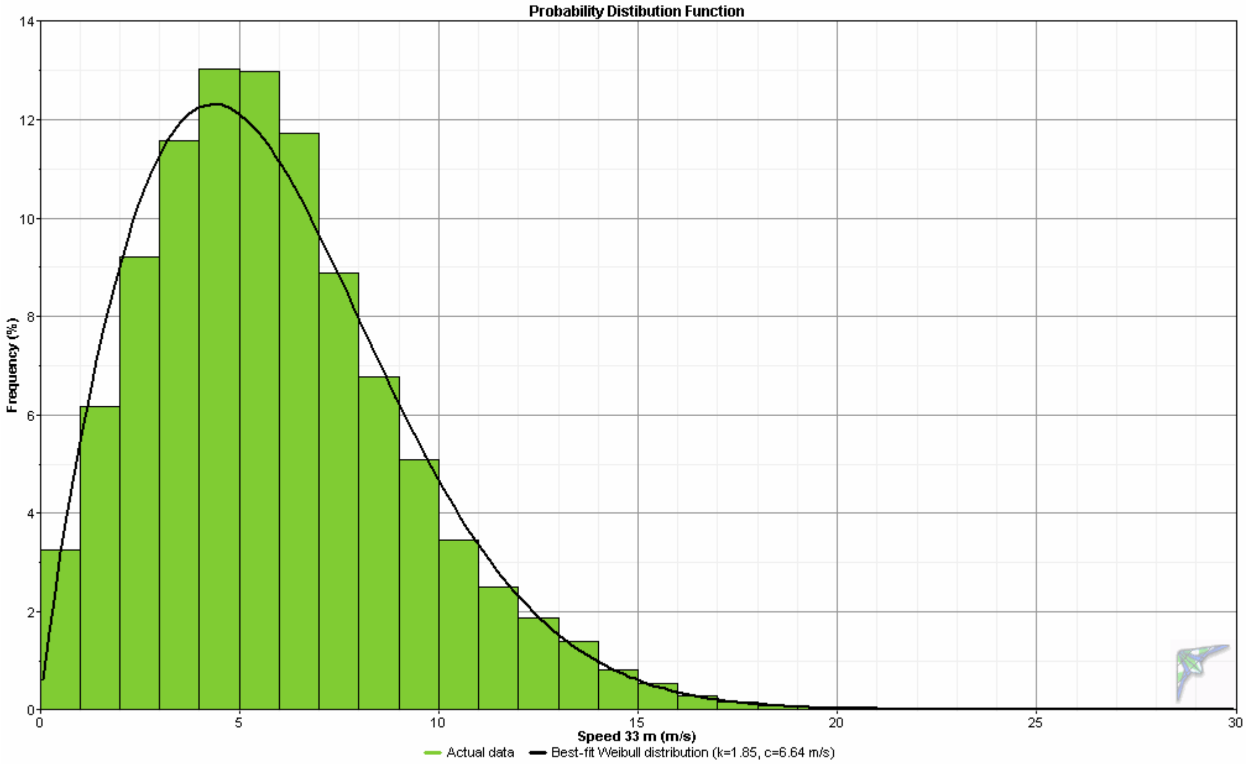



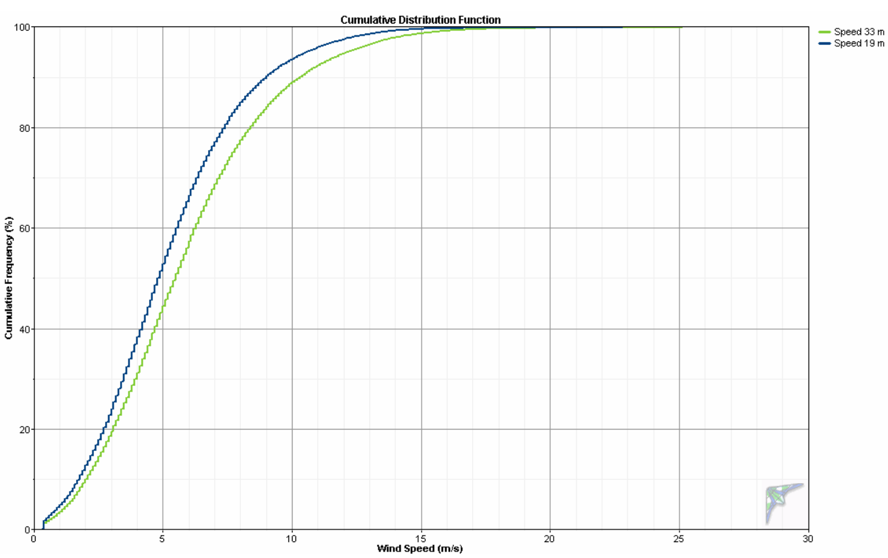

Seasonal Wind Shear Profile
Power Law Exponent
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


Daily Wind Shear Profile
Power Law Exponent
0.30
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. The black line in the graph is a best fit Weibull distribution. At the 30 meter level, Weibull parameters are k = 1.85 (indicates a relatively low distribution of wind speeds) and c = 6.64 m/s (scale factor for the Weibull distribution). The PDF information is shown visually in another manner in the second graph, the Cumulative Distribution Function.

