Nelson Lagoon, Alaska Wind and Solar Resource Assessment Report

Nelson Lagoon met tower, photo by Marsh Creek, LLC

March 10, 2016

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Summary

The wind resource measured at the Nelson Lagoon met tower site is excellent to outstanding with a mean annual wind speed of 6.67 m/s and a wind power density of 349 W/m^2 at 12 meters above ground level. This confirms the AWS Truepower wind resource map which predicts Class 5 winds in (or near) Nelson Lagoon. The predicted solar resource is fair to moderate due to frequent cloudy skies associated with Nelson Lagoon's maritime climate.

Met tower data synopsis

Data dates	5/22/2012 to 3/26/2013 and 9/12/2014 to 3/9/2015 (16 months)
Wind speed mean, 12 m, annual	6.65 m/s (14.9 mph)
Wind power density mean, 12 m	348 W/m^2
Max. 10-min wind speed	25.4 m/s
Maximum 2-sec. wind gust	32.2 m/s (72.0 mph), January 2013
Weibull distribution parameters	k = 1.91, c = 7.63 m/s
Wind shear power law exponent	Not measured
Surface roughness	Not measured
IEC 61400-1, 3rd ed. classification	Class III-B
Turbulence intensity, mean (at 12 m)	0.125 (at 15 m/s)
Calm wind frequency (at 34 m)	25% (< 4 m/s) (16 mo. measurement period)

Test Site Location

A 40 ft. (12 meter) tubular-type tower with flanged joints, purchased from Susitna Energy in Anchorage, was installed in Nelson Lagoon on the southern edge of the community near the city water plant and water storage tanks. Nelson Lagoon is located on the northern coast of the Alaska Peninsula, on a narrow sand spit that separates the lagoon from the Bering Sea. Nelson Lagoon falls within the southwest maritime climate zone, characterized by persistently overcast skies, high winds, and frequent cyclonic storms. Frequent and dramatic weather changes occur, with a constant prevailing wind of 20 to 25 mph. Nelson Lagoon is located 580 miles southwest of Anchorage.

Nelson Lagoon has been used historically as an Unangan summer fish camp. The resources of the lagoon and nearby Bear River are excellent. The lagoon was named in 1882 for Edward William Nelson of the U.S. Signal Corps, an explorer in the Yukon Delta region between 1877 and 1920. A salmon saltery operated from 1906 to 1917, which attracted Scandinavian fishermen, but there has been no cannery since. In 1965 a school was built, and the community began to be occupied year-round. The culture is focused on commercial fishing and subsistence activities. There is a strong community pride and loyalty among the residents, with a desire to maintain their lifestyle with slow, monitored growth and development that can be managed by the residents.

Site information

Site number	1312
Latitude/longitude	N 55° 59.982', W 161° 12.434'
Time offset	-9 hours from UTC (Yukon/Alaska time zone)
Site elevation	4 meters (13 ft.)
Datalogger type	NRG SymphoniePLUS3, 10 minute averaging time step
Tower type	Tubular, ~15 cm (6 in.) diameter, 12 meter (40 ft.) height

Tower sensor information

Channel	Sensor type	Designation	SN	Height	Multiplier	Offset	Orientation
1	NRG #40C anemometer	12 m A	197389	12.2 m	0.766	0.38	115 T
2	NRG #40C anemometer	12 m B	197388	12.2 m	0.765	0.40	295 T
7	NRG #200P wind vane	Direction		12.2 m	0.351	033	033 T
12	NRG #110S Temp C	Temp		2 m	0.136	-86.38	000 T

Tower sensor photograph, south side (Marsh Creek, LLC photo)

Met tower site photographs (Marsh Creek, LLC photos)

