Selawik, Alaska
Wind-Diesel Analysis

Google Earth image of Selawik

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Contents

Introduction

Alaska Village Electric Cooperative (AVEC) is the electric utility for the City of Selawik, Alaska. AVEC was awarded a grant from the Alaska Energy Authority (AEA) to complete resource assessment and feasibility work for installation of wind turbines in the community of Selawik.

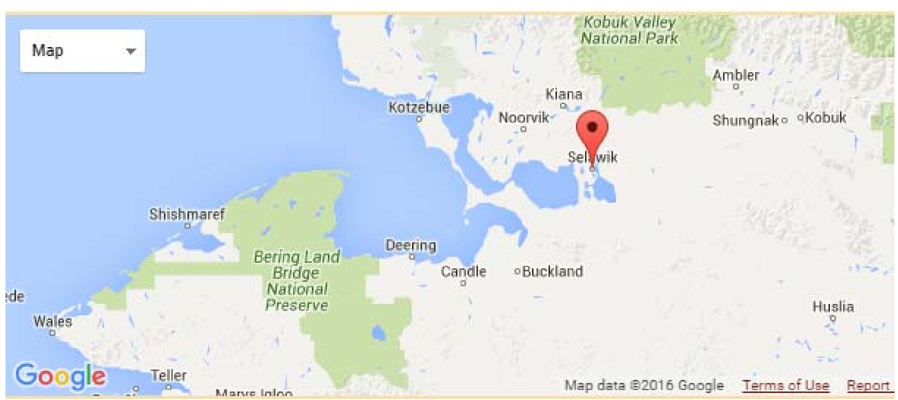
Executive Summary

Selawik has a moderate wind resource for wind power development, but the new Northern Power Systems NPS100C-24 wind turbine is expressly designed for lower wind class environments and modeling results predict very good energy production, especially given the very cold temperatures in Selawik. Wind turbine site options are limited in Selawik and the existing wind turbine site is best suited. The preferred option would be to decommission the existing AOC 15/50 wind turbines and re-power the site with the new turbine. The electrical load demand in the community is high enough to consider four new NPS100C turbines at a high hub height if FAA permitting allows. A project economic analysis per Alaska Energy Authority method indicates a positive economic benefit for a wind power project in the community.

Village of Selawik

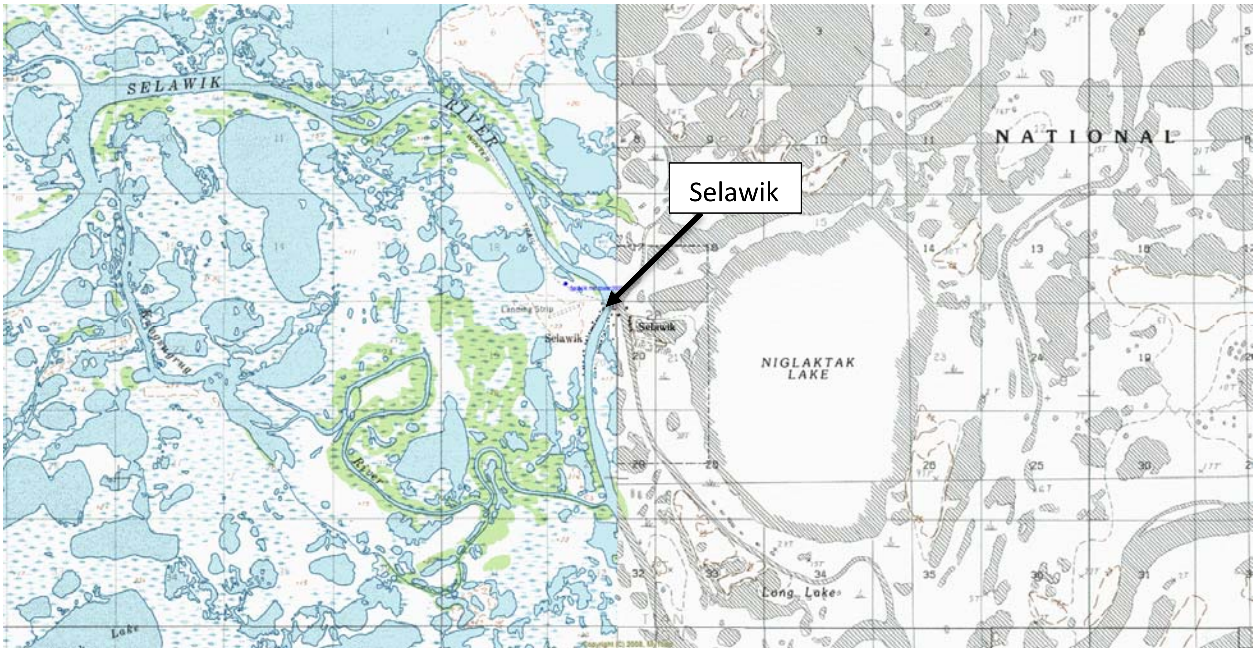
Selawik is located at the mouth of the Selawik River, where it empties into Selawik Lake, about 90 miles east of Kotzebue. It lies 670 miles northwest of Anchorage. The city is near the Selawik National Wildlife Refuge, a key breeding and resting spot for migratory waterfowl. It is an Inupiat Eskimo community active in traditional subsistence fishing and hunting.

Lt. L.A. Zagoskin of the Imperial Russian Navy first reported the village in the 1840s as "Chilivik." Ivan Petroff counted 100 "Selawigamute" people in his 1880 census. Selawik is an Eskimo name for a species of fish. Around 1908, the site had a small wooden schoolhouse and church. The village has continued to grow and has expanded across the Selawik River onto three banks, linked by bridges. Selawik incorporated as a first-class city in 1974 but in 1977 changed to a second-class city government.



Selawik falls within the arctic climate zone, characterized by seasonal extremes in temperature. Winters are long and harsh, and summers are short but warm. Temperature extremes have been recorded from -50 to 83 °F. The Selawik River is navigable from early June to mid-October.

Topographic map of Selawik



Google Earth image of Selawik (view to southeast)

Wind Resource

A 34 meter NRG Systems, Inc. tubular-type meteorological (met) tower was installed in Selawik in an open area of NANA Regional Corporation land immediately west of the northernmost AVEC wind turbine on the north side of the community. The met tower was operational for nearly fourteen months, from early November 2014 to late December 2016.

The wind resource measured at the Selawik met tower site is fair to marginal with a mean annual wind speed of 5.62 m/s and a wind power density of 236 W/m^2 at 34 meters above ground level. This confirms the AWS Truepower wind resource map which predicts Class 2 winds in Selawik. The wind resource is summarized below, but one may reference *Selawik, Alaska Wind Resource Assessment Report*, Feb. 18, 2016, V3 Energy, LLC in Appendix A for a complete discussion.

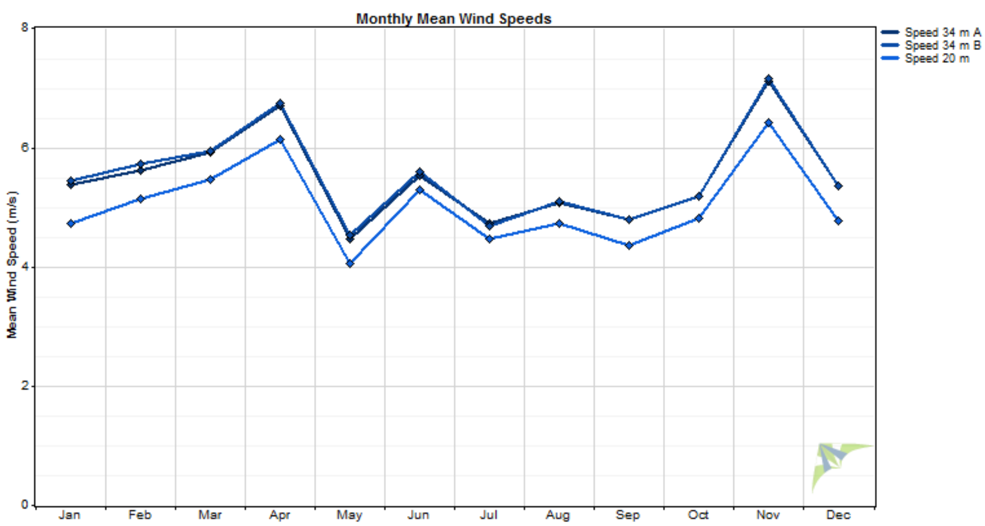
Selawik met tower data synopsis

Data dates	11/04/2014 to 1/4/2016 (14 months)
Wind speed mean, 34 m, annual	5.52 m/s (12.3 mph)
Wind power density mean, 34 m	229 W/m^2
Max. 10-min wind speed	20.8 m/s
Maximum 2-sec. wind gust	25.5 m/s (57.0 mph), February 2015
Weibull distribution parameters	k = 1.60, c = 6.18 m/s
Wind shear power law exponent	0.187 (low)
Surface roughness	0.15 meters (agricultural land)
IEC 61400-1, 3rd ed. classification	Class III-C
Turbulence intensity, mean (at 34 m)	0.075 (at 15 m/s)
Calm wind frequency (at 34 m)	34% (< 4 m/s) (14 mo. measurement period)

Measured Wind Speeds

During the measurement period, winds at the test site measured 5.52 m/s (annualized), which can be considered fair for wind power development, provided a wind turbine optimized for lower wind speeds is selected.

