Levelock, Alaska Wind Resource Assessment Report

Levelock met tower, photo by Douglas Vaught

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Contents

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Summary

This report documents measurement of the wind resource in the community of Levelock in the Bristol Bay Region of Alaska. V3 Energy, LLC was contracted by Lake and Peninsular Borough to assist with site selection, install a 34 meter meteorological (met) test tower, review data periodically, compare the met tower data to a nearby reference station, create a wind flow model of surrounding area, and recommend a wind turbine for estimate energy production. This report is a summary and compilation of those objectives.

Levelock has a moderate Class 3 wind resource which offers potential for wind power development in a battery storage configuration with a grid-forming converter. Note that although the more distant Levelock Hill may be windier, from the perspective of development costs, a near-village site is likely the best option for wind power in the community.

Levelock Met Tower

A 34-meter high met tower was installed on the south side of the village near a GCI communication tower in July, 2014. The met tower was equipped with an NRG Symphonie data logger, three anemometers, a wind vane, and temperature sensor. To enhance visibility from the air, the met tower was equipped with orange high-visibility marker balls near the top and was painted alternating bands of red and white.

Met tower data synopsis

Data dates	7/22/2014 to 3/16/2016 (20 months with 3 months missing, 9/21/2015 to 12/16/2015)
Wind speed, mean, 34 m, annual	5.65 m/s (12.6 mph)
Wind power density, mean, 34 m	246 W/m^2
Max. 10-minute average wind speed	25.8 m/s (57.7 mph)
Maximum 2-second wind gust	37.9 m/s (84.8 mph), December, 2015
Weibull distribution parameters	k = 1.91, c = 6.48 m/s
Wind shear power law exponent	0.398
Surface roughness	2.11 m
IEC[1] 61400-1, 3rd ed. classification	Class III-B
Turbulence intensity, mean	0.13 (at 15 m/s)

Test Site Location

The met tower site is immediately south of the southeast-northwest trending road on the southern edge of the community. This road serves a very high GCI cellular communications tower and the community landfill. The site itself is just off an ATV trail about 450 ft. due south of the GCI tower. The brushy nature of the site is not ideal for wind measurement and this was not the first choice of location for the met tower. A preferable location was open ground nearer the river, about 950 ft. to the southeast. FAA

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[1] International Electrotechnical Commission, a Swiss-based organization that prepares and publishes international standards for electrical, electronic, and related technologies.

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though would have required obstruction lighting of the met tower, which was not within project budget. A disadvantage of the near-river site, however, is its lower elevation.

Site information

Site number (logger ID)	7271
Latitude/longitude	N 61° 15' 30.9", W 149° 31' 53.7"
Time offset	-9 hours from UTC (Yukon/Alaska time zone)
Site elevation	1,173 meters (3,850 ft.)
Datalogger type	NRG SymphoniePLUS3, 10-minute averaging time step
Tower type	Tubular, ~15 cm (6 in.) diameter, 10-meter height

Site and met tower photographs

Tower base, brushy site vegetation

Data logger home screen

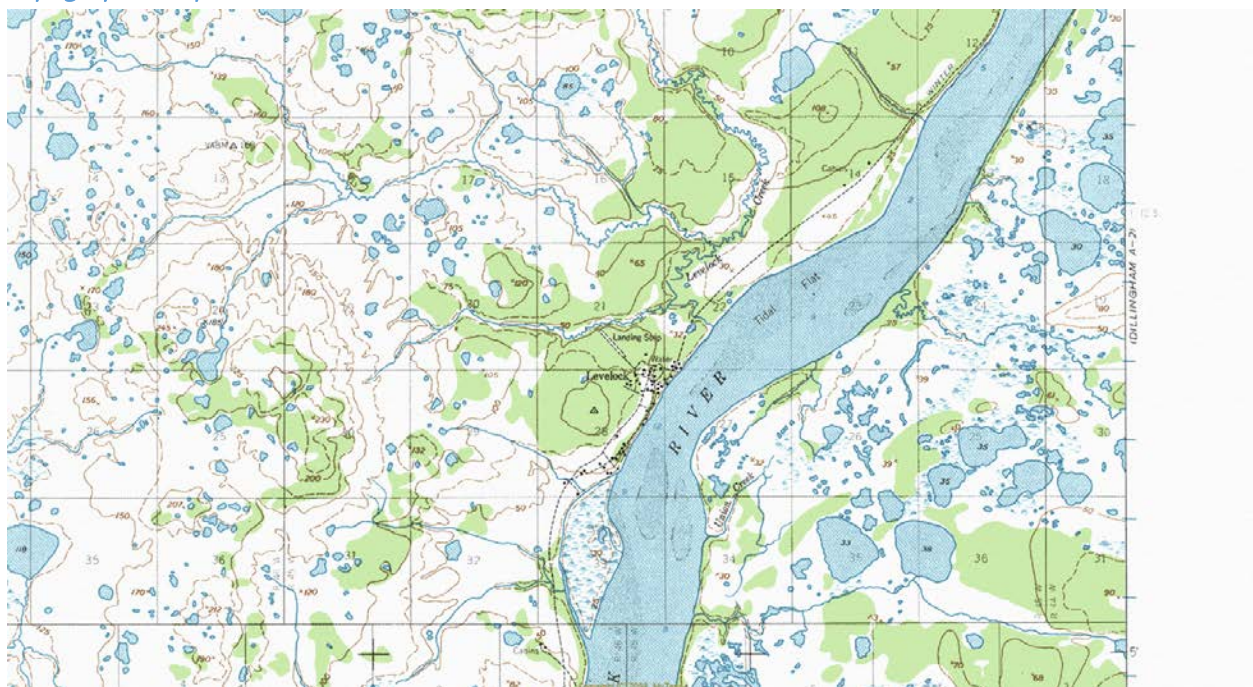Met tower and site

Data logger wiring panel

Levelock area. Google Earth image, view north

Topographic map of Levelock

Met Tower Sensors

The Levelock met tower was equipped with a standard sensor package supplied by Renewable NRG Systems, Inc. of Hinesburg, Vermont, USA. Heated sensors and sensors requiring supply power were not included. This enabled nearly maintenance-free operations, except for periodic battery changes and data card swaps.