Site view to north

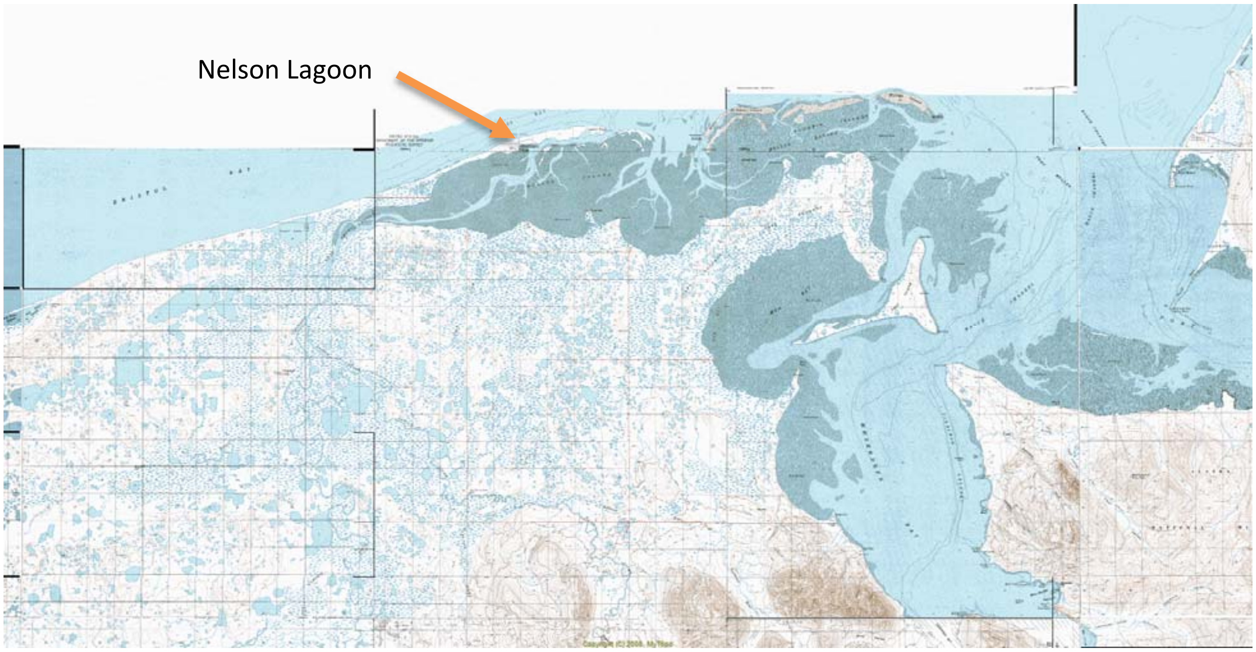
Site view to east

Site view to south

Site view to west

Google Earth image, Nelson Lagoon

Topographic map of Nelson Lagoon



Data Quality Control

Data was filtered to remove presumed icing events that yield false zero wind speed data and non-variant wind direction data. Typically, data that meets the criteria listed below is automatically filtered:

- Anemometer icing – data filtered if temperature < 1°C, speed SD = 0, and speed changes < 0.25 m/s for minimum 2 hours
- Vane icing – data filtered if temperature < 1°C and vane SD = 0 for minimum of 2 hours
- Tower shading of 34 meter A and B paired anemometers – data filtered when winds from ± 15° of behind tower; refer to graphic below

But, the temperature sensor was inoperative due to a wiring connection error and hence winter data was manually filtered for obvious icing events. In addition, invalid and/or low quality data for situations such as logger initialization and other situations was removed from the data set.

In general, icing conditions in Nelson Lagoon were infrequent indicating minimal concern for wind turbine energy production loss due to ice.

Note that although the data period spans a period from May 2012 to March 2015, an 18-month period of data, from March 2013 to September 2014, was lost or went uncollected. The result is 16 months of usable data and no data representing the month of April. For the time periods when data was collected, the following table documents data recovery from the four installed sensors: two anemometers, one wind vane, and one temperature sensor. Note that data recovery was actually slightly better than noted in that partial months of data collection are counted as full. In general, with collected data, data recovery from the Nelson Lagoon met tower as very good.

Sensor data recovery table

Data Column	Possible Records	Valid Records	Recovery Rate (%)
Speed 12 m A	76,546	69,459	90.7%
Speed 12 m B	76,546	69,529	90.8%
Direction 34 m	76,546	68,790	89.9%
Temperature	76,546	0	0.0%

Wind Speed

Anemometer data obtained from the Nelson Lagoon met tower, from the perspectives of both mean wind speed and mean wind power density, indicate a strong wind resource.

Anemometer data summary (raw and filtered)

Variable	Speed 12 m A		Speed 12 m B	
	raw	filtered	raw	filtered
Measurement height (m)	12.2	12.2	12.2	12.2
Mean wind speed (m/s)	6.74	6.70	6.82	6.79
MoMM wind speed (m/s)	6.58	6.55	6.67	6.65
Max 10-min avg. wind speed (m/s)	25.4	25.4	25.0	25.0
Max gust wind speed (m/s)	32.2	32.2	32.2	32.2
Weibull k	1.79	1.76	1.94	1.91
Weibull c (m/s)	7.53	7.48	7.67	7.63
Mean power density (W/m^2)	376	374	373	371
MoMM power density (W/m^2)	352	350	349	348
Mean energy content ($kWh/m^2/yr$)	3,297	3,279	3,263	3,249
MoMM energy content ($kWh/m^2/yr$)	3,080	3,066	3,059	3,048
Energy pattern factor	2.02	2.04	1.92	1.94
Frequency of calms (%)	26.2	26.6	24.5	24.8

MoMM = mean of monthly means

Time Series

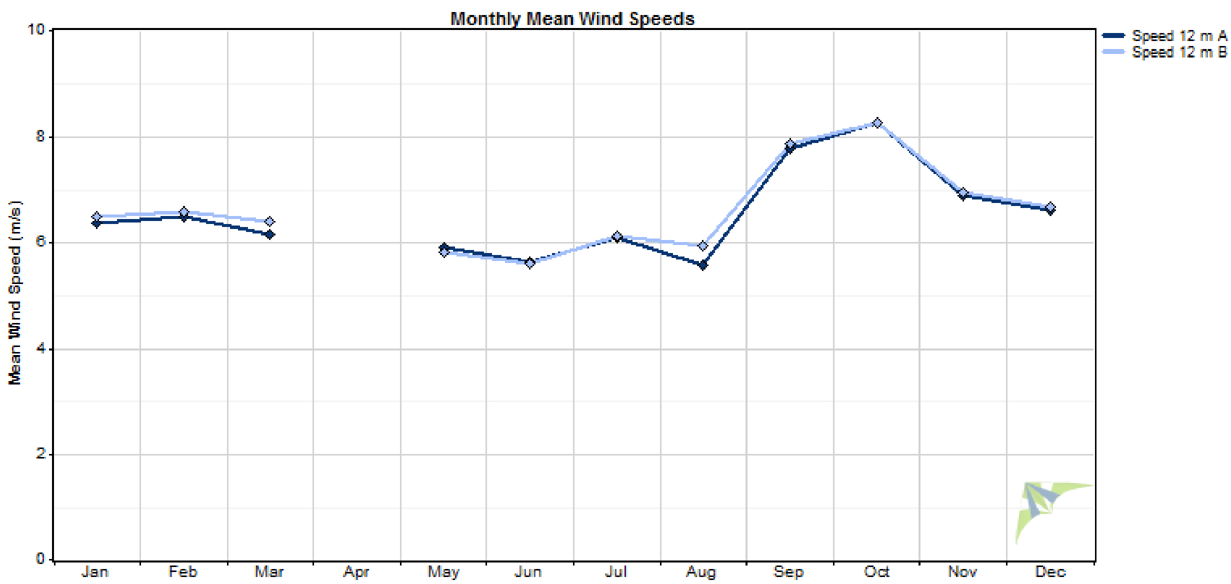
Time series calculations indicate higher wind speeds during the winter months compared to the summer months. This correlates well with a typical village load profile where there is high demand for electricity and heat during winter months and lower energy demand during summer. The daily wind profile (annual basis) indicates relatively even wind speeds throughout the day with slightly higher wind speeds during late afternoon hours.