Selawik wind speed graph

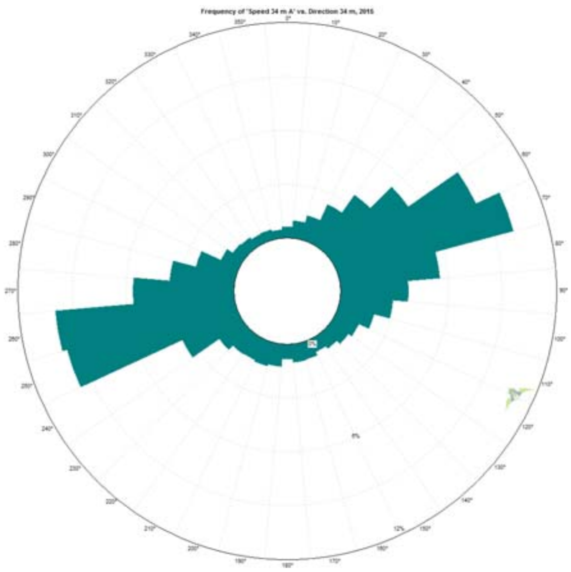


Wind Roses

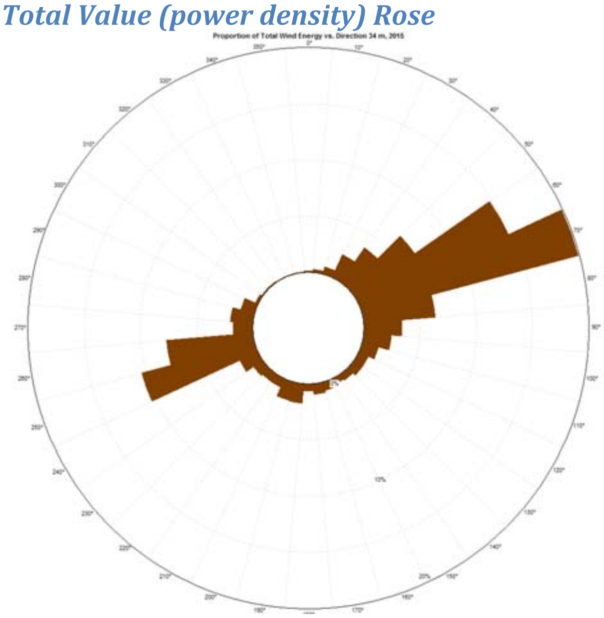
Wind frequency rose data indicates that winds at the Selawik met tower site are primarily bi-directional, with east-northeasterly and west-southwesterly winds predominating. The mean value rose indicates that ENE winds are of relatively higher intensity than WSW winds, but with more frequent ENE winds, the dominant energy winds are from that direction.

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 34 percent during the 14-month test period.

Wind Frequency Rose



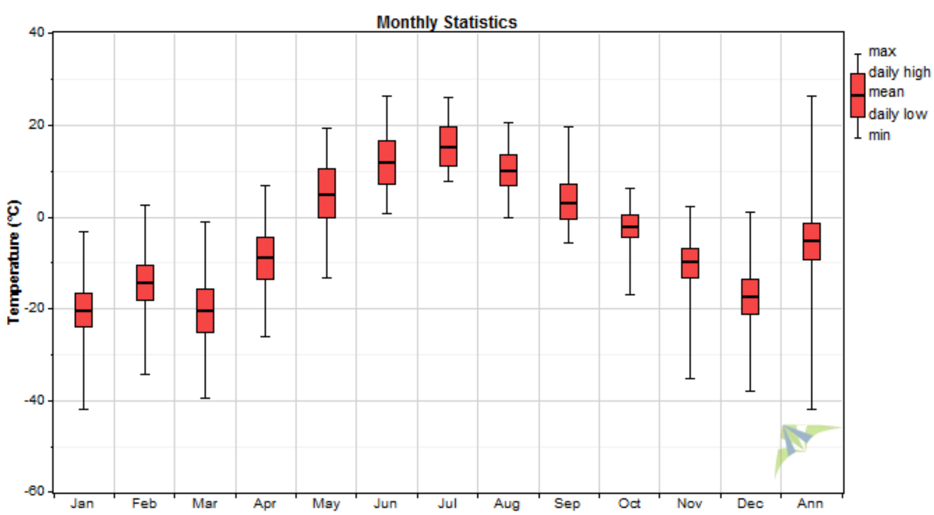
Total Value (power density) Rose



Temperature and Density

Selawik experiences cool summers and cold winters with resulting higher than standard air density. Calculated mean-of-monthly-mean (or annual) air density during the met tower test period exceeds the 1.225 kg/m^3 standard air density for a sea level elevation by 5.8 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.

Temperature boxplot



Turbulence and Extreme Wind

The turbulence intensity (TI) at the Selawik met tower site is very low with a mean turbulence intensity of 0.075 and a representative turbulence intensity of 0.095 at 15 m/s wind speed, indicating smooth air for wind turbine operations. This equates to an International Electrotechnical Commission (IEC) 61400-1, 3rd Edition (2005) turbulence category C, which is the lowest defined category.

With 14 months of available met tower data, the predicted V_{ref} for a 50 year return period (in other words, predicted to occur once every 50 years) is 25.8 to 30.8 m/s, depending on calculation method. The site classifies as extreme wind Class III by International Electrotechnical Commission 61400-1, 3rd edition, criteria, the lowest defined classification.

WAsP Wind Flow Model

WAsP (Wind Atlas Analysis and Application Program) and is PC-based software for predicting wind climates, wind resources and power production from wind turbines and wind farms and was used to model wind turbine performance within the Selawik landscape and terrain.

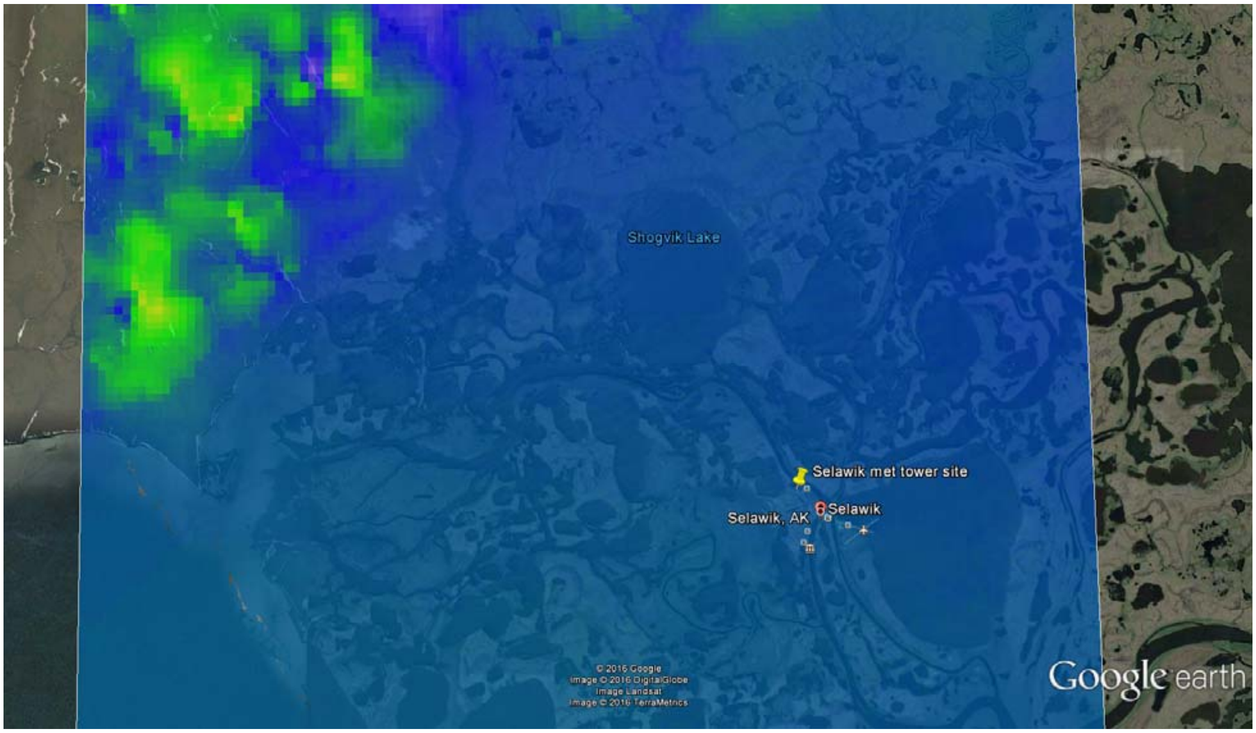
Orographic Modeling

WAsP modeling begins with import of a digital elevation map (DEM) of the subject site and surrounding area and conversion of coordinates to Universal Transverse Mercator (UTM). 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 particular 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. Elevations of the DEMs are converted to meters (if necessary) for import into WAsP software.