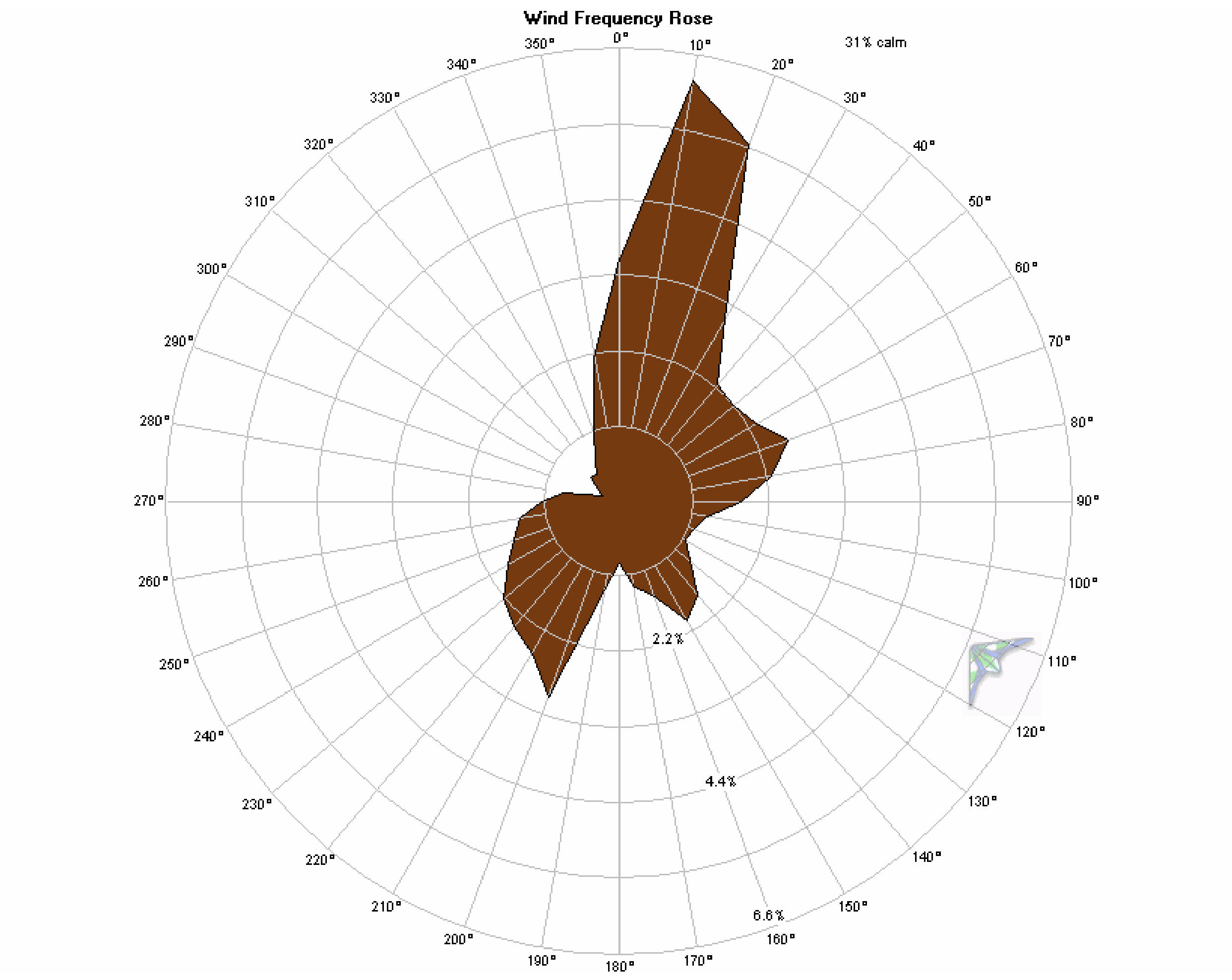


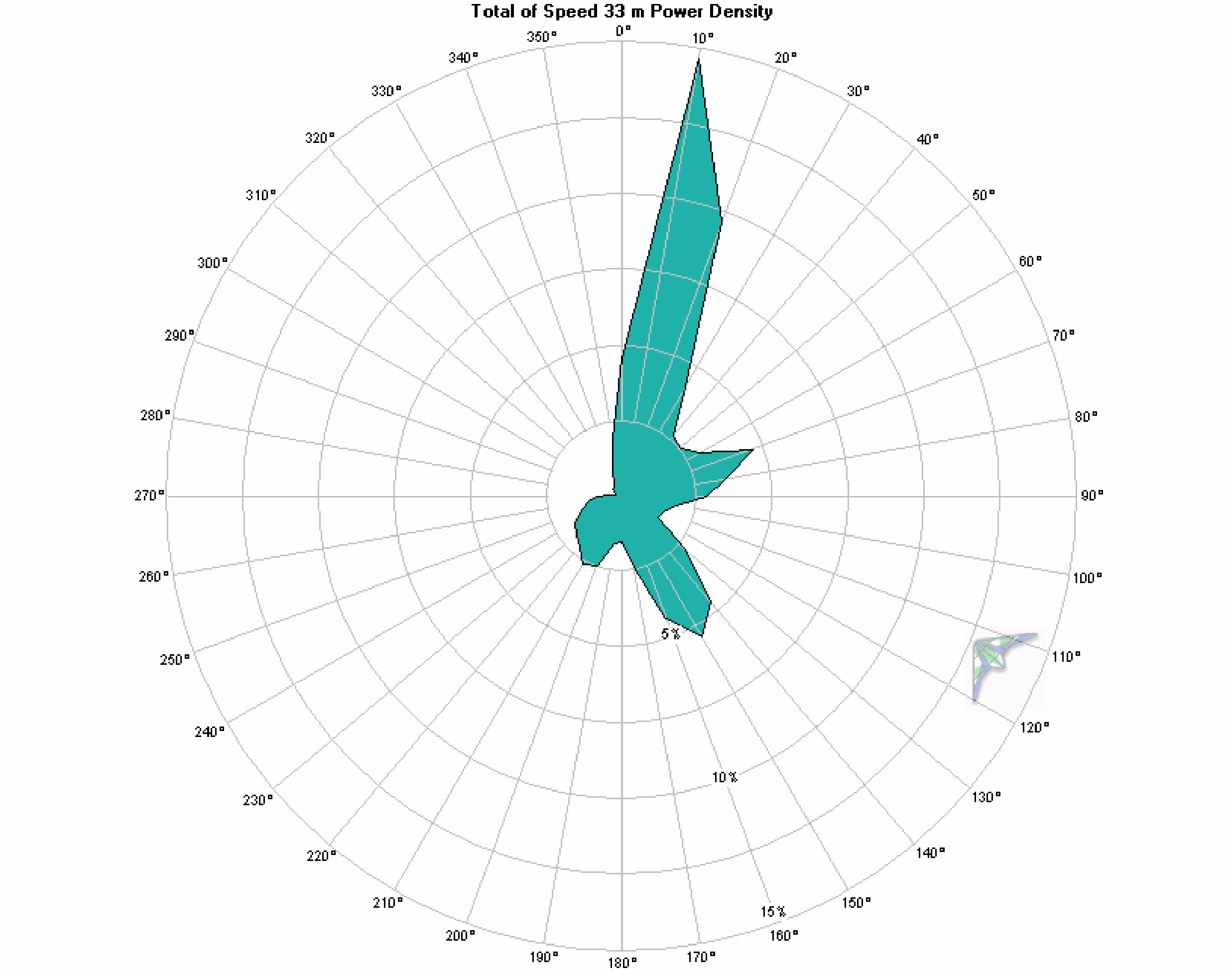
## *Wind Roses*

Dillingham winds measured at Woodriver Road were directional, mostly from the north, but this may not be completely accurate as the wind vane faced north with a bulky tower structure behind it. The wind rose for at the Kanakanak test site several miles away indicated more variability in both the wind frequency and power density roses than observed at Woodriver Road. If a wind power project is planned at the Woodriver Road area in the future, it may be advisable to log wind direction again if multiple turbines are planned and site constraints require close placement; this will avoid excess tower shadow effects if there is more wind direction variability than these wind roses indicate. The indication below of 31 percent calm winds is calculated with a 4 m/s wind speed threshold, the typical cut-in speed of wind turbines.