Tower sensor information

Logger Channel	Sensor type	Sensor Designation	Serial Number	Height AGL	Multiplier	Offset[2]	Orientation[3]
1	NRG #40C anemometer	34 m A	231806	34.2 m	0.762	0.33	045 T
2	NRG #40C anemometer	34 m B	231807	33.7 m	0.755	0.39	175 T
3	NRG #40C anemometer	20 m	231808	20.9 m	0.760	0.33	050 T
7	NRG #200P wind vane	Direction	n/a	9.0 m	0.351	000	000 T
9	NRG #110S Temp C	Temp	n/a	2 m	0.136	-86.38	000 T

Up-tower sensor photographs

North side
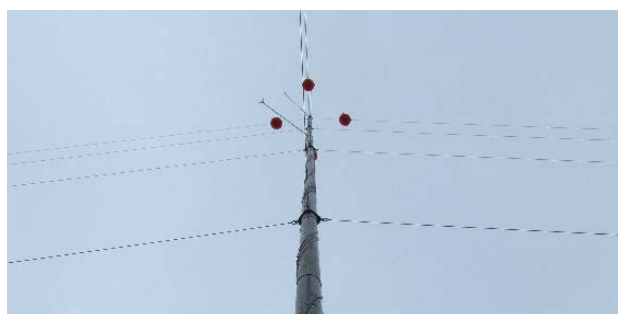
East side

South side

West side

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[2] Multiplier and offset are variables of the straight-line transfer function to calculate sensor value from its raw data inputs with the equation $y = mx + b$ where y is sensor value, m is multiplier and b is offset.
[3] In true degrees (reference pt. is Earth's geographic North Pole)

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

In addition to automatic data filtering, icing data was manually filtered in situations where the automatic filtering failed to detect obvious icing conditions, or where automatic filtering flagged data as icing when it did not appear to be so. A relative humidity sensor would have aided the detection of icing conditions, but the met tower was not equipped with one.

Met tower sensor data recovery

Met Tower Sensor Icing Loss
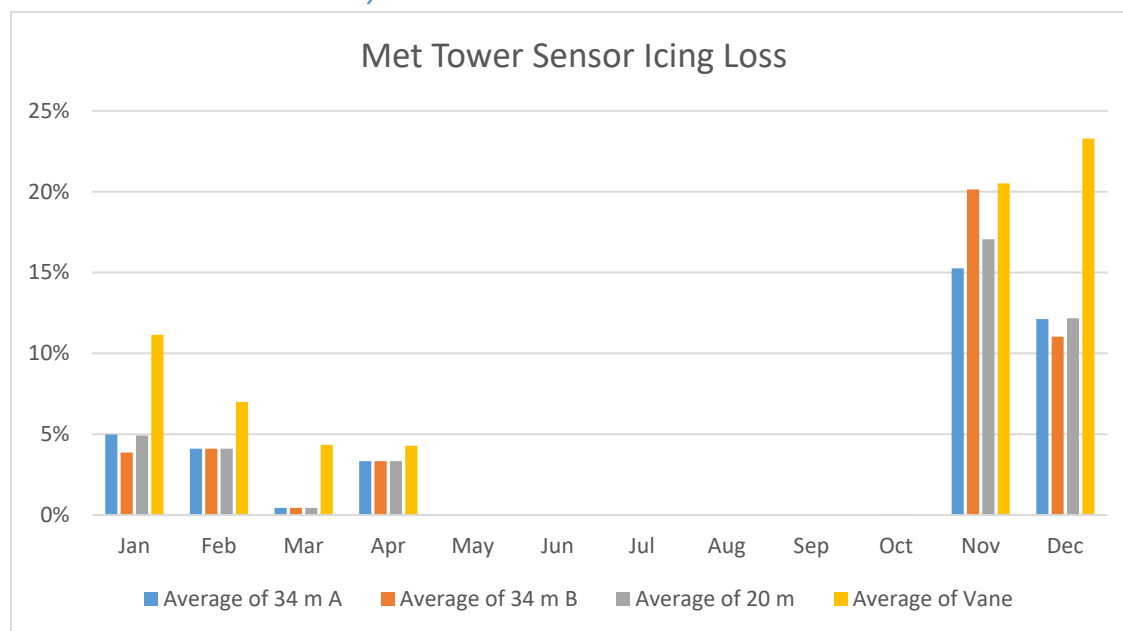
Sensor data recovery table

			Time Steps Flagged As			
Data Column	Possible Records	Missing	<Unflagged data>	Icing	Invalid	Tower shading
Speed 34 m A	86,817	12,612	67,425	2,768	75	4,156
Speed 34 m B	86,817	12,612	58,841	2,788	75	13,012
Speed 20 m	86,817	12,612	71,421	2,851	75	0
Direction 34 m	86,817	12,612	69,107	5,098	72	0
Temperature	86,817	12,612	74,205	0	72	0

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Wind Speed

Anemometer data obtained from the Levelock met tower, from the perspectives of both mean wind speed and mean wind power density, indicate a moderate wind resource. The table below includes wind filtered (for icing and tower shadow) and raw wind data.

Anemometer data summary (filtered and raw)

	Speed 34 m A		Speed 34 m B		Speed 20 m	
	filtered	raw	filtered	raw	filtered	raw
Mean measured wind speed (m/s)	5.76	5.51	5.60	5.37	4.70	4.54
Mean annual wind speed (m/s)	5.66	5.41	5.63	5.26	4.64	4.45
Mean annual wind speed (mph)	12.7	12.1	12.6	11.8	10.4	10.0
Max 10-min wind speed (m/s)	25.9	25.9	25.7	25.7	22.3	22.3
Max gust wind speed (m/s)		37.9		36.0		33.2
Max gust wind speed (mph)		84.8		80.5		74.3
Weibull k	1.92	1.70	1.81	1.70	1.82	1.63
Weibull c (m/s)	6.48	6.12	6.29	5.98	5.27	5.03
Mean annual power density (W/m²)	235	220	246	207	136	129
Mean annual energy content (kWh/m²/yr)	2,059	1,924	2,151	1,815	1,192	1,126
Energy pattern factor[4]	2.02	2.17	2.17	2.21	2.12	2.27
Frequency of calms (%) (< 4 m/s speed)	31.2	34.4	34.5	35.8	45.0	47.1

Time Series

Time series calculations indicate higher wind speeds during the winter months compared to the summer months, which is an expected seasonal variation. The daily wind profile (annual basis) indicates relatively even wind speeds throughout the day with slightly higher wind speeds during late afternoon hours, which is an expected diurnal variation.