A met tower reference point is added to the digital elevation map, wind turbine locations identified, and a wind turbine(s) selected to perform the calculations. WAsP considers the orographic (terrain) effects on the wind (plus surface roughness and obstacles) and calculates how wind flow increases or decreases at each node of the DEM grid. The mathematical model has a number of limitations, including the assumption of overall wind regime of the turbine site is the same as the met tower reference site, prevailing weather conditions are stable over time, and the surrounding terrain at both sites is sufficiently gentle and smooth to ensure laminar, attached wind flow. WAsP software is not capable of modeling turbulent wind flow resulting from sharp terrain features such as mountain ridges, canyons, shear bluffs, etc.

Given the very flat terrain in the vicinity of Selawik, orographic modeling with the met tower station as the reference wind atlas, indicates a fair wind resource with no appreciable variation short of the hilly upload terrain which begins approximately nine miles north of Selawik and continues to the Kobuk River valley. As such, there are no topographic features near enough to Selawik to develop for wind power, or at least none that would be superior to the wind resource measured by the met tower itself.

WAsP wind modeling of Selawik and vicinity



Wind Turbine Project Site Options

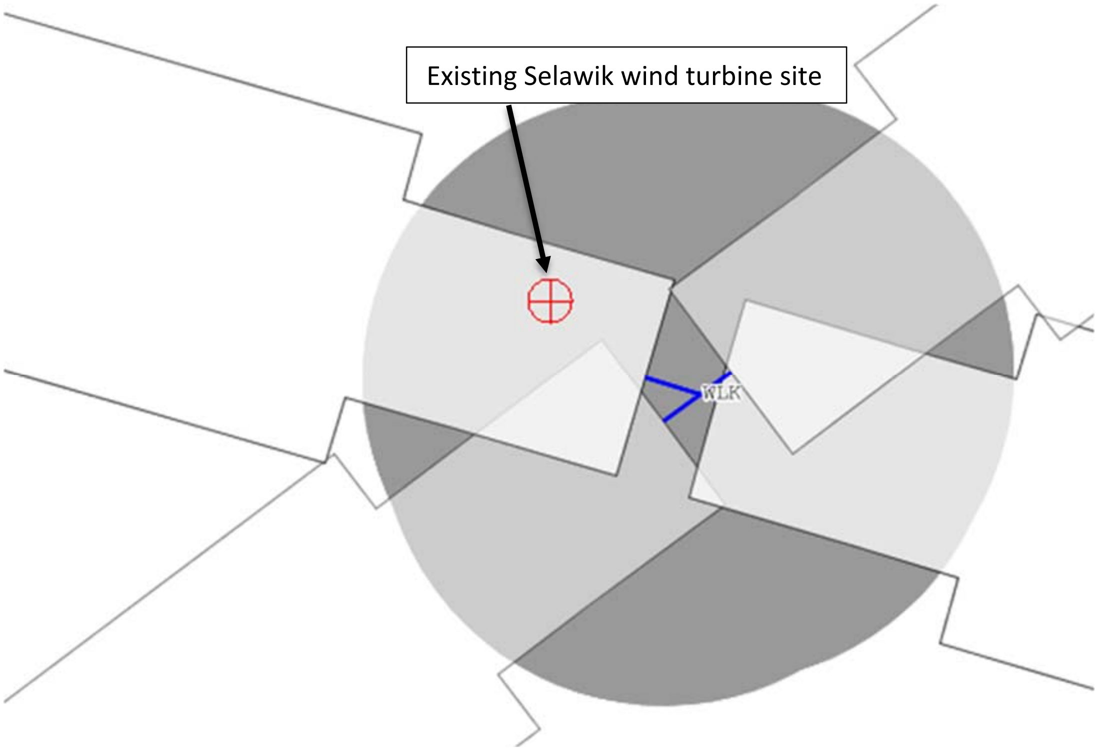
Four AOC 15/50 wind turbines are presently operational in an array immediately north of the powerplant on the north side of the village. One option is to decommission these turbines and re-power at the existing site (but likely with fewer turbines) and another option is to identify a new site. The existing turbines were permitted by FAA in 2002, although a site identification error in FAA's database placed the turbines approximately 500 meters east of actual position. This error was corrected in 2013 and the turbines are considered obstructions for airport operations. It should be noted, however, that there are other obstructions noted by FAA for Selawik as the airport is located very near the community and has two operational runways. FAA's IFR Takeoff Minimums and (Obstacle) Departure Procedures for Selawik note the following:

> **Rwy 4**, multiple brushes beginning 176' from departure end of runway (DER), 429' left of centerline, up to 18' AGL/18' MSL. **Rwy 22**, antenna on building, 1040' from DER, 448' right of centerline, 30' AGL/47' MSL. **Rwy 27**, multiple antennas and buildings beginning 270' from DER, right and left side of centerline, up to 108' AGL/125' MSL. Bridge 2148' from DER, 249' right of centerline, 60' AGL/90' MSL. Wind turbines beginning 3310' from DER, 1194' right of centerline, up to 110' AGL/165' MSL.

It is worth noting here that the existing wind turbines are obstructions for departure from Runway 27, but are not actually the most significant obstacles; they would be the multiple antennas and buildings which are nearer the runway DER and nearer runway centerline, even though slightly less high. It should also be noted the Runway 9/27 is the crosswind runway and as such, given Selawik's strongly predominant ENE and WSW prevailing winds, Runway 27 is not a common departure route from Selawik.

The image below of FAA's notice criteria tool (NCT) of the Selawik airport shows the location of the existing wind farm with an overlay of instrument approach surfaces. The NCT result indicates that a 115 ft. AGL obstruction (the wind turbine) exceeds an instrument approach area (for Runway 27) by 110 ft. Clearly though by that criteria nearly every building and object in Selawik also exceed the instrument approach area for Runway 27 and as such the wind turbines should be considered within that context.

FAA Notice Criteria Tool for wind turbine at existing Selawik wind farm



The grey area in the image above indicates the 150 ft. AGL (of airport height of record) horizontal surface and, as noted with respect to the wind turbine, the rectangles attached to the runways note instrument approach areas. Given these constraints, it is not realistic to find a wind turbine site location in Selawik that is free of either restriction as the horizontal surface itself extends well past the developed extent of the community, with the possible exception of the landfill to the northwest.

The instrument approach areas though pose the more significant problem, if one's intent is to identify a location where wind turbines of even modest height do not violate standards. With reference to the above image, one can see that instrument approach areas blanket all of developed Selawik; open areas (without instrument approach restrictions) near developed Selawik are four small triangles of land inside the DER of each runway, intersecting with adjacent DER's. These locations are highly restrictive though as they are either on airport property, in water, or otherwise difficult or unsuitable for development of wind power, although a possible site option is the isthmus of land north of small lagoon north the airport (see Google Earth image below). A few residences are located along the shoreline and hence access and power infrastructure exists at least to some extent. For the most part, however, this location does not appear particularly suitable for wind power development.

Selawik, near airport areas without instrument approach airspace conflicts

Land ownership of the two parcels circled above which are south and west of the runway intersection is State of Alaska DOT&PF. The parcel north of the airport – the narrow isthmus – is owned by NANA Regional Corporation.

Selawik, near airport land ownership

Referring again to the FAA Notice Criteria Tool image of Selawik, besides immediately near the airport, the only other viable areas for development which completely avoids instrument approach areas are 1.5+ miles north, south and west of the airport, with areas east of the airport precluded by Niglaktak Lake. Ares north and south of the airport are presently inaccessible with no existing infrastructure, but the area to the west is a possible wind turbine site location with development potential, although as with areas to the north and south, it is also not accessible at present with no existing infrastructure.