*Wind Frequency Rose (33 meters)*

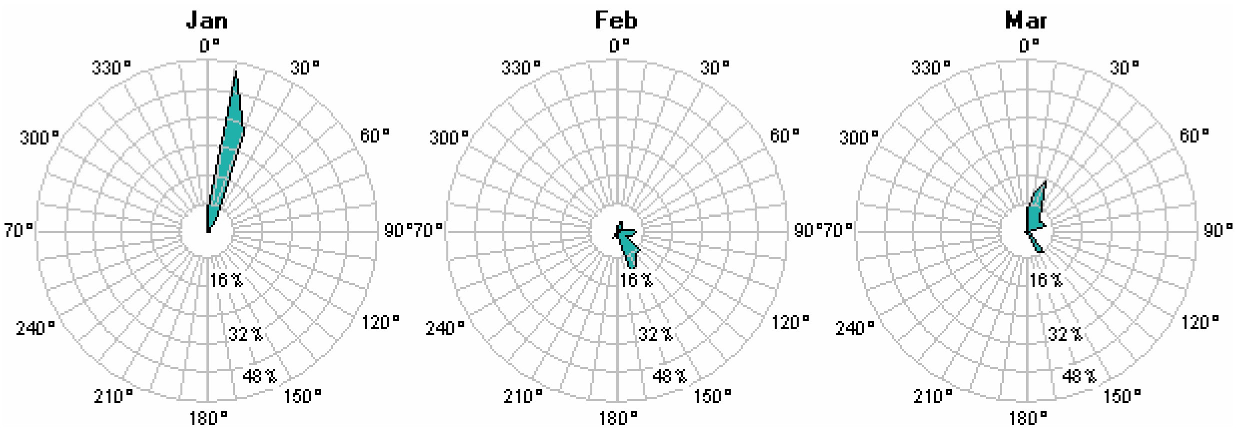


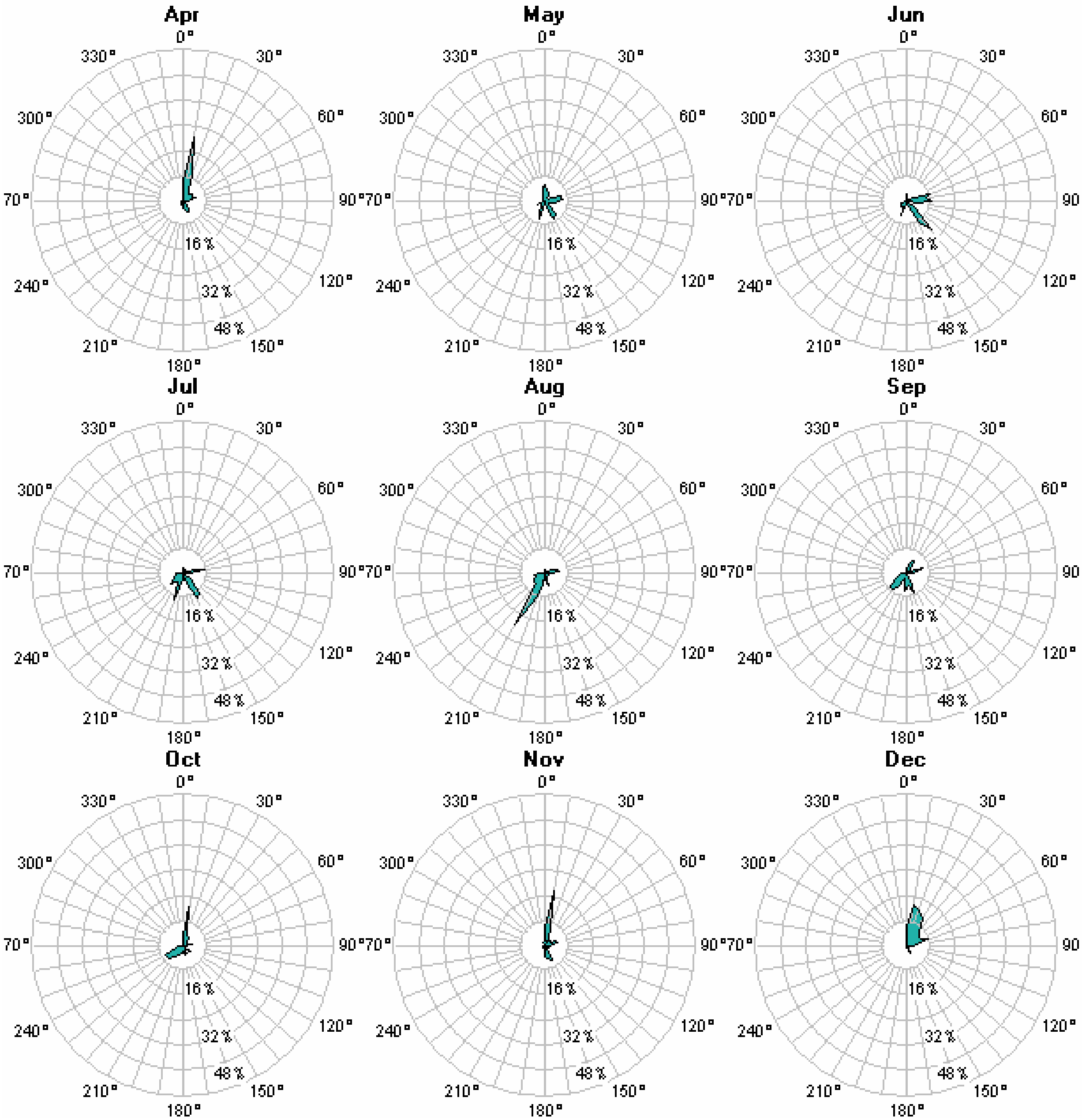
*Wind Power Density Rose (33 meters)*




*Wind Power Density Rose by Month (33 meters)*

Note: scale is common

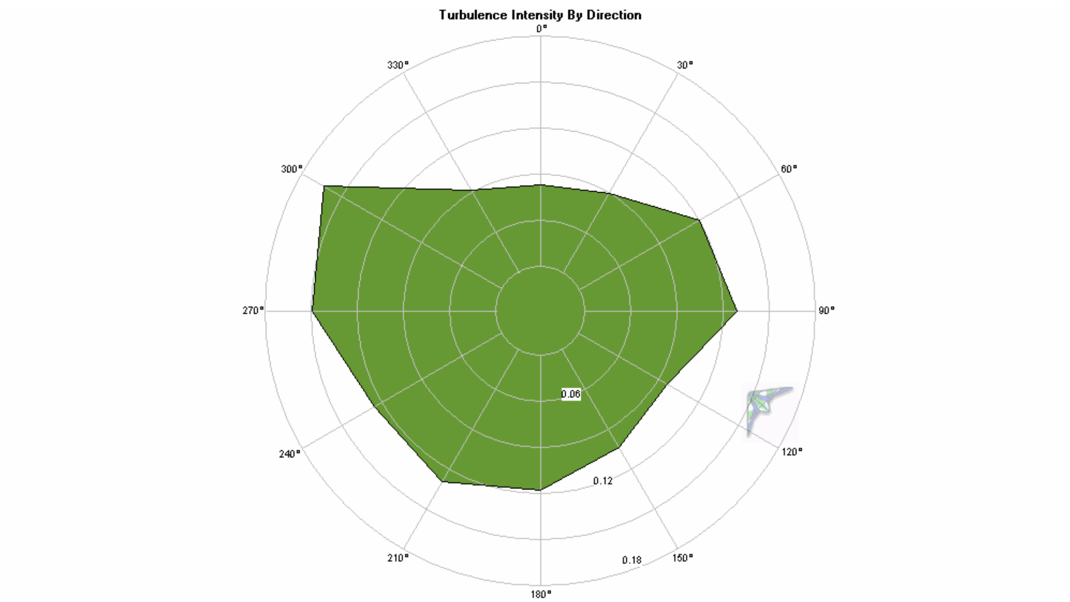



Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
0°
30°
60°
90°
120°
150°
180°
210°
240°
270°
300°
330°
16 %
32 %
48 %

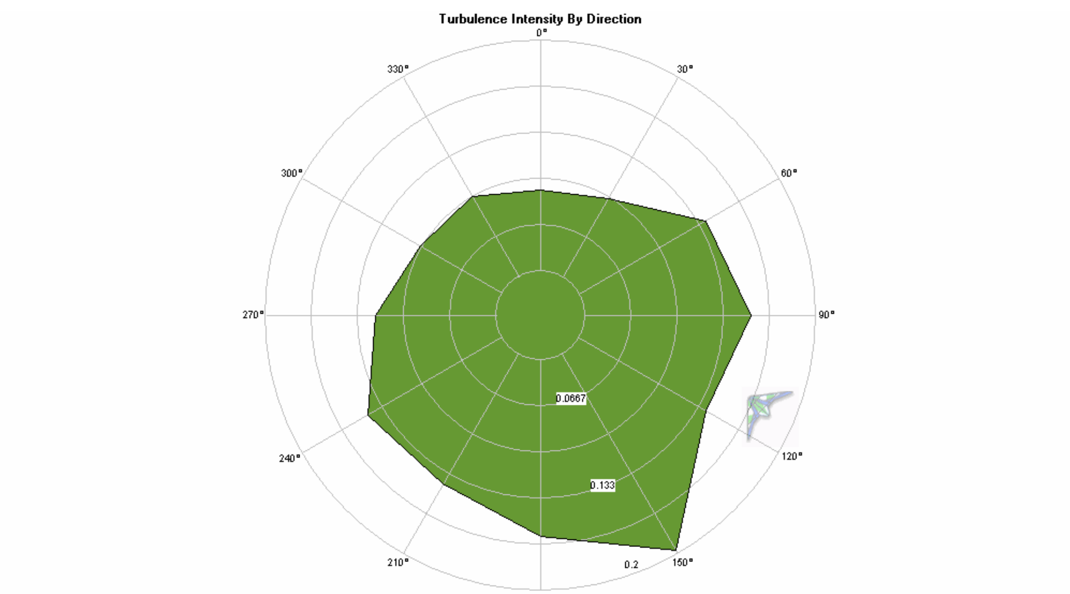
## *Turbulence Intensity*

The turbulence intensity (TI) is acceptable for all wind direction, with a mean turbulence intensity at 33 meters of 0.110 (Channel 1) and at 19 meters of 0.128 (Channel 2), indicating moderately smooth air. The higher turbulence intensity to the southeast in the second TI rose below is because the 19 meter anemometer faced to the northwest. Southeast winds blew through the lattice structure of the tower, creating abnormally turbulent air. These TIs are calculated with a threshold wind speed of 4 m/s.