34 m A anemometer data summary

| Month	Mean (m/s)	Max (m/s)	Gust (m/s)	Std. Dev. (m/s)	Weibull k (-)	Weibull c (m/s)
Jan	7.37	21.6	29.3	3.32	2.27	8.25
Feb	6.80	21.6	29.3	3.41	2.05	7.65
Mar	6.06	20.0	26.9	3.15	1.94	6.79
Apr	5.64	17.3	23.7	2.64	2.25	6.37
May	4.23	13.5	19.1	2.41	1.81	4.75
Jun	4.58	11.7	15.5	2.04	2.38	5.16
Jul	4.25	15.6	20.0	2.24	1.95	4.78
Aug	4.81	13.1	17.6	2.26	2.23	5.42
Sep	4.71	13.3	18.3	2.35	2.08	5.30

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[4] With an assumption of constant air density, energy pattern factor is the ratio of the actual mean wind power density to the wind power density calculated from only the mean wind speed. Definition obtained from Windographer 4.0 Help file.
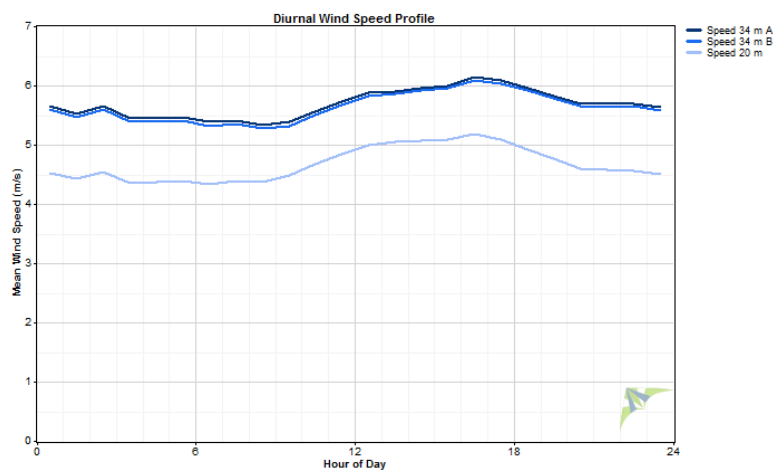
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Month	Mean (m/s)	Max (m/s)	Gust (m/s)	Std. Dev. (m/s)	Weibull k (-)	Weibull c (m/s)
Oct	5.38	14.0	20.0	2.39	2.35	6.04
Nov	7.14	20.2	28.1	3.77	1.97	8.04
Dec	6.88	25.9	37.9	3.67	1.96	7.76
Annual	5.63	25.9	37.9	3.09	1.91	6.42

*Monthly time series of mean wind speed*
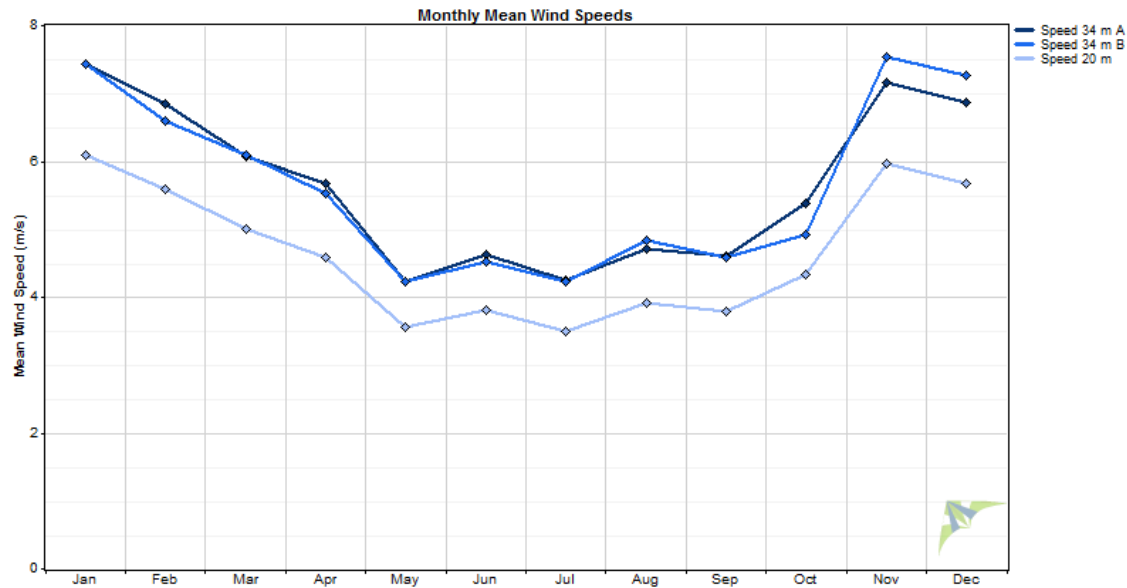
Daily wind profile

Long-term Wind Speed Comparison

Comparing the 17 months of measured wind speed data at the Levelock met tower to a long-term reference source is difficult in that the Levelock airport is not equipped with an automatic surface observing system (ASOS) or automatic weather observing system (AWOS). Nearest stations are King

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Salmon, Dillingham, and Igiugig, all of which are rather distant. Nevertheless, regional wind patterns have broad impact and hence comparing Levelock to a reference station is valuable.

The King Salmon Airport weather station indicates declining wind speeds from 1990 through 2016 but possibly a view earlier in time may indicate that 1990 to 1994 was windier than normal, in which case the declining trend would be less pronounced or not exist. Note that the operational years of the Levelock met tower – 2014 and 2015 mostly – were windier than the preceding 20 years.