Selawik, west of airport area without instrument approach airspace conflict

This land is owned by NANA Regional Corporation, which presumably would support wind power development in this location, but the very high cost of road construction across low-lying, wet terrain to gain access makes this an unlikely location for wind power development.

Recommended Turbine Site

Although the existing wind turbines are within an instrument landing area (airspace) for Runway 27, this location is the only truly viable wind power site in Selawik. Its primary attributes are that it is already developed, it is immediately adjacent to the barge landing, and it is immediately adjacent to the power plant. The primary drawback of this site of course is that the existing wind turbines (and any new ones as well) extend into airspace of an instrument landing area. As noted previously, however, so do many other structures within Selawik. Presumably, FAA would grant approval to repower this site with turbines at or very near the height of the existing turbines, but possibly they would allow higher yet.

Selawik wind turbine site, view to the east

Selawik Power System

The Selawik power system at present consists of three diesel generators with heat recovery, four older AOC 15/50 wind turbines, and a three-phase power distribution network throughout the community.

Diesel Generators

The HOMER model was constructed with all three Selawik generators. Information pertinent to the HOMER model is shown in the table below. Note that the Selawik power plant is equipped with automatic switchgear which supports a new wind project for the community. This enables the diesel generators to automatically operate in parallel with wind turbines and each other. For the HOMER model, the diesel generators are allowed to operate at a low-load condition (15% loading) to reflect AVEC's new grid-bridging wind-diesel control technology with ultra-capacitors.

Selawik power plant diesel generators

Generator	Electrical Rating	Diesel Engine	Generator
1	363 kW	Detroit Diesel S60K4 1800 rpm	MAR 572 RSL 4027
2	499 kW	Cummins QSX15 G9	NEW I544F
3	900 kW	Cummins K38G4 1800	CMS 1000DF JD

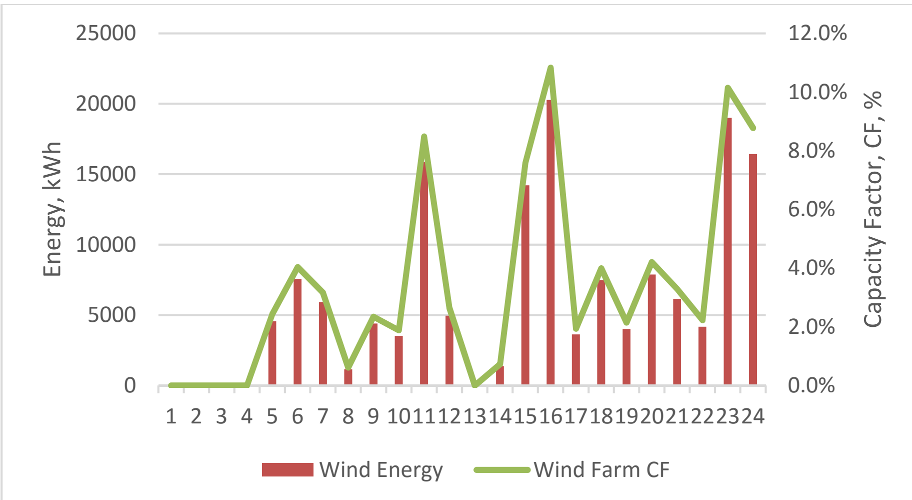
AOC 15/50 Wind Farm

The four AOC 15/50 wind turbines presently operational in Selawik were installed in 2002 and have had a checked history due to early problems with blade tip brake retraction and latching. Recently though those problems have been resolved and the turbines have had a much improved operational status. Still, the AOC 15/50 is a very old asynchronous generator wind turbine design with a relatively small rotor diameter and is not particularly well optimized for the lower wind speeds of Selawik.

The AOC 15/50 is rated at 50 kW capacity but actual maximum power output per a 2003 NREL power performance test is 65 kW. The rotor diameter is 15 meters and in Selawik the turbines are mounted on 100 ft. (30 meter) Rohn lattice towers. The four turbine array is arranged in a line on a southeast-northwest alignment with an inter-turbine spacing of 75 meters, or 5 rotor diameters.

Wind farm production has been improved in 2015 compared to 2014, but maximum monthly fleet capacity factor in the two-year period was only 11 percent and typically much less than that.

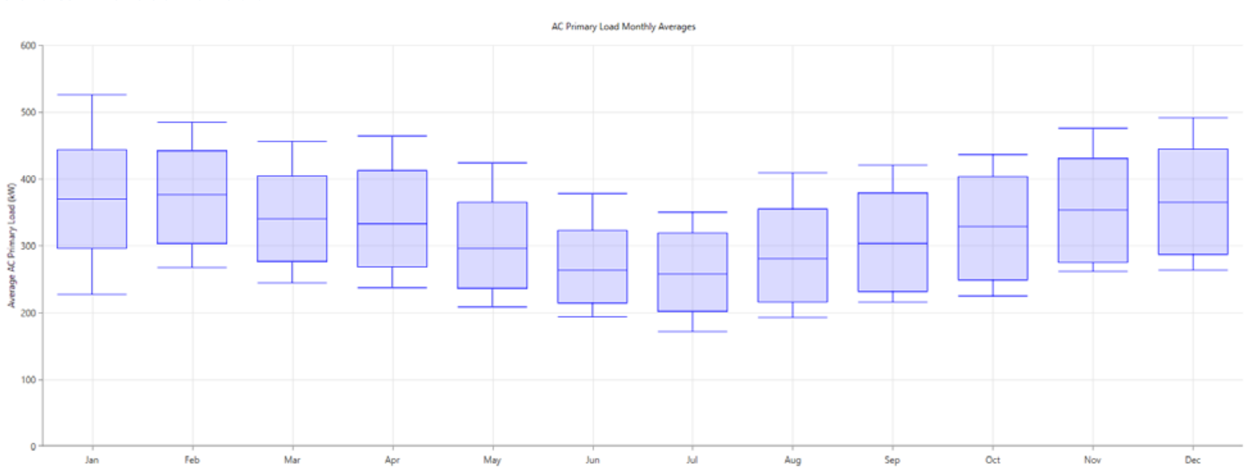
Selawik AOC 15/50 Wind Production, 2014-2015



Electric Load

Selawik electric load was synthesized with the Alaska Village Electric Load Calculator, developed by AEA in 2005 to create a "virtual" village load profile where actual electric load data is not available. Although AVEC automatically logs and records Selawik electric load data, file errors prevented its use for this report. Reference for the Alaska Village Electric Load Calculator was AVEC's 2015 Annual Generation Report, which documented an average load in Selawik of 318 kW, a 636 kW peak load (in December), and a total load demand for the year of 2,782 MWh.

Selawik electric load



Thermal Load

Jacket water heat from the Selawik powerplant diesel engines is routed to the nearby community water plant via a heat recovery system. Although the precise thermal load profile was not evaluated for this study, typical water plant thermal heat demand is high enough to absorb considerable excess energy production via a secondary load controller/electric boiler configuration.

Wind-Diesel Hybrid System Design and Equipment

Wind-diesel power systems are categorized based on their average penetration levels, or the overall proportion of wind-generated electricity compared to the total amount of electrical energy generated. Commonly used categories of wind-diesel penetration levels are very low, low, medium, and high penetration. The wind penetration level is roughly equivalent to the amount of diesel fuel displaced by wind power. Note however that the higher the level of wind penetration, the more complex and expensive a control system and demand-management strategy is required.

Categories of wind-diesel penetration levels

Penetration Category	Wind Penetration Level		Operating Characteristics and System Requirements
	Instantaneous	Average	
Very Low	<60%	<8%	• Diesel generator(s) runs full time • Wind power reduces net load on diesel • All wind energy serves primary load • No supervisory control system
Low	60 to 120%	8 to 20%	• Diesel generator(s) runs full time • At high wind power levels, secondary loads are dispatched to insure sufficient diesel loading, or wind generation is curtailed • Relatively simple control system
Medium	120 to 300%	20 to 50%	• Diesel generator(s) runs full time • At medium to high wind power levels, secondary loads are dispatched to insure sufficient diesel loading • At high wind power levels, complex secondary load control system is needed to ensure heat loads do not become saturated • Sophisticated control system
High (Diesels-off Capable)	300+%	50 to 150%	• At high wind power levels, diesel generator(s) may be shut down for diesels-off capability • Auxiliary components required to regulate voltage and frequency • Sophisticated control system

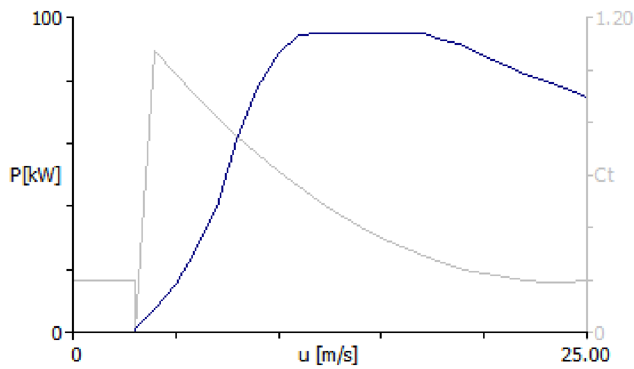
Medium penetration is a good compromise between of displaced fuel usage and relatively minimal system complexity and is AVEC's preferred system configuration. Installation of wind turbines in Selawik would likely be configured at the medium penetration level.