*Turbulence Intensity Rose – 33 meters*

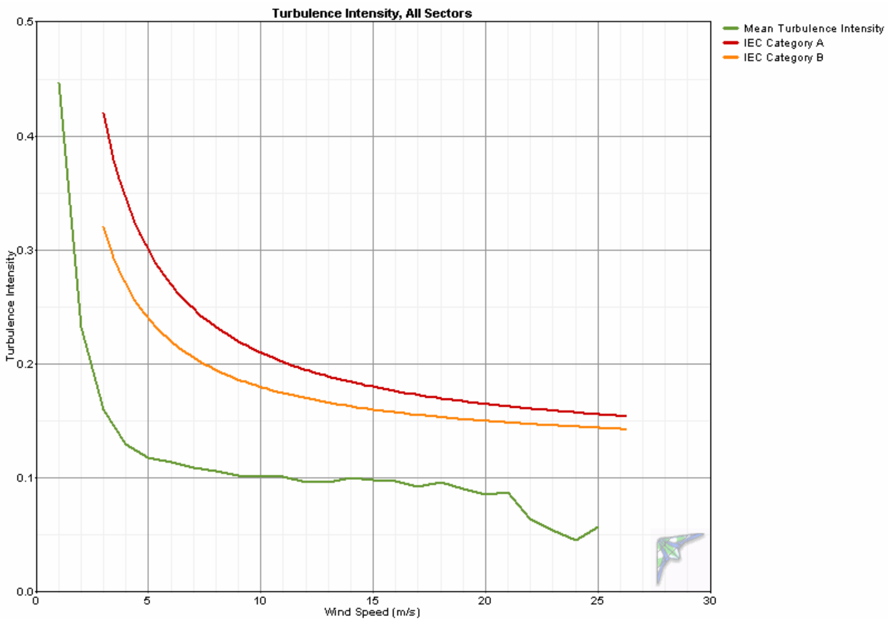


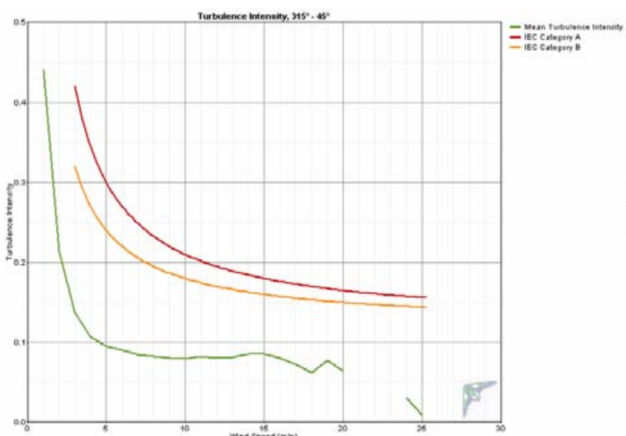

*Turbulence Intensity Rose – 19 meters*

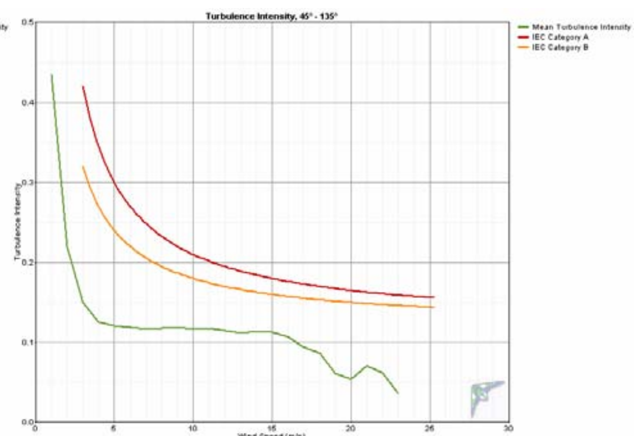


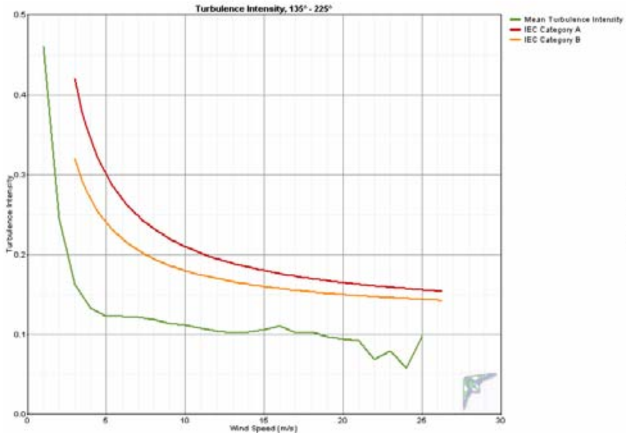
*IEC Turbulence Intensity Standards*

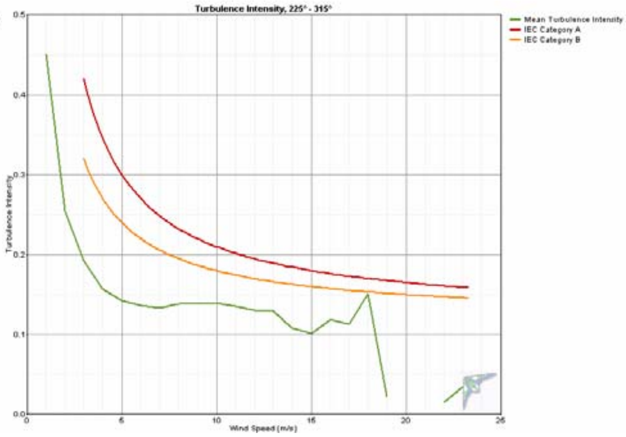
Turbulence at the Dillingham Woodriver met tower test site is within International Electrotechnical Commission (IEC) standards at all measured wind speeds and from all four quadrants of the wind rose (except for IEC Category B at higher wind speeds in 315° to 45° sector (this sector experiences infrequent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






*Turbulence Table*

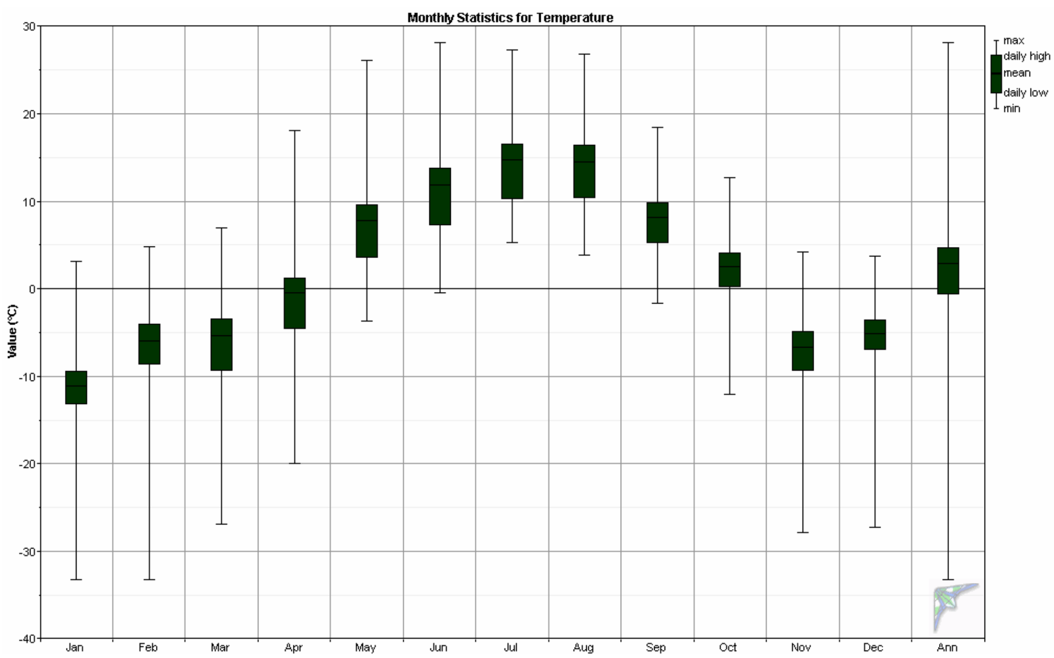
33 meter anemometer, 4/22/04 to 7/13/06, threshold 4 m/s