King Salmon Airport ASOS weather station, 1990-2016
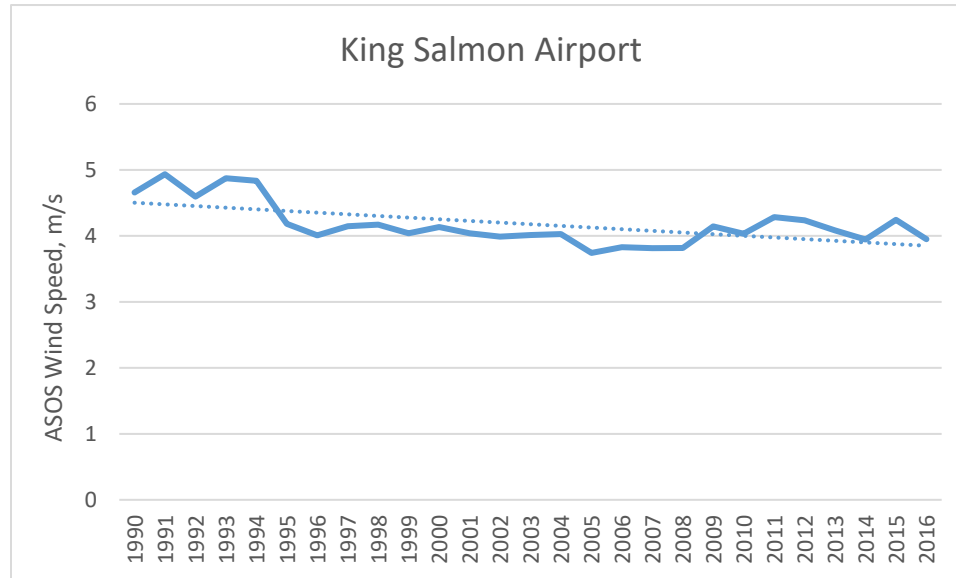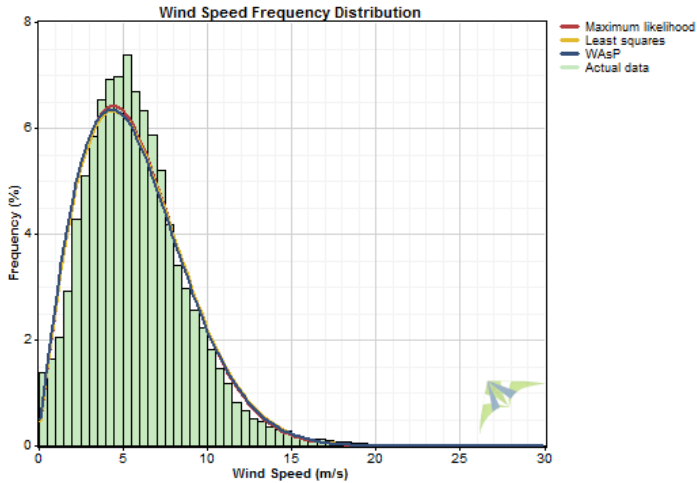

Probability Distribution Function

The probability distribution function (PDF), or histogram, of the Levelock met tower site wind speed indicates a shape curve reflective of a standard wind profile, known as the Rayleigh distribution[5] where Weibull k = 2.0. The Rayleigh distribution is defined as the default wind probability distribution for wind power analysis.

Weibull values table, 34 m A anemometer, all data

Algorithm	Weibull k	Weibull c (m/s)	Mean (m/s)	Proportion Above 5.803 m/s	Power Density (W/m2)	R Squared (-)
Maximum likelihood	1.92	6.48	5.75	0.450	232	0.979
Least squares	1.90	6.54	5.81	0.456	241	0.976
WAsP	1.88	6.47	5.74	0.448	237	0.975
Actual data			5.80	0.389	397	

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[5] One form of the Weibull distribution is the Rayleigh, which occurs when k = 2.0. This is equivalent to a standard deviation of 52% of the mean wind speed. Wind turbine manufacturers provide standard performance data based on a wind resource with a Rayleigh distribution. Definition from www.wind-power-program.com and www.windpower.org.

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PDF of 10m B anemometer (all data)   *Weibull k shape curve table*
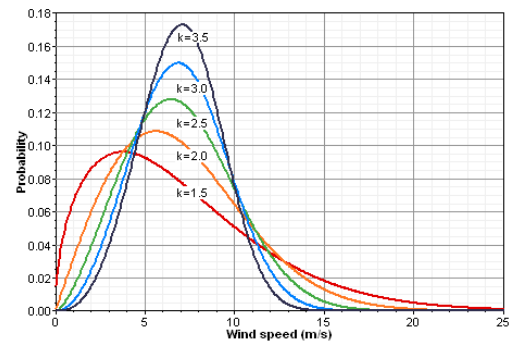
Wind Shear and Roughness

Wind shear[6] and roughness at the Levelock met tower site is quite high with a calculated power law exponent (shear) value of 0.398, using data from the northeast-facing 34m A and 20m anemometers. The calculated surface roughness is 2.15 meters. Both the power law exponent and the surface roughness length are too high; a 0.20 to 0.25 power law exponent and 0.2 to 0.5 m surface roughness length are more reasonable. The high value can be explained by only two anemometer measurement heights, which can in locations with heavy brush lead to excessive variation in wind speed measurements between the two heights. Brush dramatically slows surface winds compared to higher wind speeds above. This results in a wind shear calculation that is not representative of higher elevations above the top-most anemometer and/or more open and less brushy locations.

Wind shear profile

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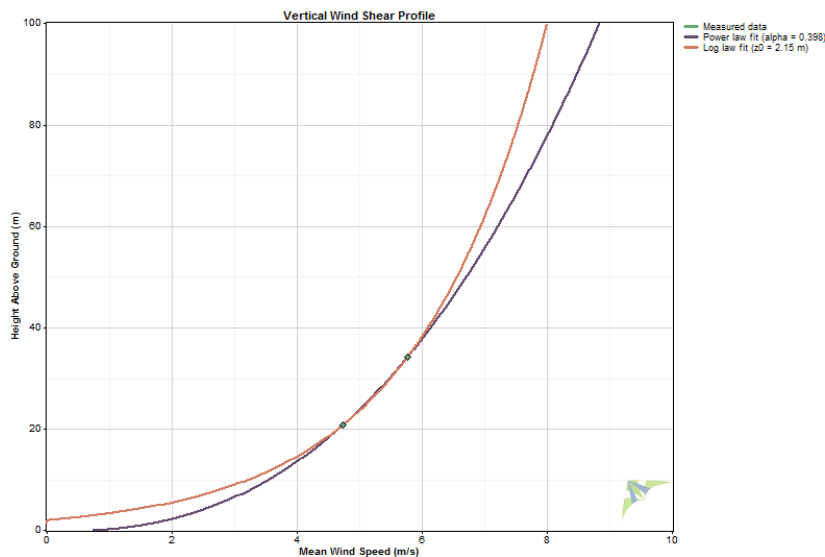
[6] Change in wind velocity with height above ground level.