12 m B anemometer data summary

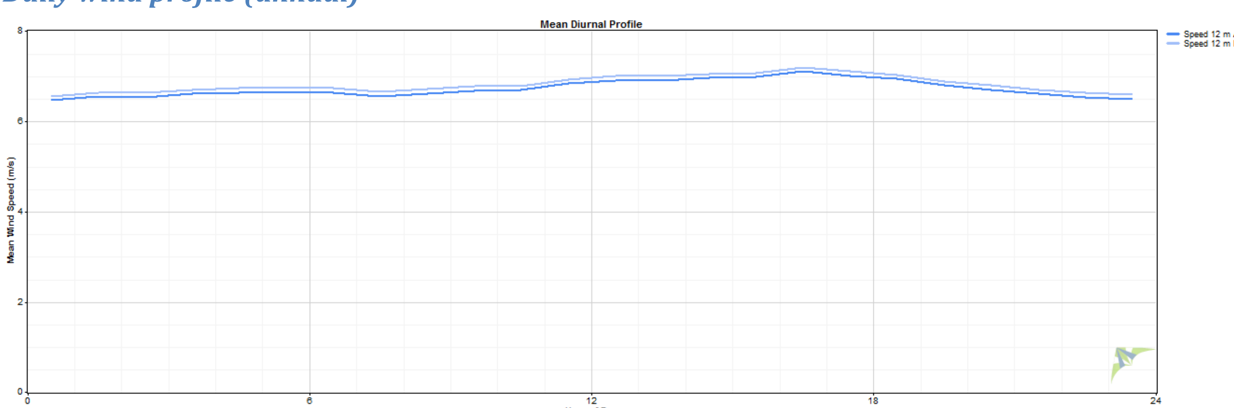
Month	Mean (m/s)	Max (m/s)	Gust (m/s)	Std. Dev. (m/s)	Weibull k (-)	Weibull c (m/s)
Jan	6.40	25.0	32.2	3.47	1.86	7.17

Month	Mean (m/s)	Max (m/s)	Gust (m/s)	Std. Dev. (m/s)	Weibull k (-)	Weibull c (m/s)
Feb	6.49	18.6	26.0	3.68	1.75	7.23
Mar	6.35	19.2	26.0	3.50	1.90	7.17
Apr						
May	5.82	14.2	18.5	2.73	2.20	6.54
Jun	5.62	15.5	19.3	2.88	2.04	6.35
Jul	6.12	18.2	28.3	3.00	2.11	6.88
Aug	5.96	14.7	18.5	2.96	2.13	6.73
Sep	7.86	21.6	28.3	3.82	2.16	8.87
Oct	8.28	19.2	27.1	3.78	2.33	9.33
Nov	6.97	22.1	27.1	3.64	1.99	7.85
Dec	6.68	20.9	28.3	3.88	1.62	7.36
Annual	6.65	25.0	32.2	3.63	1.91	7.63

Monthly time series, mean wind speeds



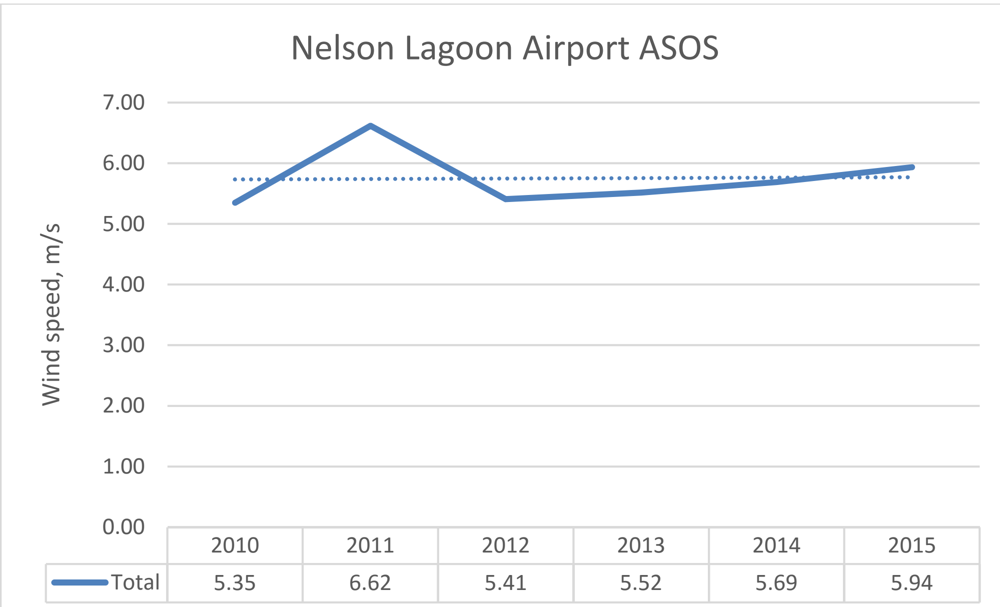
Daily wind profile (annual)



Long-term Wind Speed Comparison

Comparing the sixteen months of measured wind speed data at the Nelson Lagoon met tower to a long-term reference source is possible with the nearby Nelson Lagoon Airport automated weather station. Data for airport weather station (ASOS) was obtained for the time period of Feb. 22, 2010 through Dec. 31, 2015, which is a shorter period of time than ideal for long-term comparison, but was the only data available. For this 6-year time period, the ASOS station recorded an average wind speed of 5.76 m/s (at a 10-meter measurement height) and recorded winds were fairly constant through the met tower operational timeframe of (parts of) 2012 through 2015.