| 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 | 5127 | 0.421 | 0.446 | 0.183 | 0.629 |
| 2 | 1.5 | 2.5 | 9286 | 0.453 | 0.233 | 0.117 | 0.350 |
| 3 | 2.5 | 3.5 | 12374 | 0.473 | 0.160 | 0.079 | 0.239 |
| 4 | 3.5 | 4.5 | 14497 | 0.514 | 0.130 | 0.061 | 0.191 |
| 5 | 4.5 | 5.5 | 15299 | 0.585 | 0.118 | 0.053 | 0.171 |
| 6 | 5.5 | 6.5 | 14781 | 0.677 | 0.114 | 0.046 | 0.160 |
| 7 | 6.5 | 7.5 | 12119 | 0.754 | 0.109 | 0.042 | 0.150 |
| 8 | 7.5 | 8.5 | 8988 | 0.842 | 0.106 | 0.038 | 0.144 |
| 9 | 8.5 | 9.5 | 6895 | 0.916 | 0.103 | 0.038 | 0.140 |
| 10 | 9.5 | 10.5 | 4969 | 1.002 | 0.101 | 0.036 | 0.137 |
| 11 | 10.5 | 11.5 | 3423 | 1.108 | 0.101 | 0.032 | 0.134 |
| 12 | 11.5 | 12.5 | 2512 | 1.155 | 0.097 | 0.032 | 0.129 |
| 13 | 12.5 | 13.5 | 1929 | 1.252 | 0.097 | 0.032 | 0.129 |
| 14 | 13.5 | 14.5 | 1250 | 1.394 | 0.100 | 0.031 | 0.131 |
| 15 | 14.5 | 15.5 | 767 | 1.474 | 0.099 | 0.030 | 0.129 |
| 16 | 15.5 | 16.5 | 467 | 1.546 | 0.097 | 0.032 | 0.129 |
| 17 | 16.5 | 17.5 | 278 | 1.565 | 0.092 | 0.031 | 0.123 |
| 18 | 17.5 | 18.5 | 119 | 1.724 | 0.097 | 0.038 | 0.134 |
| 19 | 18.5 | 19.5 | 92 | 1.712 | 0.090 | 0.035 | 0.125 |
| 20 | 19.5 | 20.5 | 79 | 1.702 | 0.085 | 0.031 | 0.117 |
| 21 | 20.5 | 21.5 | 57 | 1.839 | 0.088 | 0.034 | 0.122 |
| 22 | 21.5 | 22.5 | 38 | 1.408 | 0.064 | 0.037 | 0.102 |
| 23 | 22.5 | 23.5 | 14 | 1.240 | 0.054 | 0.035 | 0.090 |
| 24 | 23.5 | 24.5 | 9 | 1.090 | 0.046 | 0.033 | 0.079 |
| 25 | 24.5 | 25.5 | 4 | 1.430 | 0.057 | 0.048 | 0.105 |
| 26 | 25.5 | 26.5 | 0 | 1.430 | 0.057 | 0.048 | 0.105 |

## *Air Temperature and Density*

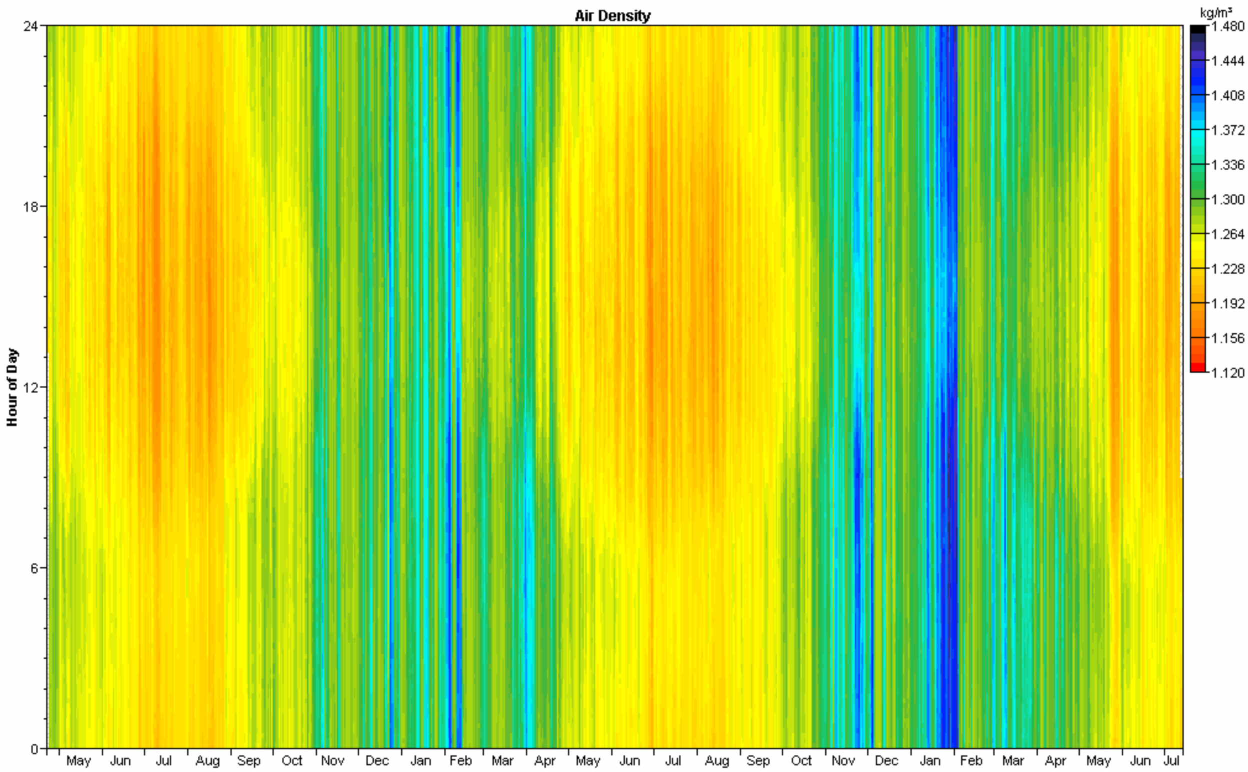
Over the reporting period, Dillingham Woodriver had an average temperature of 2.1° C. The minimum recorded temperature during the measurement period was -33.2° C and the maximum temperature was 28.2° C, indicating a wide variability of an ambient temperature operating environment important to wind turbine operations. Consequent to Dillingham's cool temperatures, the average air density of 1.278 kg/m$^3$ is approximately five percent higher than the standard air density of 1.221 kg/m$^3$ (at 14.7° C temperature and 100.84 kPa pressure at 38 meters elevation), indicating that Dillingham, due to its cool annual temperature average, has denser air than standard. 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 | -11.1 | -33.2 | 3.1 | 8.43 | 1.342 | 1.272 | 1.464 |
| Feb | -5.9 | -33.2 | 4.8 | 8.54 | 1.316 | 1.264 | 1.464 |
| Mar | -5.4 | -26.9 | 7.0 | 5.98 | 1.313 | 1.254 | 1.427 |
| Apr | -0.5 | -20.0 | 18.1 | 5.89 | 1.289 | 1.206 | 1.388 |
| May | 7.8 | -3.7 | 26.1 | 4.93 | 1.251 | 1.174 | 1.304 |
| Jun | 11.9 | -0.4 | 28.2 | 4.47 | 1.233 | 1.166 | 1.288 |
| Jul | 14.8 | 5.3 | 27.3 | 4.02 | 1.220 | 1.169 | 1.262 |
| Aug | 14.5 | 3.9 | 26.8 | 3.98 | 1.222 | 1.171 | 1.268 |
| Sep | 8.2 | -1.7 | 18.5 | 3.62 | 1.249 | 1.205 | 1.294 |
| Oct | 2.5 | -12.1 | 12.7 | 4.38 | 1.275 | 1.229 | 1.346 |
| Nov | -6.7 | -27.8 | 4.2 | 7.22 | 1.319 | 1.267 | 1.432 |
| Dec | -5.1 | -27.3 | 3.7 | 6.47 | 1.312 | 1.269 | 1.429 |
| Annual | **2.1** | -33.2 | 28.2 | 10.41 | **1.278** | 1.166 | 1.464 |