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Extreme Winds

International Electrotechnical Commission (IEC) 61400-1, 3rd edition extreme wind probability classification is one criteria – with turbulence the other – that describes a site with respect to suitability for wind turbine models. Extreme wind is described by the 50 year (10-minute average) V_{ref}; in other words, the 10-minute average wind speed predicted to occur once every 50 years.

IEC extreme wind classification

IEC 61400-1, 3rd ed.	
Class	V_{ref}, m/s
I	50
II	42.5
III	37.5
S	designer-specified

Periodic Maxima

One method to estimate V_{ref} is a Gumbel distribution analysis modified for monthly maximum winds versus annual maximum winds, which are typically used for this calculation. Seventeen months of data though are minimal for this method. 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 32.9 m/s at 34 meters above ground level. This result meets IEC 3rd edition Class III criteria, the lowest defined.
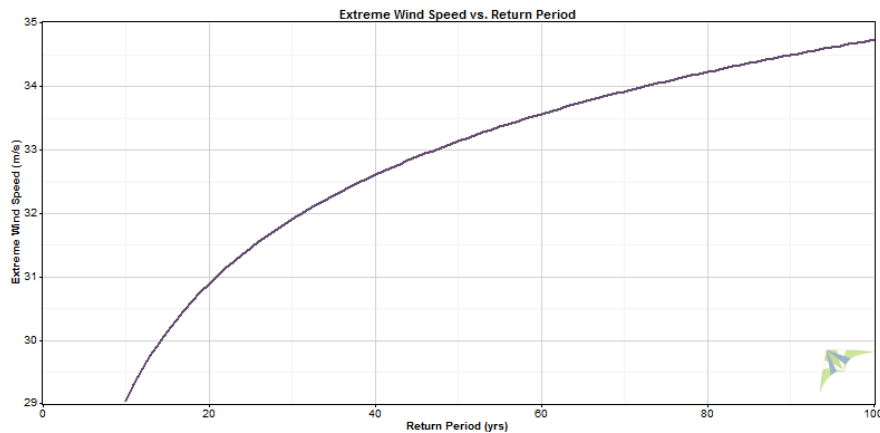
### Periodic maxima cumulative distribution, 34 m A anemometer
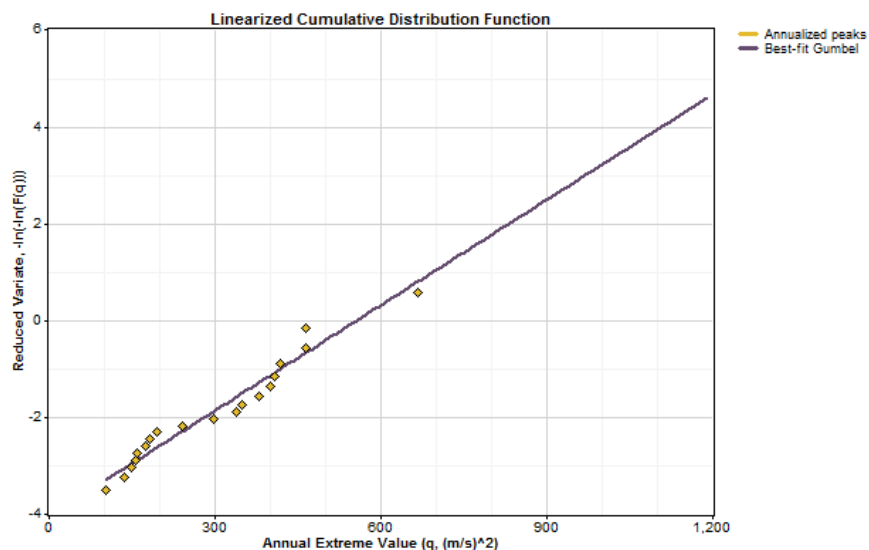
Method of Independent Storms

A second technique, Method of Independent Storms, yields a V_{ref} estimate of 33.2 m/s, near that predicted by the periodic maxima method.

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Method of Independent Storms, extreme wind vs. return period

EWTS II

A third method, known 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 – Exact, Gumbel and Davenport – which yields a V_{ref} between 25.6 and 28.1 m/s. This is lower than the other methods and well within IEC 3rd edition Class III extreme wind criteria.

EWTS II plot
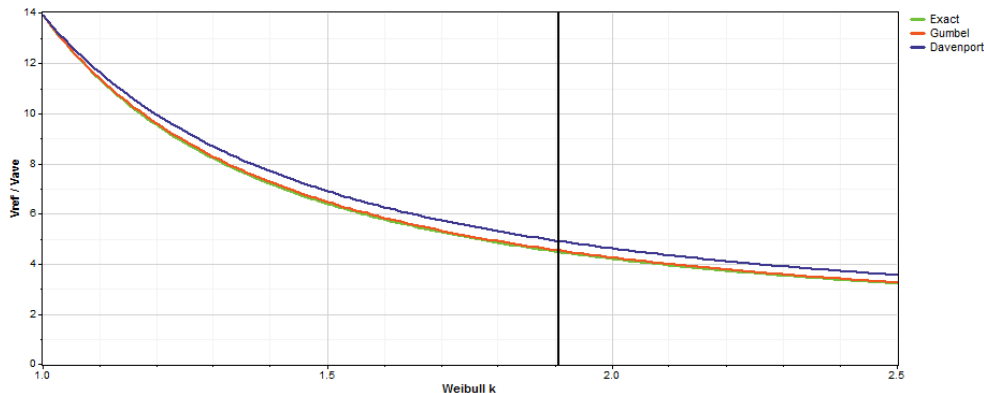
Summary

The calculated V_{ref} wind speeds by the three methods described above all meet IEC 61400-1, 3rd edition criteria for Class III wind classification, which has a V_{ref} limit of 37.5 m/s. The practical importance is that any wind turbine on the market is suitable for Levelock, based on extreme wind behavior.