Nelson Lagoon Airport wind speed



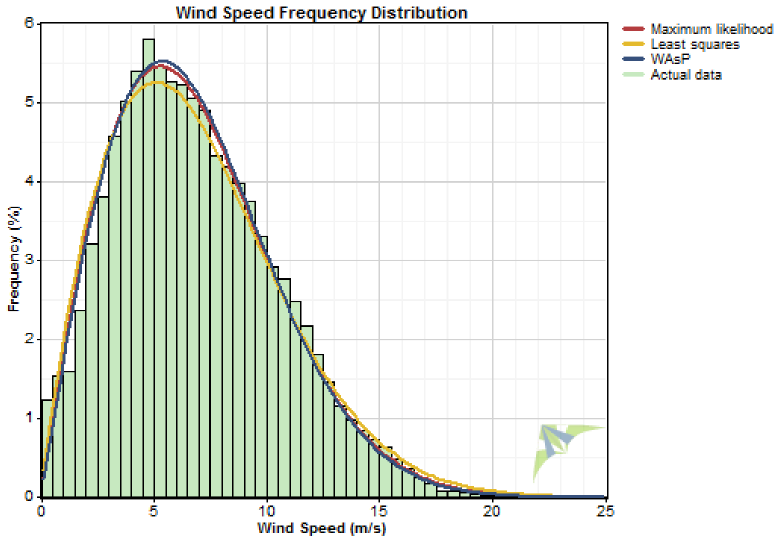
Probability Distribution Function

The probability distribution function (PDF), or histogram, of the Nelson Lagoon met tower site wind speed indicates a shape curve dominated by moderate wind speeds and is mostly reflective of a "normal" shape curve, known as the Rayleigh distribution (Weibull k = 2.0), which is defined as the standard wind distribution for wind power analysis.

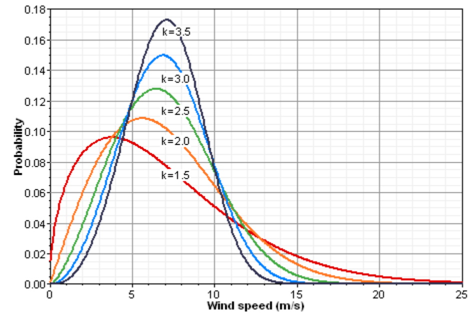
Weibull values table, 12 m B anemometer, all data

Algorithm	Weibull k	Weibull c (m/s)	Mean (m/s)	Proportion Above 6.821 m/s	Power Density (W/m2)	R Squared
Maximum likelihood	1.94	7.67	6.80	0.451	380	0.988
Least squares	1.85	7.75	6.89	0.454	414	0.984
WAsP	1.97	7.67	6.80	0.452	374	0.988
Actual data			6.82	0.452	374	

PDF of 12 m B anemometer (all data)

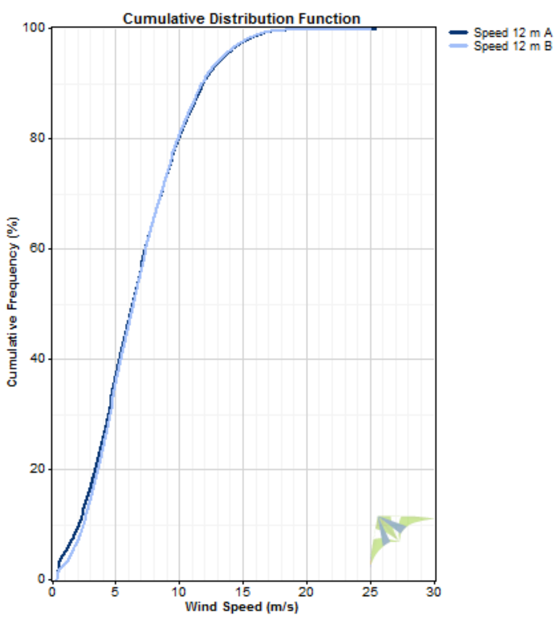


Weibull k shape curve table



As seen below in the wind speed distribution of the 12 meter B anemometer, the most frequently occurring wind speeds are between 3 and 8 m/s with very few wind events exceeding 25 m/s (note that the cutout speed of most wind turbines is 25 m/s; see cumulative distribution function graph).

Cumulative distribution function



Wind Shear and Roughness

Wind shear at the Nelson Lagoon met tower site cannot be calculated as the two anemometers were installed at the same height (12 meters) above ground level. Typically, wind shear across flat, fairly featureless terrain with surrounding water is low, in the power law exponent range of 0.14 to 0.19.