Proposed Wind Turbine

The Northern Power Systems NPS 100C-24 wind turbine is proposed for Selawik to replace the existing AOC 15/50. The NPS 100C-24 is rated at 95 kW and is equipped with a permanent magnet, synchronous generator for direct drive (no gearbox) operation. The turbine has a 24.4-meter diameter rotor and is available with three tubular tower heights: 22, 29, and 37 meters. The 24-meter model is specifically optimized for lower wind speed sites and classifies as IEC 61400-1, 3rd edition, Class III-C.

The NPS100 is stall-regulated and for Selawik would be equipped with an arctic package enabling operation at temperatures as low as -40° C. The NPS 100 is the most widely represented village-scale wind turbine in Alaska with a significant number of installations in the Yukon-Kuskokwim Delta and on St. Lawrence Island. The NPS 100 wind turbine is manufactured in Barre, Vermont, USA. More information can be found at http://www.northernpower.com/. The power and thrust curves of the NPS 100C-24 are shown below.

NPS 100C-24 power and thrust curves



Northern Power Systems 100 (B model) wind turbines, Shaktoolik, Alaska

HOMER Software Model

HOMER energy modeling software was used to analyze the Selawik power System. HOMER is a static energy model designed to analyze hybrid power systems that contain a mix of conventional and renewable energy sources, such as diesel generators, wind turbines, solar panels, batteries, etc. HOMER software is widely used in the State of Alaska to aid development of village wind-diesel power projects.

The HOMER model was constructed with the three Selawik diesel generators. Information pertinent to the HOMER model is shown in the table below. Note that the Selawik power plant is presently equipped with manual switchgear which would be upgraded to automated switchgear for a wind project. This would enable the diesel generators to automatically operate in parallel with wind turbines and each other. For the HOMER model, the diesel generators are allowed to operate at a no-load condition (0 kW) to reflect AVEC's new grid-bridging wind-diesel control technology with ultra-capacitors.

Modeling Assumptions

HOMER modeling assumptions are detailed in the table below. Many assumptions, such as project life, discount rate, operations and maintenance (O&M) costs, etc. are AEA default values. The base or comparison scenario is the existing Selawik power plant with its present configuration of diesel generators.

New NPS100C-24 wind turbines constructed at the Selawik site are assumed to operate in parallel with the diesel generators, as are the existing turbines. Excess energy, if sufficient, will serve thermal loads via a secondary load controller and electric boiler to serve thermal loads in the community water plant. Installation cost of the wind turbines assumes new foundations to replace those presently in place for the AOC 15/50 turbines. This report models scenarios of two and four wind turbines. Two wind turbines should fit within existing AOC 15/50 array, but four turbines would require more space by either extending the existing array to the northwest or construction two turbines elsewhere, potentially on City of Selawik and/or NANA Regional Corporation land across the road and immediately west of the powerplant.

HOMER and AEA modeling assumptions

Economic Assumptions	
Project life	20 years (2018 to 2037)
Discount rate	3% (reference: AEA *EvaluationModelREFR9Final* spreadsheet)
Operating Reserves	
Load in current time step	10%
Wind power output	100% (HOMER setting to ensure diesels-on operation)
Diesel Generators	
O&M cost	$0.107/kWh (reference: AEA *EvaluationModelREFR9Final* spreadsheet)
Minimum load	15 percent (grid-bridging control)
Schedule	Optimized
Wind Turbines	
Net AEP	80% (accounts for all losses)
O&M cost	1% of capex/year (reference: AEA *EvaluationModelREFR9Final* spreadsheet)

Wind speed	5.44 m/s at 34 m, measured at met tower
Density adjustment	1.280 (from Site 0064 met tower data)
Wind shear	0.187 power law exponent
Energy Loads	
Electric	7.62 MWh/day average Selawik electric load
Thermal	Modeled as infinite

Model Results

HOMER energy modeling software was used to calculate wind turbine energy production and excess energy available (not demanded by the electrical load). Note that inclusion of wind turbines as a wind-diesel power system, even at lower penetration levels, can result in energy generation greater than electrical load demand. This is due to spinning reserve and minimum loading requirements of the diesel generators. Note that wind turbine energy production in these analyses is calculated at 80 percent of gross. HOMER software does not model system dynamic response. Possible system instability would be addressed during design.

Given a presumed height limitation at the turbine site due to FAA airspace consideration, the NPS 100C-24 is modeled on a 22-meter tower, the shortest available. But, considering the high value of additional energy production at higher hub heights, the 37-meter tower is also modeled.

Northern Power NPS100C-24, two turbines, 22 m hub height

This configuration is two Northern Power NPS100C-24 wind turbines on 22-meter towers at the recommended (existing) wind turbine site. The 60-minute time average simulation models wind energy production at 80 percent net (or 80 percent of annual gross). In this scenario, wind turbine penetration (percent electrical power production by wind) would be 12.1 percent. Excess energy is modeled at a negligible 43 kWh/year; an SLC/boiler to “dump” excess energy to the diesel engine jacket water heat recovery loop would not be necessary.

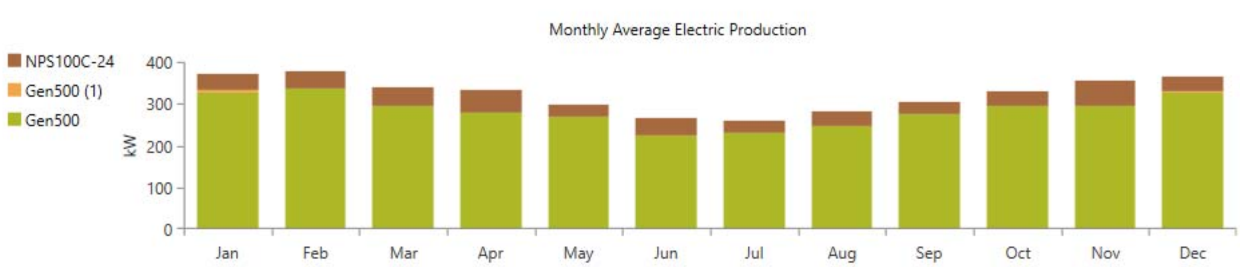
Energy table, two NPS 100C-24 turbines, 22-meter tower, 80% net AEP

Production	kWh/yr	%
500kW Genset	2,476,581	87.67
500kW Genset (1)	6,000	0.21
Northern Power NPS100C-24	342,263	12.12
Total	2,824,844	100.00

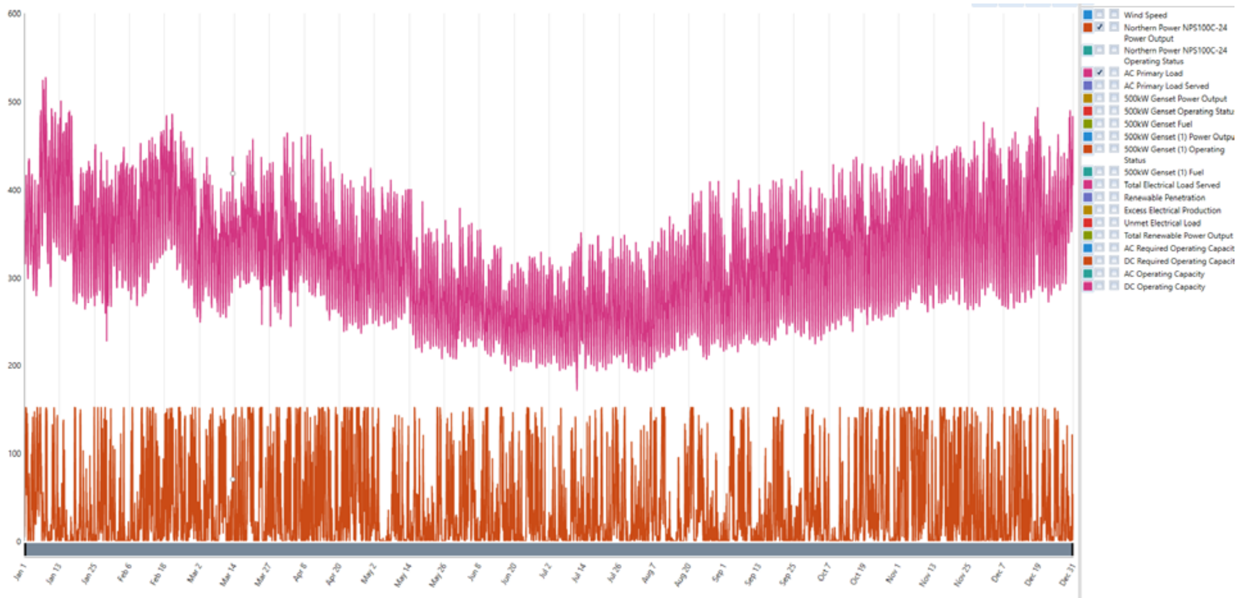
Consumption	kWh/yr	%
AC Primary Load	2,824,810	100.00
DC Primary Load	0	0.00
Total	2,824,810	100.00