EWTS II table

Method	Vref (50 yr) (m/s)
Periodic Maxima	32.9
Method of Independent Storms	33.2
EWTS II (Exact)	25.6
EWTS II (Gumbel)	25.9
EWTS II (Davenport)	28.1

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Temperature, Density, and Relative Humidity

Levelock experiences relatively warm summers and not especially cold winters by interior Alaska standards, although note that the two winters of the met tower measurement period were warmer than typical. Calculated mean air density during the met tower test period exceeds the 1.225 kg/m³ standard air density for a sea level elevation by 2.9 percent. This is advantageous in wind power operations as wind turbines produce more power at low temperatures (high air density) than at standard temperature and density.

Monthly temperature and density table

| Month	Temp (°C)			Temp (°F)			Mean Density
	Mean (°C)	Min (°C)	Max (°C)	Mean (°F)	Min (°F)	Max (°F)	(kg/m³)
Jan	-4.6	-24.6	6.6	23.7	-12.3	43.9	1.311
Feb	-2.3	-22.7	12.3	27.9	-8.9	54.1	1.299
Mar	-1.6	-24.2	11.5	29.1	-11.6	52.7	1.294
Apr	1.7	-8.8	15.3	35.1	16.2	59.5	1.279
May	8.2	0.2	22.3	46.8	32.4	72.1	1.249
Jun	13.5	3.6	31.6	56.3	38.5	88.9	1.225
Jul	13.8	3.0	27.2	56.8	37.4	81.0	1.223
Aug	13.1	0.1	26.5	55.6	32.2	79.7	1.227
Sep	9.0	-4.1	20.3	48.2	24.6	68.5	1.241
Oct	-0.7	-13.2	13.2	30.7	8.2	55.8	1.255
Nov	0.8	-16.0	8.9	33.4	3.2	48.0	1.251
Dec	-2.9	-19.0	6.7	26.8	-2.2	44.1	1.281
Annual	4.0	-24.6	31.6	39.2	-12.3	88.9	1.261

Levelock temperature boxplot graph
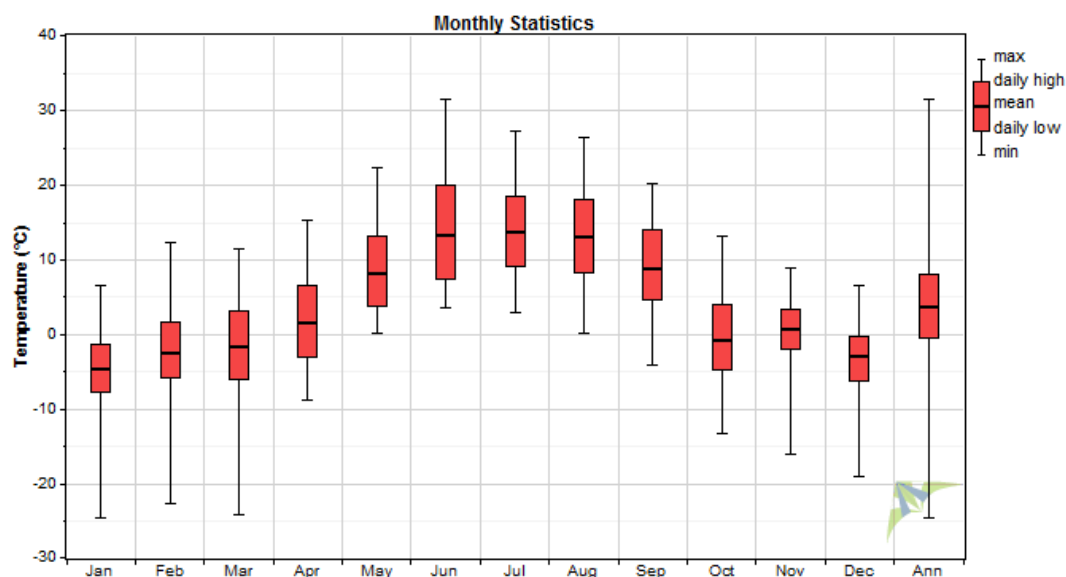
Wind Direction

Wind rose data indicates that winds in Levelock are primarily northerly, northeasterly and to a lesser extent southwesterly. The energy component of the wind rose indicates that the power-producing winds are strongly northeasterly to easterly, and less often, northerly.

*Levelock met tower wind rose*
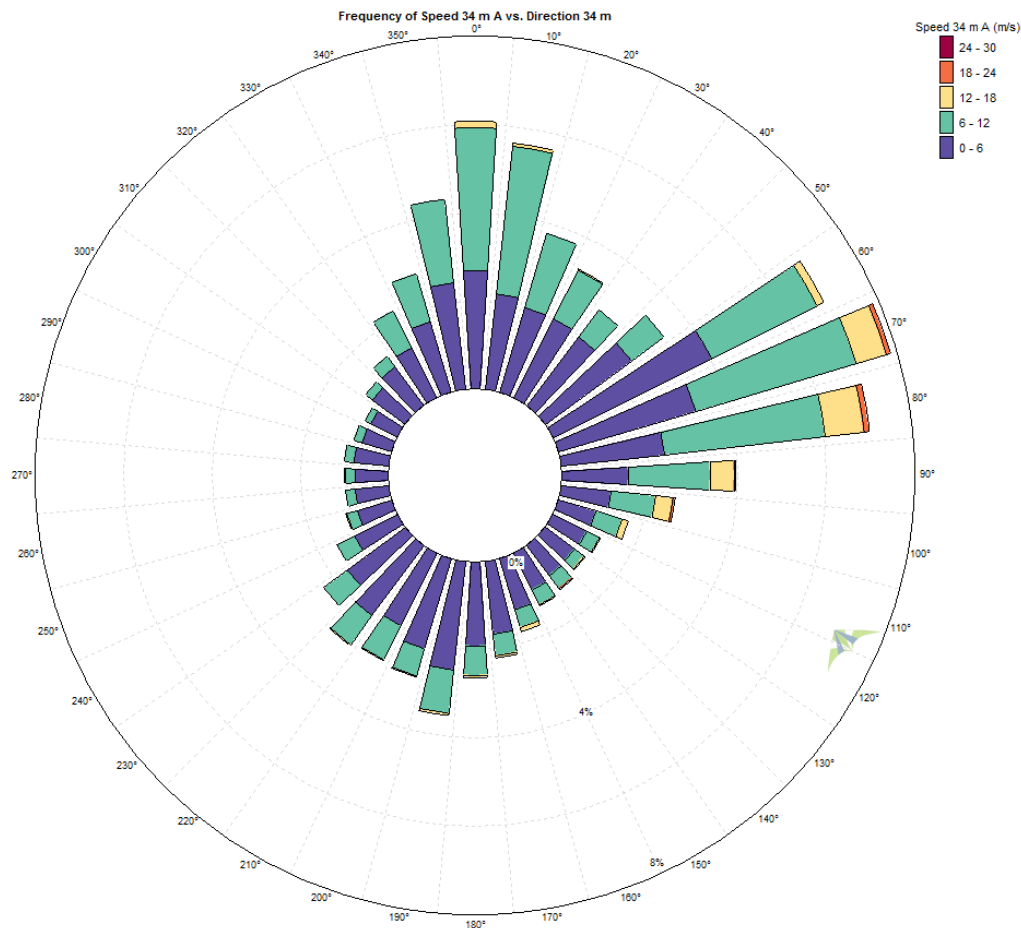
Turbulence