Extreme Winds

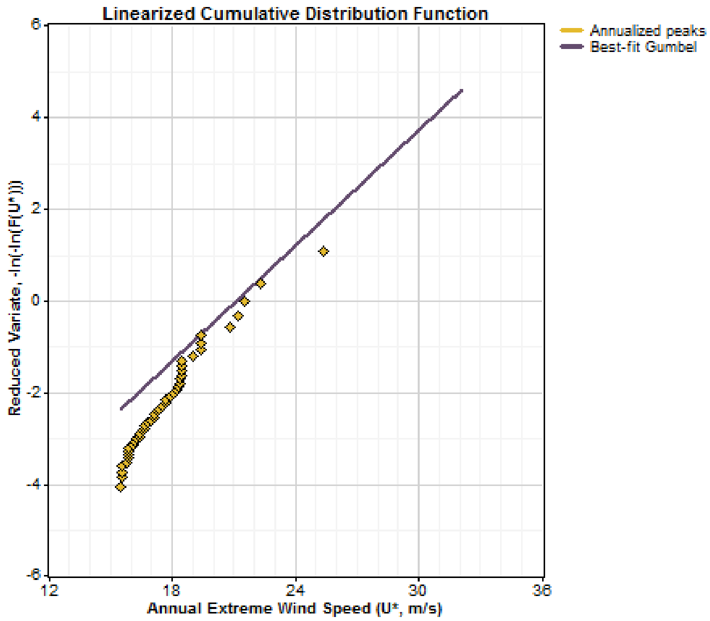
One method to estimate V_{ref}, or the maximum 50 year (10-minute average) wind speed, is a Gumbel distribution analysis modified for monthly maximum winds vice annual maximum winds. Sixteen months of data however are minimal at best and hence results should be viewed with caution. Nevertheless, with data available the predicted V_{ref} in a 50 year return period (in other words, predicted to occur once every 50 years) by this method is 32.4 m/s, at 12 meters above ground level. This result classifies the site as Class III by International Electrotechnical Commission 61400-1, 3rd edition (IEC3) criteria.

Site extreme wind probability table, 12 m B data

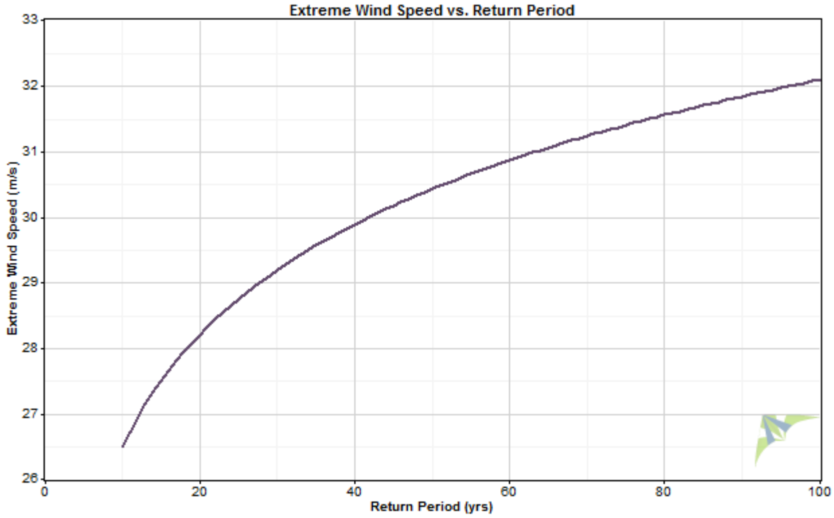
Period (years)	V_{ref} (m/s)	Gust (m/s)	IEC 61400-1, 3rd ed. Class	V_{ref}, m/s
3	24.4	32.4	I	50.0
10	28.4	37.8	II	42.5
20	29.4	39.1	III	37.5
30	31.1	41.4	S	designer-specified
50	32.4	43.1		
100	34.1	45.4		
average gust factor:	1.33			

A second technique, Method of Independent Storms, yields a similar, but slightly lower, calculation of V_{ref} – 30.4 m/s.

Method of Independent Storms, CDF

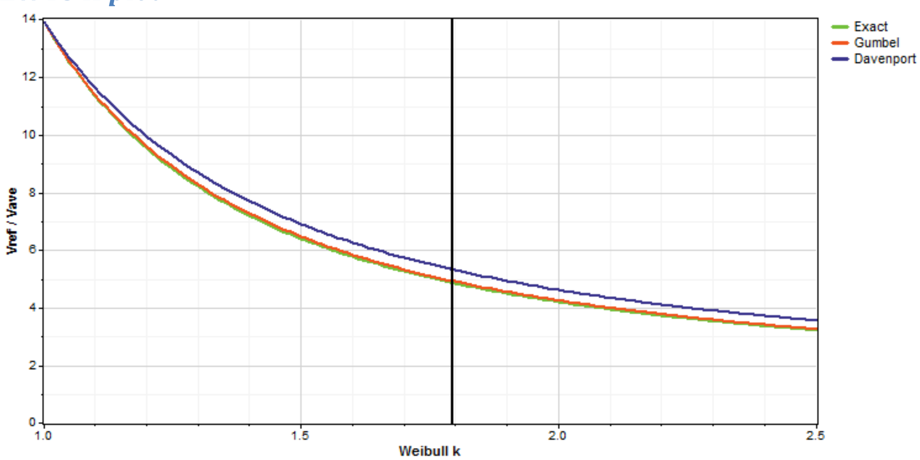


Method of Independent Storms, extreme wind vs. return period



A third method, referred to as EWTS II (European Wind Turbine Standards II) ignores recorded peak wind speeds and calculates V_{ref} from the Weibull k factor. There are three variations of this method and from the Nelson Lagoon wind data V_{ref} is calculated between 32.9 and 36.0 m/s. As with the modified Gumbel distribution, the Method of Independent Storms and EWTS II methods both estimate an IEC Class III wind regime in Nelson Lagoon. Note again however the minimal measured wind data for these calculations and the fact that these calculations are at a very low 12-meter elevation. Typical wind turbine hub height is much higher and consequent extreme wind will be higher as well, possibly in the IEC Class II range.