Quantity	kWh/yr	%
Excess Electricity	43.1	0.0
Unmet Electric Load	0.0	0.0
Capacity Shortage	0.0	0.0

Quantity	Value
Renewable Fraction	12.1
Max. Renew. Penetration	71.6



Chart, two NPS 100C-24 turbines, 22-meter tower, 80% net AEP



Northern Power NPS100C-24, four turbines, 22 m hub height

This configuration is four Northern Power NPS100C-24 wind turbines on 22-meter towers at the recommended (existing) wind turbine site. The 60-minute time average simulation models wind energy production at 80 percent net (or 80 percent of annual gross). In this scenario, wind turbine penetration (percent electrical power production by wind) would be 22.8 percent. Excess energy is modeled at 40.5 MWh/yr, or 1.4 percent of energy generated. This energy should be directed to an SLC/boiler to "dump" it to the diesel engine jacket water heat recovery loop.

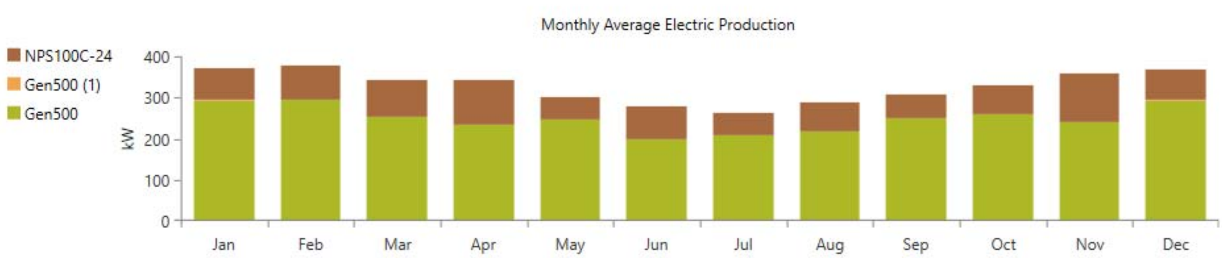
Energy table, four NPS 100C-24 turbines, 22-meter tower, 80% net AEP

Production	kWh/yr	%
500kW Genset	2,175,854	75.94
500kW Genset (1)	4,875	0.17
Northern Power NPS100C-24	684,525	23.89
Total	2,865,255	100.00

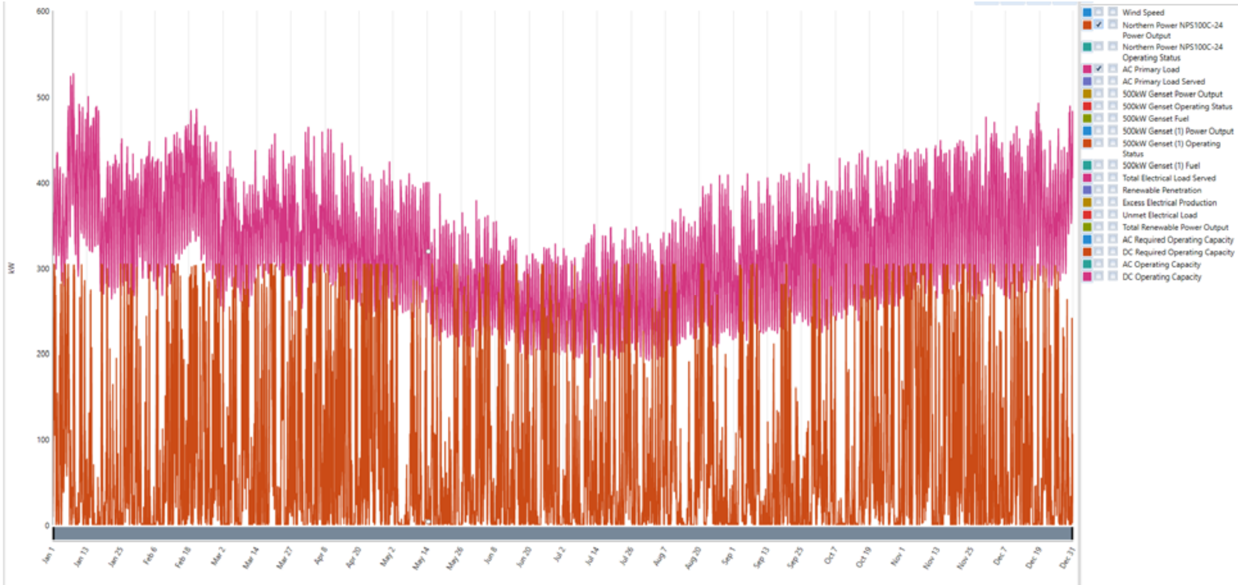
Consumption	kWh/yr	%
AC Primary Load	2,824,810	100.00
DC Primary Load	0	0.00
Total	2,824,810	100.00

Quantity	kWh/yr	%
Excess Electricity	40,459.0	1.4
Unmet Electric Load	0.0	0.0
Capacity Shortage	0.0	0.0

Quantity	Value
Renewable Fraction	22.8
Max. Renew. Penetration	143.2



Chart, two NPS 100C-24 turbines, 22-meter tower, 80% net AEP



Northern Power NPS100C-24, two turbines, 37 m hub height

This configuration is two Northern Power NPS100C-24 wind turbines on 37-meter towers at the recommended (existing) wind turbine site. The 60-minute time average simulation models wind energy production at 80 percent net (or 80 percent of annual gross). In this scenario, wind turbine penetration (percent electrical power production by wind) would be 14.3 percent. Excess energy is modeled at a negligible 85 kWh/year; an SLC/boiler to “dump” excess energy to the diesel engine jacket water heat recovery loop would not be necessary.

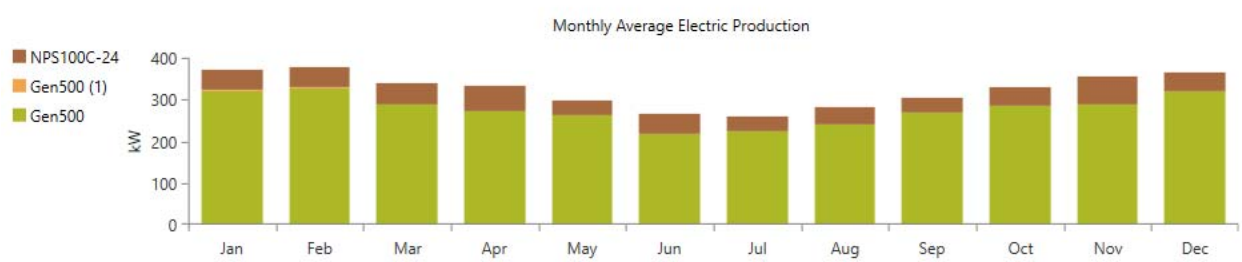
Energy table, two NPS 100C-24 turbines, 37-meter tower, 80% net AEP

Production	kWh/yr	%
500kW Genset	2,416,082	85.53
500kW Genset (1)	5,325	0.19
Northern Power NPS100C-24	403,479	14.28
Total	2,824,887	100.00