*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.



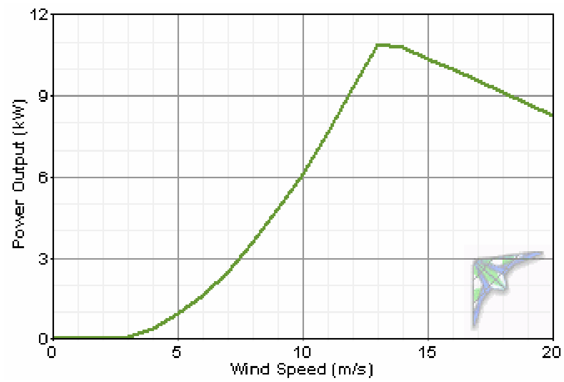
## *Turbine Performance Predictions*

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.

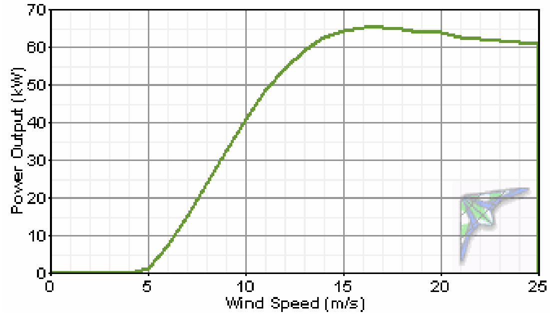
Note that these performance estimates were predicted with use of Windographer® wind analysis software; power curves provided by manufacturers are not independently verified and are assumed to be accurate. The power curves are presented for a standard air density of 1.225 kg/m$^3$ at sea level and 15°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

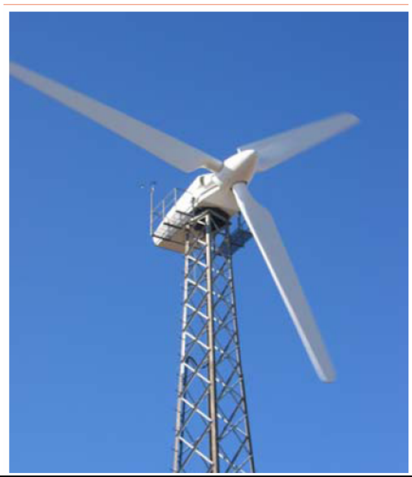
**Bergey Excel-S**: 10 kW rated power output, 6.7 meter rotor diameter, stall-controlled. Available tower heights: 18, 24, 30, 37 and 43 meters. Additional information is available at www.bergey.com.

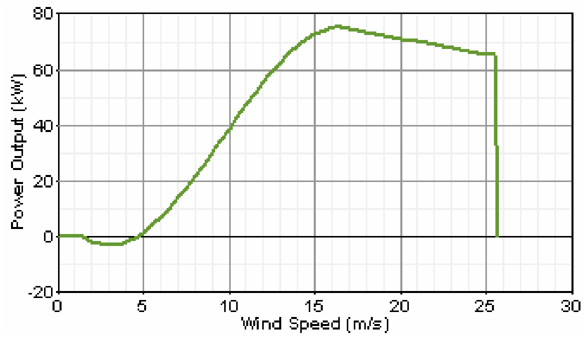



**Entegrity eW-15:** 65 kW rated power output, 15 meter rotor, stall-controlled (power curve provided by Entegrity Energy Systems). Available tower heights: 25 and 31 meters. Additional information is available at http://www.entegritywind.com/.

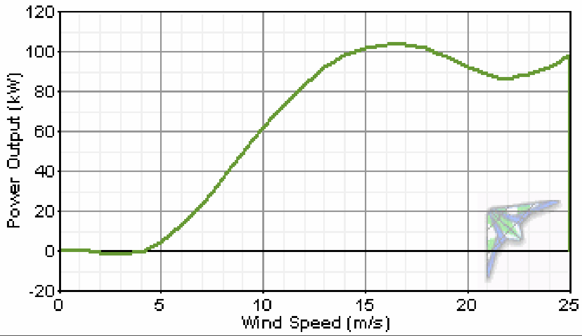



**Vestas V15**: 75 kW rated power output, 15 meter rotor, stall-controlled (power curve provided by Powercorp Alaska LLC). Available tower heights: 25, 31 and 34 meters. Additional information is available at http://www.pcorpalaska.com/.

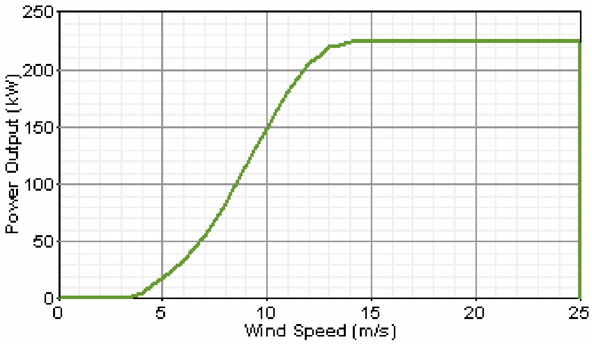




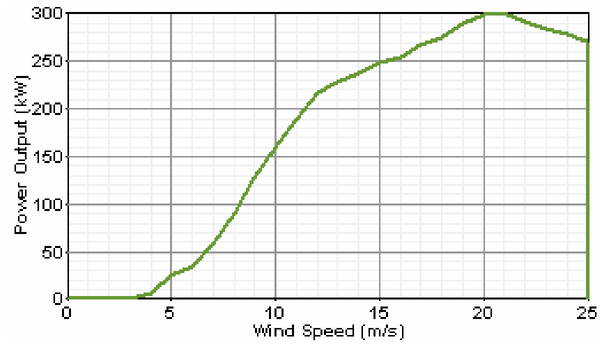

**Northwind 100/20:** 100 kW rated power output, 20 meter rotor (19 meter rotor blades with 0.6 meter blade root extensions added), stall-controlled (power curve provided by Northern Power Systems). Available tower heights: 25 and 32 meters. Additional information is available at http://www.northernpower.com/.