The turbulence intensity (TI) at the Levelock met tower site at 34 meters above ground level is somewhat high with a mean turbulence intensity of 0.134 and a representative turbulence intensity of 0.161 at 15 m/s wind speed, indicating moderately rough air for wind turbine operations. This classifies as International Electrotechnical Commission (IEC) 61400-1, 3rd Edition (2005) turbulence category B (Category A is most turbulent; C is least). Note however that the brush surrounding the met tower site has a significantly deleterious impact on turbulence. It is very likely that turbulence in a more open location, such as tundra or along the river, or appreciably higher than 34 meters at the met tower site, would be much lower.

Turbulence table

| Wind Speed Sensor | Height (m) | All Speed Bins | | | | | 15 m/s Speed Bin | | | | IEC 3 ed. |
		Data Points	Mean TI	SD of TI	Repres. TI	Peak TI	Data Points	Mean TI	SD of TI	Repres. TI	Turbulence Category
Speed 34 m A	34.2	67,425	0.17	0.10	0.30	1.61	348	0.13	0.02	0.16	B
Speed 34 m B	33.7	58,841	0.18	0.11	0.31	1.27	316	0.13	0.02	0.16	B
Speed 20 m	20.9	71,421	0.23	0.12	0.38	1.49	148	0.17	0.02	0.19	S

IEC turbulence classification

IEC 61400-1, 3rd ed.	
Category	I_{ref}, m/s
A	0.16
B	0.14
C	0.12
S	designer-specified

Turbulence intensity, all direction sectors
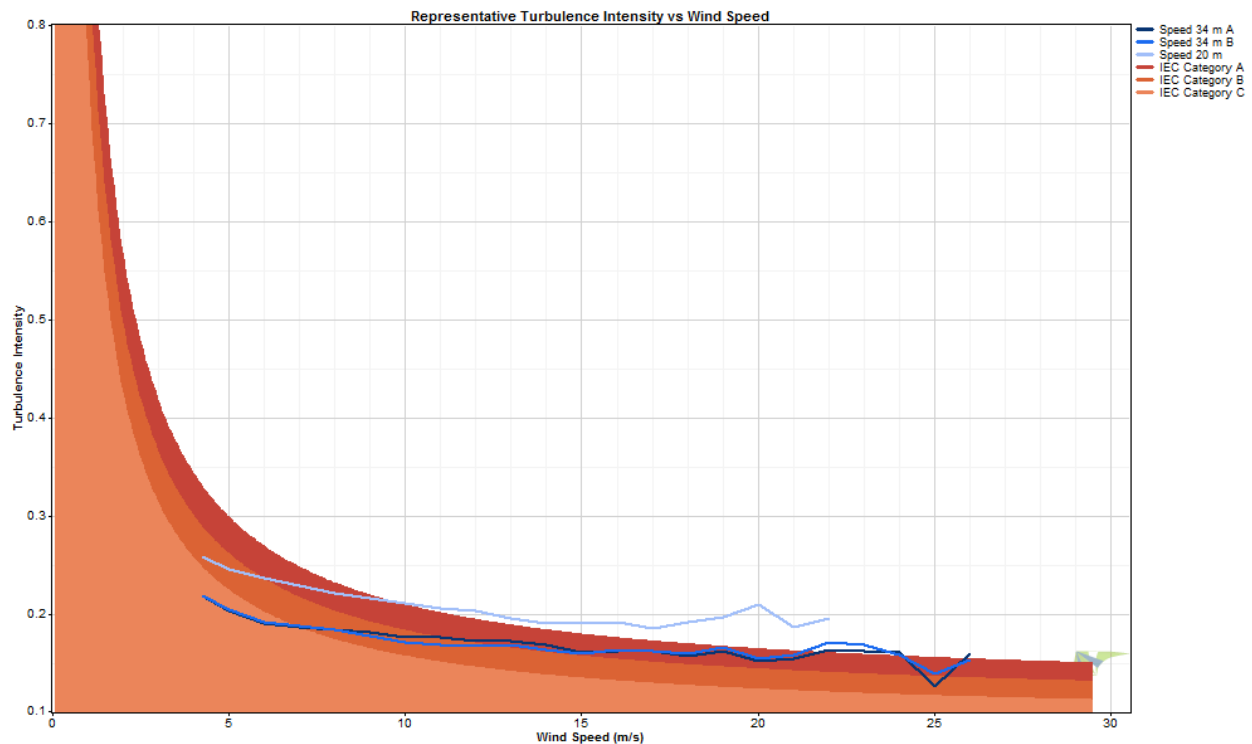

WAsP Wind Flow Model

Wind flow modeling was accomplished with WAsP (Wind Atlas Analysis and Application Program), a Danish PC-based software for predicting wind climates, wind resources and power production from wind turbines and wind farms and can be used to predict wind turbine performance. WAsP is the most widely used wind power analysis software in the world. Modelling begins with a digital elevation map

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(DEM) of the wind farm site and surrounding area and conversion of coordinates to Universal Transverse Mercator (UTM).[7]

A wind data (or wind atlas) reference point is added to the digital elevation map, wind turbine locations identified, and a wind turbine selected to perform annual energy production calculations. WAsP considers the orographic (terrain) effects on the wind, plus surface roughness and obstacles, and calculates wind velocity increase or decrease at all nodes of the map. The mathematical model has several limitations, including the assumption that the overall wind regime of the turbine site is same as the met tower reference site, prevailing weather conditions are stable over time, and surrounding terrain at the wind data reference point and turbine sites is sufficiently gentle and smooth to ensure laminar, attached wind flow.