EWTS II plot



EWTS II table

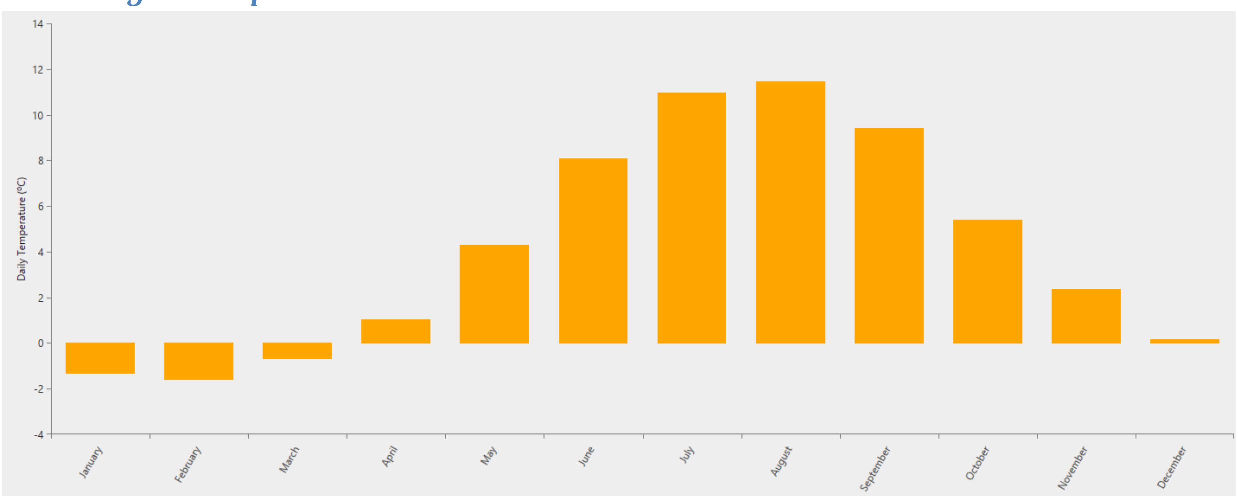
Method	Vref / Vave	Vref (m/s)
Exact	4.88	32.9
Gumbel	4.95	33.3
Davenport	5.35	36.0

Note that IEC extreme wind probability classification is one criteria – with turbulence the other – that describes a site with respect to suitability for particular wind turbine models. Note that the IEC3 Class III extreme wind classification indicates that wind turbines installed at this location can be rated as IEC3 Class III. Note again though the measurement height of only 12 meters.

Temperature, Density, and Relative Humidity

Although the temperature sensor on the met tower was inoperative, temperature data for Nelson Lagoon was obtained from the NASA surface meteorology and solar energy database. Average monthly temperatures vary from a low of 1.6° C (29.1° F) in February to a high of 11.5° C (52.7° F) in August. This is an extremely moderate temperature range by Alaska standards and indicative of Nelson Lagoon's maritime-influenced climate without winter sea ice.

Nelson Lagoon temperature



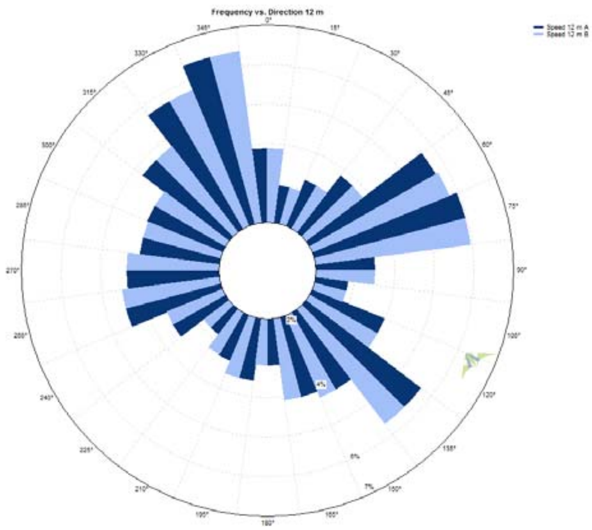
Wind Direction

Wind frequency rose data indicates that winds at the Nelson Lagoon met tower site are primarily northeasterly, southeasterly, and north-northwesterly. The wind energy rose indicates that the power-producing winds are southeasterly and north-northwesterly.

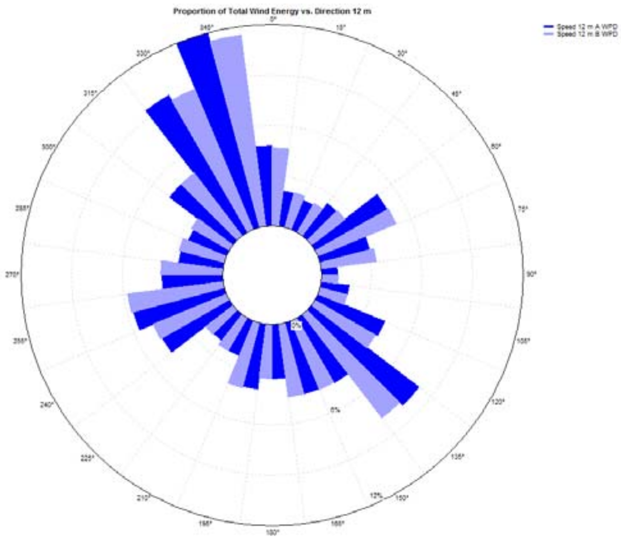
Calm frequency, the percent of time that winds at the 34-meter level are less than 4 m/s, a typical cut-in speed of larger wind turbines, was approximately 25 percent during the 16-month data measurement period.