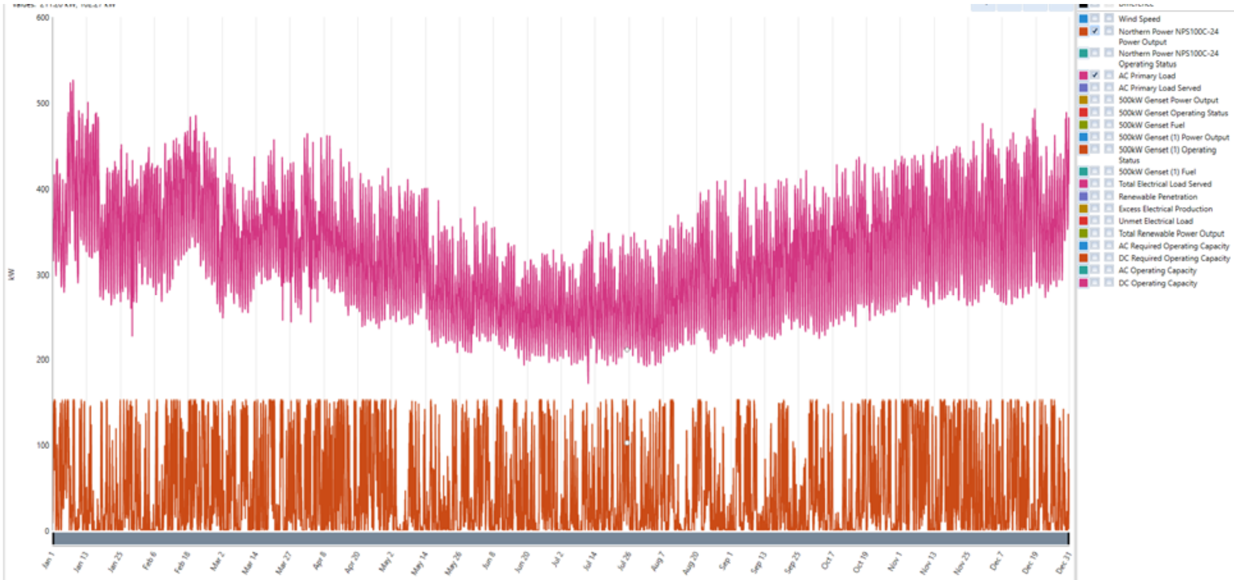
Consumption	kWh/yr	%
AC Primary Load	2,824,810	100.00
DC Primary Load	0	0.00
Total	2,824,810	100.00

Quantity	kWh/yr	%
Excess Electricity	84.9	0.0
Unmet Electric Load	0.0	0.0
Capacity Shortage	0.0	0.0

Quantity	Value
Renewable Fraction	14.3
Max. Renew. Penetration	73.4



Chart, two NPS 100C-24 turbines, 37-meter tower, 80% net AEP



Northern Power NPS100C-24, four turbines, 37 m hub height

This configuration is four Northern Power NPS100C-24 wind turbines on 37-meter towers at the recommended (existing) wind turbine site. The 60-minute time average simulation models wind energy production at 80 percent net (or 80 percent of annual gross). In this scenario, wind turbine penetration (percent electrical power production by wind) would be 26.6 percent. Excess energy is modeled at 55.5 MWh/yr, or 1.9 percent of energy generated. This energy should be directed to an SLC/boiler to "dump" it to the diesel engine jacket water heat recovery loop.

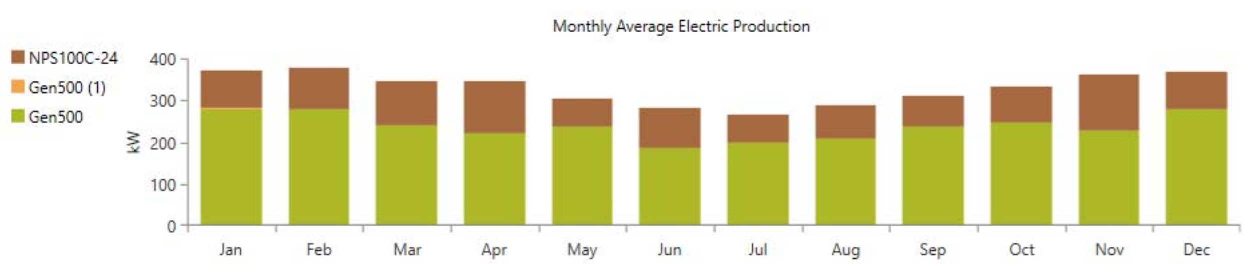
Energy table, four NPS 100C-24 turbines, 37-meter tower, 80% net AEP

Production	kWh/yr	%
500kW Genset	2,068,888	71.83
500kW Genset (1)	4,500	0.16
Northern Power NPS100C-24	806,959	28.02
Total	2,880,347	100.00

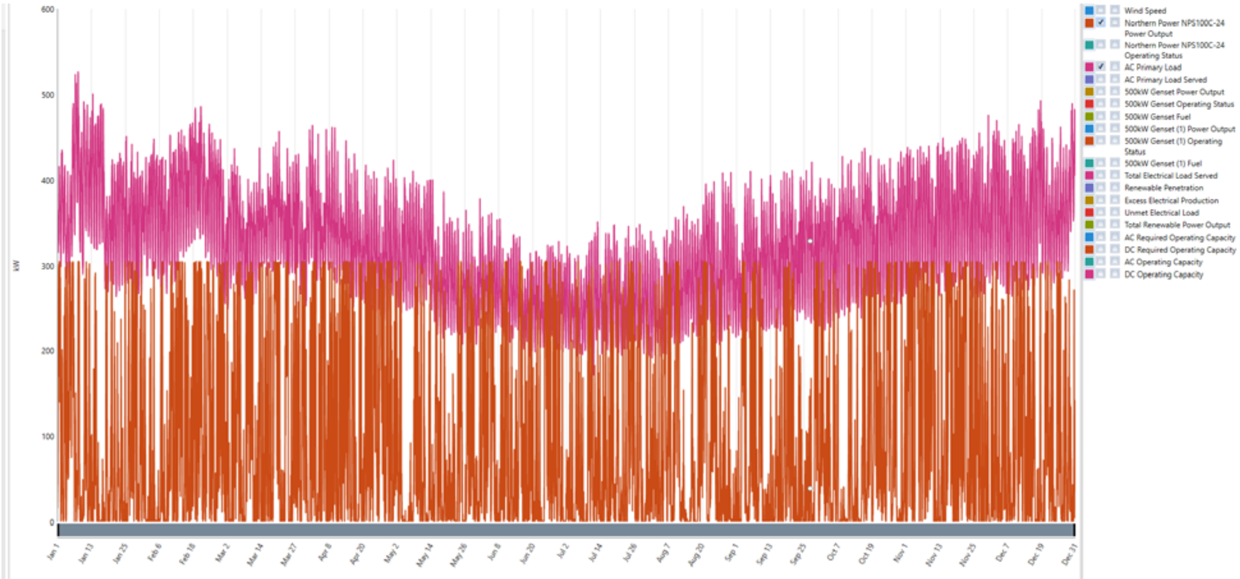
Consumption	kWh/yr	%
AC Primary Load	2,824,810	100.00
DC Primary Load	0	0.00
Total	2,824,810	100.00

Quantity	kWh/yr	%
Excess Electricity	55,548.0	1.9
Unmet Electric Load	0.0	0.0
Capacity Shortage	0.0	0.0

Quantity	Value
Renewable Fraction	26.6
Max. Renew. Penetration	146.8



Chart, four NPS 100C-24 turbines, 37-meter tower, 80% net AEP



Wind Turbine Layout

WAsP software calculates gross and net annual energy production (AEP) for turbines contained within wind farms, such as an array of two or more turbines in proximity to each other. For a single turbine array, WAsP calculates gross AEP. With one turbine, net AEP is identical to gross AEP as there is no wake loss to consider.

Using WAsP, an array of four NPS100C-24 wind turbines at 37-meter hub heights was evaluated. The wind turbines were aligned to minimize wake loss from the measured prevailing and secondary winds. Two of the NPS100C turbines are on the existing AOC 15/50 wind turbine array and the other two are on City of Selawik and NANA Regional Corporation land between the powerplant and the river.

NPS 100C-24 four turbine layout, view to southwest, with wind direction rose overlays

WAsP Modeling Results for Turbine Array Options

The following table presents the WAsP software analysis of energy production of four NPS 100C-24 turbines at 100% turbine availability (percent of time that the turbine is on-line and available for energy production with no energy production losses other than WAsP-calculated wake loss). The NPS 100C-24 wind turbine models very well in the Selawik wind regime with acceptable annual energy production and minimal array wake loss.