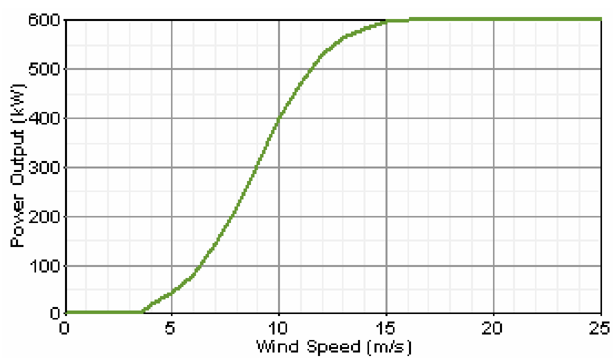

**Vestas V27**: 225 kW output, 27 meter rotor, pitch-controlled (power curve provided by Alaska Energy Authority).

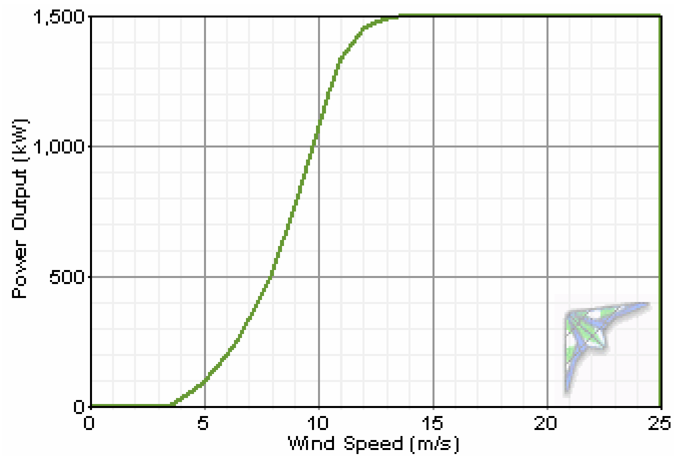

**Fuhrländer FL250**: 250 kW output, 29.5 meter rotor, stall-controlled (power curve provided by Lorax Energy Systems). Available tower heights: 42 and 50 meters. Additional information is available at [www.lorax-energy.com](http://www.lorax-energy.com).




**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 | 6.30 | 9.4 | 5.2 | 2.7 | 23,961 | 27.4 |
| Entegrity eW-15 60 Hz | 31 | 5.85 | 31.4 | 2.3 | 14 | 122,137 | 21.5 |
| Vestas V15 | 34 | 5.97 | 37.7 | 1.5 | 14 | 118,038 | 18.0 |
| Northern Power NW 100/20 | 32 | 5.89 | 31.1 | 2.1 | 21 | 182,435 | 20.9 |
| Vestas V27 | 50 | 6.53 | 12.6 | 2.7 | 66 | 572,781 | 29.1 |
| Fuhrländer FL250 | 50 | 6.53 | 9.1 | 0.3 | 73 | 640,500 | 24.4 |
| Vestas RRB 47/600 | 50 | 6.53 | 21.1 | 1.8 | 171 | 1,493,985 | 28.5 |
| General Electric 1.5s | 65 | 6.94 | 19.5 | 6.8 | 496 | 4,331,722 | 33.0 |

| | |
|---|---|
| Capacity Factor <20% | (orange) |
| Capacity Factor >20%, <30% | (yellow) |
| Capacity Factor >30%, <40% | (green) |
| Capacity Factor >40%, <50% | (cyan) |
| Capacity Factor >50% | (blue) |

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 | 9.5 | 4.8 | 2.4 | 21,649 | 24.8 |
| Entegrity eW-15 60 Hz | 31 | 5.77 | 31.9 | 2.1 | 12.1 | 110,351 | 19.4 |
| Vestas V15 | 34 | 5.88 | 38.3 | 1.3 | 11.7 | 106,647 | 16.3 |
| Northern Power NW 100/20 | 32 | 5.80 | 31.6 | 1.9 | 18.1 | 164,830 | 18.9 |
| Vestas V27 | 50 | 6.43 | 12.8 | 2.6 | 57.2 | 517,508 | 26.3 |
| Fuhrländer FL250 | 50 | 6.43 | 9.3 | 0.3 | 63.9 | 578,692 | 22.1 |
| Vestas RRB 47/600 | 50 | 6.43 | 21.4 | 1.6 | 149 | 1,349,815 | 25.7 |
| General Electric 1.5s | 65 | 6.94 | 19.5 | 6.8 | 496 | 3,913,711 | 29.9 |

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 | 21,649 | 1,415 | $2,476 | $2,830 | $3,184 | $3,537 | $3,891 | $4,245 | $4,599 | 43 |
| Entegrity eW-15 60 Hz | 110,351 | 7,212 | $12,622 | $14,425 | $16,228 | $18,031 | $19,834 | $21,637 | $23,441 | 31 |
| Vestas V15 | 106,647 | 6,970 | $12,198 | $13,941 | $15,683 | $17,426 | $19,169 | $20,911 | $22,654 | 34 |
| Northern Power NW 100/20 | 164,830 | 10,773 | $18,853 | $21,546 | $24,240 | $26,933 | $29,626 | $32,320 | $35,013 | 32 |
| Vestas V27 | 517,508 | 33,824 | $59,192 | $67,648 | $76,104 | $84,560 | $93,016 | $101,472 | $109,928 | 50 |
| Fuhrländer FL250 | 578,692 | 37,823 | $66,190 | $75,646 | $85,102 | $94,557 | $104,013 | $113,469 | $122,925 | 50 |
| Vestas RRB 47/600 | 1,349,815 | 88,223 | $154,391 | $176,446 | $198,502 | $220,558 | $242,614 | $264,670 | $286,726 | 50 |
| General Electric 1.5s | 3,913,711 | 255,798 | $447,647 | $511,596 | $575,546 | $639,495 | $703,445 | $767,394 | $831,344 | 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.