Note that the measured wind rose at the met tower site correlates reasonably well with that that observed by the automated weather station at the nearby Nelson Lagoon Airport.

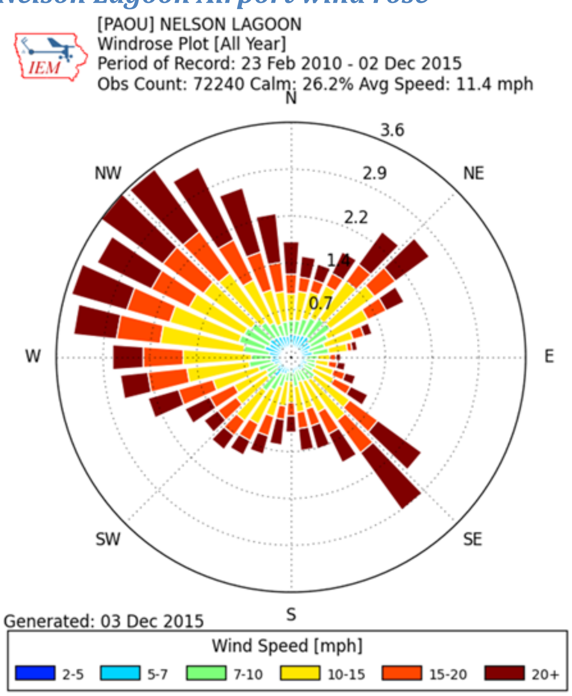
Wind frequency rose



Wind energy rose



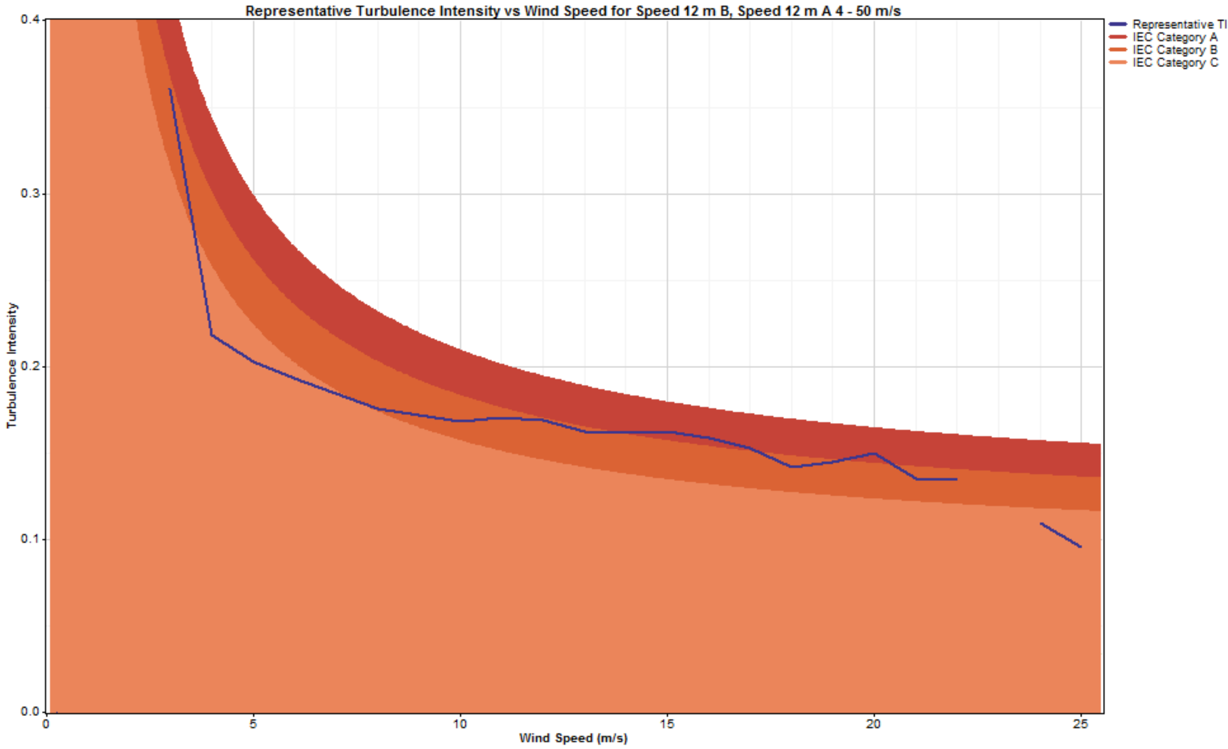
Nelson Lagoon Airport wind rose



Turbulence

The turbulence intensity (TI) at the Nelson Lagoon met tower site is somewhat high with a mean turbulence intensity of 0.125 and a representative turbulence intensity of 0.163 at 15 m/s wind speed, indicating moderately rough air for wind turbine operations. This equates to an International Electrotechnical Commission (IEC) 61400-1, 3rd Edition (2005) turbulence category B, which is the middle defined category (A is most turbulent; C is least). Note however the low sensor height of only 12 meters and the presence of nearby structures. It is very likely that actual turbulence in a more open location and/or a higher elevation above ground level would be much lower and IEC turbulence category C.