WAsP wind speed[8] map of Levelock area
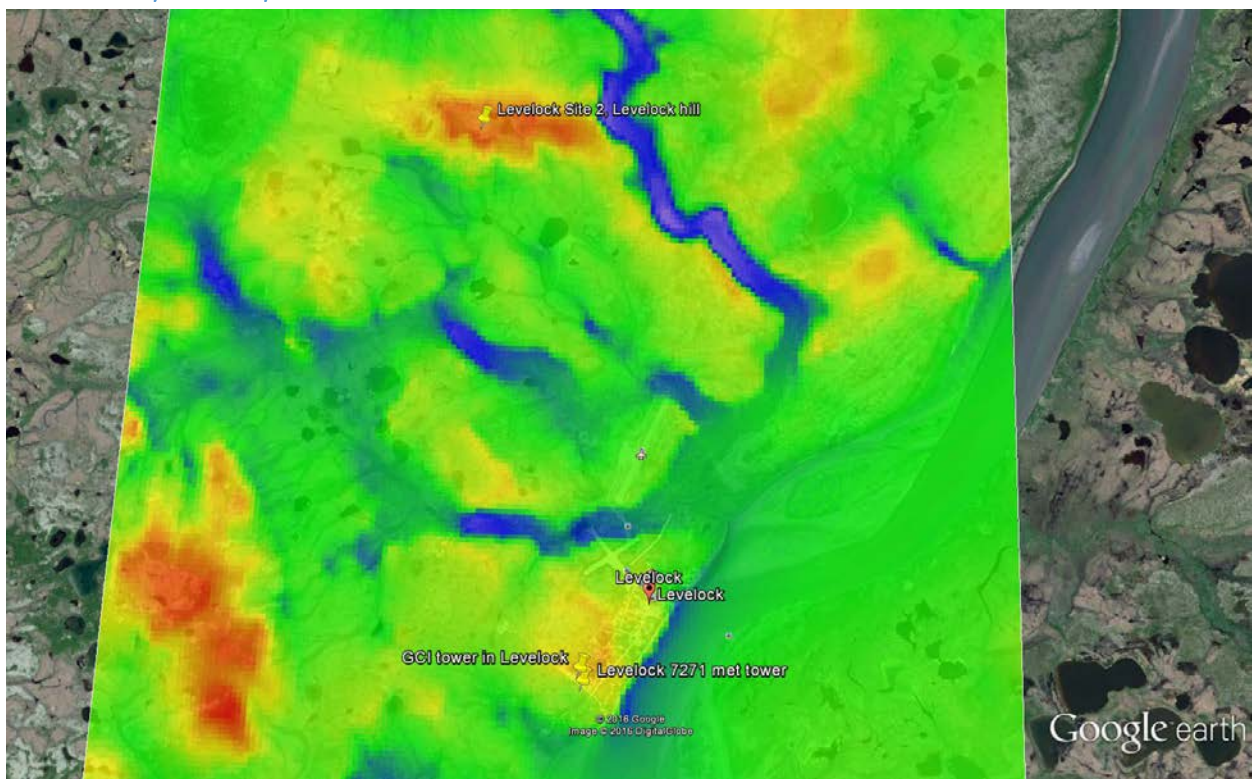
For this analysis, a simplified WAsP model without a roughness map was employed. This will result in moderate error when projecting wind speed from the brushy terrain where the met tower had been located to more open terrain where wind shear and roughness length would be less. But, the purpose here is to illustrate possible site options should alternate sites be considered. One such alternate site is an exposed plateau-like, tundra-covered location referred to as Levelock Hill and/or Levelock Site 2 in the site investigation phase of the project. Levelock Hill is approximately 2.1 miles northwest of the

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[7] UTM is a geographic coordinate system that uses a two-dimensional Cartesian coordinate system to identify locations on the surface of Earth. UTM coordinates reference the meridian of its zone (60 longitudinal zones are further subdivided by 20 latitude bands) for the easting coordinate, and distance from the equator for the northing coordinate. Units are meters.

[8] Projected 37 meter level, 5.5 (blue color) to 6.4 m/s (red color) mean annual

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north threshold of Levelock Airport, but nearer 2.7 miles by ATV trail. The site is on the winter trail to New Stuyahok, is well exposed, and is quite suitable for a wind power site except for its distance from existing power distribution infrastructure. This distance would be a severe challenge as distribution line construction across undeveloped permafrost terrain is very expensive.

Wind Turbine Energy Production

Met tower data was projected to 37 meters – the hub height of the Northern Power NPS100C-24 wind turbine – for creation of the preceding map. The NPS100C-24 is a possible wind turbine option for Levelock. It is manufactured in Barre, Vermont and is in wide use in Alaska for village wind projects.

At the met tower site, WAsP software predicts that at 100% annual energy production (AEP), the NPS100C-24 turbine would generate 271 MWh/year of electricity. This equates to a capacity factor[9] of 32.5%. At a more realistic 80% net AEP (assuming 20% production loss due to electrical, icing, maintenance, curtailment, wake, etc.), a NPS100C-24 would generate 217 MWh/year of energy at a 26.0% capacity factor.

At Levelock Hill (or Site 2), with the NPS100C-24 wind turbine at 37 meters hub height, WAsP predicts 297 MWh/year energy production (35.6% capacity factor) at 100% AEP, or 238 MWh/year (28.4% capacity factor) at 80% AEP.

Recommendations

Although Levelock's wind resource is moderate, there are opportunities to develop wind power in the community. The challenge though is to avoid the standard configuration where wind turbine(s) operate in parallel with the diesel generator(s). Levelock's electric load is too low for this type configuration and a design of this nature would be difficult to control and would not be efficient. A preferable approach is to consider a battery storage option with a grid-forming converter. In this configuration, the converter controls grid voltage and frequency as the prime mover and the diesel generator operates in droop mode. Wind turbines and possibly other renewable generation such as photovoltaic panels operate in parallel when available with excess energy directed to the battery and/or a remote thermal node such as the school's hydronic heat system.

Evaluation of the design aspects and economic merits of this approach are beyond the scope of this report, but recent developments in lithium ion batteries and inverter technology are promising and warrant further investigation.

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[9] Capacity factor is percent annual energy generated, or predicted, compared to maximum possible (100% power output 100% of the time)

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