Turbulence intensity, all direction sectors

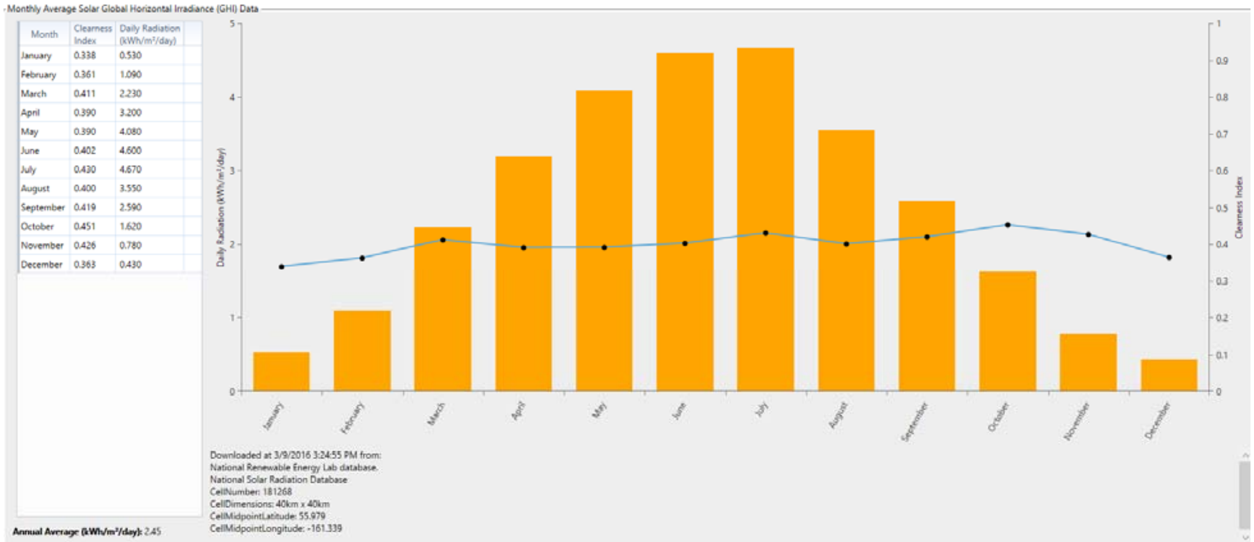


Solar Resource

Although the Nelson Lagoon met tower was not equipped with a pyranometer to measure solar radiation, solar radiation data is available from NREL's National Solar Radiation Database (NASA data source). With this, one can see that the winter solar power resource in Nelson Lagoon is low during the winter months and significantly higher during summer, which one expects at northerly latitudes. Solar power has proven to be remarkably successful in a number of installations in Alaska, including several in villages near Kotzebue. Nelson Lagoon is further south and has better solar irradiance, but it is a coastal village dominated by a maritime climate and hence cloudier than Interior locations. This can be seen in the clearness index, which averages approximately 0.4.

From HOMER Energy website: "The clearness index is a measure of the clearness of the atmosphere. It is the fraction of the solar radiation that is transmitted through the atmosphere to strike the surface of the Earth. It is a dimensionless number between 0 and 1, defined as the surface radiation divided by the extraterrestrial radiation. The clearness index has a high value under clear, sunny conditions, and a low value under cloudy conditions. Typical values of clearness range from 0.25 (a very cloudy month, such as an average December in London) to 0.75 (a very sunny month, such as an average June in Phoenix)."

Nelson Lagoon solar resource (NREL data)



Renewable Energy Generation

This report is focused on the renewable energy resource of Nelson Lagoon and is not oriented toward the feasibility of renewable energy generation for the community, whether wind-diesel, solar-diesel, or wind-solar-diesel. But, for reference, modeling software can estimate wind turbine and PV panel performance based on the resource information collected for the community.

Wind Power

Installing wind turbines in Nelson Lagoon as a wind-diesel system is possible in a standard diesels-on configuration of wind turbines that primarily offset electric power demand and secondarily supply energy to a heat load such as a water plant or school. For comparison, two turbines are chosen, a Bergey Excel-S rated at 10 kW, and a Northern Power Systems NPS100C-21, rated at 100 kW. The Bergey is a small wind turbine typically used for farm and other off-grid applications, while the Northern is a village-scale wind turbine in wide use in Alaska. Given Nelson Lagoon's small population and relatively low electric load demand, neither turbine may be ideal, but the table below provides an understanding of possible turbine performance.

Out of concern regarding airspace restrictions and avian impact, both turbines are modeled at their lowest available hub heights. At higher hub heights, turbine energy production would be significantly higher. Note also that the turbines are modeled at 100% annual energy production with no discount for losses such as maintenance downtime, icing, curtailment, faults, etc. Losses must be considered during project planning, should that be pursued.

In general, both the Bergey and Northern Power turbines model very well, with net capacity factors of 33 to 35 percent. Note again that this is at 100% AEP. Typical net AEP estimate for an Alaska village wind-diesel project is 80% with real world operational experience even lower at 45 to 65% of gross.

Wind turbine performance, 100% net AEP

Turbine	Hub Height (m)	Wind Speed (m/s)	Net Power (kW)	Net AEP (kWh/yr)	NCF (%)
Bergey Excel-S	18	7.11	3.3	29,040	33.2
Northern Power 100-21	22	7.32	35.9	314,068	35.9

NCF = net capacity factor

Solar Power

A flat-plate solar panel, at the solar irradiance of Nelson Lagoon's latitude and with the clearness index estimated by NASA and obtained from NREL, models at 12.3% capacity factor, with no de-rating applied. If 20% de-rating (for soiling of the panels, snow, etc.) were considered, net capacity factor would be 9.8%. For a 25 kW solar array, this would equate to an annual energy production of 27,000 kWh/year with no derating, and 21,600 kWh year energy production with 20% de-rating.

PV power output, 100% net AEP