NPS 100C-24 four turbine array, WAsP model results, 100% AEP

Parameter	Total (MWh/yr)	Average per (MWh/yr)	Minimum per (MWh/yr)	Maximum per (MWh/yr)
Net AEP	1,095.0	273.7	271.6	275.5
Gross AEP	1,105.6	276.4	276.3	276.5
Wake loss	0.95%	-	-	-

Economic Analysis

AEA's 2015 *EvaluationModelREFR9Final (1)* Excel spreadsheet was used to evaluate the potential economic benefit of a wind power project in Selawik. For this, two of the four modeled wind scenarios are chosen: two NPS100C-24 turbines at 22-meter hub heights and four NPS100C-24 wind turbines at 37-meter hub heights.

Project Capital Cost

Capital and installation costs of wind turbines to serve Selawik is estimated from AEA's 2015 *EvaluationModelREFR9Final (1)* Excel spreadsheet default assumption of $10,897/kW installed wind power capacity. With this assumption, capital cost for economic benefit calculation is $2.18M for a two turbine project and $4.36M for a four turbine project.

Fuel Cost

A fuel price of $4.98/gallon was chosen for the initial HOMER analysis by reference to the AEA's 2015 *EvaluationModelREFR9Final (1)* Excel spreadsheet. This price reflects the average estimated fuel price in Selawik between the 2018 (the assumed project start year) fuel price of $4.06/gallon and the 2036 (20-year project end year) fuel price of $5.89/gallon using diesel fuel price projection in the spreadsheet. This price projection includes an average CO_2-equivalent allowance cost of $0.71/gallon.

Economic Valuation

HOMER software was used in this wind-diesel analysis to model the wind resource, wind turbine energy production, effect on the diesel engines when operated with wind turbines, and excess wind energy that could be used to serve thermal loads. Although HOMER software is designed to evaluate economic valuation by ranking alternatives, including a base or "do nothing" alternative by net present cost, AEA economic valuation methodology differs in its assumptions of O&M costs, fuel cost for each year of the project life, and disposition of excess energy. Excess energy is valued in the ISER spreadsheet with an assumption that the power plant is not co-generation. In other words, excess energy is valued without consideration of possible thermal production loss due to reduced diesel engine loading as would occur in a co-generation system configuration.

In an effort to align economic valuation of project alternatives with Alaska Energy Authority methods, this feasibility analysis uses AEA's economic evaluation methods. The model is updated every July in preparation for the next round of Renewable Energy Fund requests for proposals in the form of an explanation report and an Excel spreadsheet. The latest version of the spreadsheet has a file name of *EvaluationModelREFR9Final (1)* and is available on AEA's website.

Project economic valuation

Turbine	No.	Hub Height (m)	(in $ millions) Project Cost	NPV Benefits	NPV Costs	B/C ratio	Diesel Fuel Saved (gal/yr)	Heat Oil Saved (gal/yr)	Petroleum Fuel Saved (gal/yr)
100C-24	2	22	2.18	2.41	2.18	1.11	27,378	0	27,378
	4	37	4.36	5.53	4.36	1.27	60,112	1,323	61,435

Recommendations

Selawik has a low-to-moderate wind resource for wind power development, but the new Northern Power Systems NPS100C-24 wind turbine is designed for lower wind class environments and modeling indicates very respectable energy production and turbine capacity factor. The very cold temperatures of Selawik are a bonus in that there is a not inconsiderable performance boost due to increased aerodynamic lift across the rotor blades compared to standard conditions.

Wind turbine site options are very limited in Selawik and the existing wind turbine site is most suitable, although possibly City of Selawik and/or NANA Regional Corporation east of the powerplant offer an expansion option for wind turbines.

Given the poor history and lackluster performance of the AOC 15/50 wind turbines, decommissioning the turbines and re-powering with NPS100C-24 turbines is recommended. Also recommended is working with FAA to possibly allow a 37-meter tower instead of the minimum 22-meter tower option.

Selawik Wind Resource Assessment Report

Selawik, Alaska Wind Resource Assessment Report

Selawik met tower and AOC15/50 wind turbines, photo by Douglas Vaught

February 18, 2016

Douglas Vaught, P.E.
V3 Energy, LLC
Eagle River, Alaska

V3 Energy LLC
Eagle River, Alaska 907.350.5047

Summary

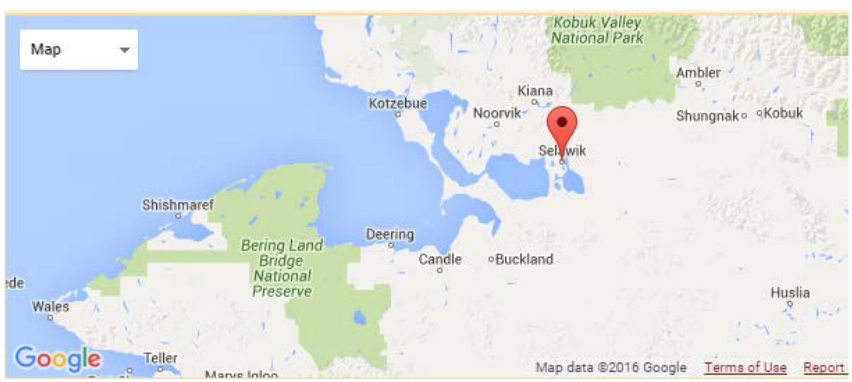
The wind resource measured at the Selawik met tower site is fair to marginal with a mean annual wind speed of 5.62 m/s and a wind power density of 236 W/m^2 at 34 meters above ground level. This confirms the AWS Truepower wind resource map which predicts Class 2 winds in Selawik. Although the wind resource in Selawik is modest compared to nearby Kotzebue, development of renewable power in the village may be viable with turbines specifically suited to lower wind environments. Also of consideration is the high cost of fuel in Selawik and the environmental risk of transporting and storing fossil fuel. Wind power provides a long-term renewable energy alternative for Selawik that has the potential to buffer residents from unpredictable variations of the petroleum market. These and other issues will be explored in a companion wind-diesel study report.

Met tower data synopsis

Data dates	11/04/2014 to 1/4/2016 (14 months)
Wind speed mean, 34 m, annual	5.52 m/s (12.3 mph)
Wind power density mean, 34 m	229 W/m^2
Max. 10-min wind speed	20.8 m/s
Maximum 2-sec. wind gust	25.5 m/s (57.0 mph), February 2015
Weibull distribution parameters	k = 1.60, c = 6.18 m/s
Wind shear power law exponent	0.187 (low)
Surface roughness	0.15 meters (agricultural land)
IEC 61400-1, 3rd ed. classification	Class III-C
Turbulence intensity, mean (at 34 m)	0.075 (at 15 m/s)
Calm wind frequency (at 34 m)	34% (< 4 m/s) (14 mo. measurement period)

Test Site Location

A 34 meter NRG Systems, Inc. tubular-type meteorological (met) tower was installed in Selawik in an open area of NANA Regional Corporation land immediately west of the northernmost AVEC wind turbine on the north side of the community. Selawik is located at the mouth of the Selawik River, where it empties into Selawik Lake, about 90 miles east of Kotzebue. It lies 670 miles northwest of



Anchorage. The city is near the Selawik National Wildlife Refuge, a key breeding and resting spot for migratory waterfowl. It is a traditional Inupiat Eskimo village, population of 829 people (2010 data), largely dependent on fishing and subsistence activities (Alaska DCED website). Selawik falls within the arctic climate zone, characterized by seasonal extremes in temperature. Winters are long and harsh, and summers are short but warm. Temperature extremes have been recorded from -50 to 83 °F. The Selawik River is navigable from early June to mid-October.

Site information

Site number	0003
Latitude/longitude	N 66° 36’ 31.29”, W 160° 1’ 13.35”
Time offset	-9 hours from UTC (Yukon/Alaska time zone)
Site elevation	9 meters (29 ft.)
Datalogger type	NRG SymphoniePLUS3, 10 minute averaging time step
Tower type	Tubular, 15 cm (6 in.) diameter, 34 meter (112 ft.) height

Tower sensor information

Channel	Sensor type	Designation	SN	Height	Multiplier	Offset	Orientation
1	NRG #40C anemometer	34 m A	218101	33.9 m	0.747	0.38	090 T
2	NRG #40C anemometer	34 m B	218100	33.7 m	0.753	0.35	270 T
3	NRG #40C anemometer	20 m	219012	20.9 m	0.755	0.34	090 T
7	NRG #200P wind vane	Direction		33.2 m	0.351	180	000 T
4	NRG #110S Temp C	Temp		2.5 m	0.136	86.383	000 T
5	LiCor LI-200 pyranometer	Pyran.	PY80402	3.0 m	1.278	0	180 T
6	RH5X relative humidity	RH		2.0 m	0.097	0	000 T

Tower sensor photographs

North side, up tower

East side, up tower

South side, up tower

West side, up tower

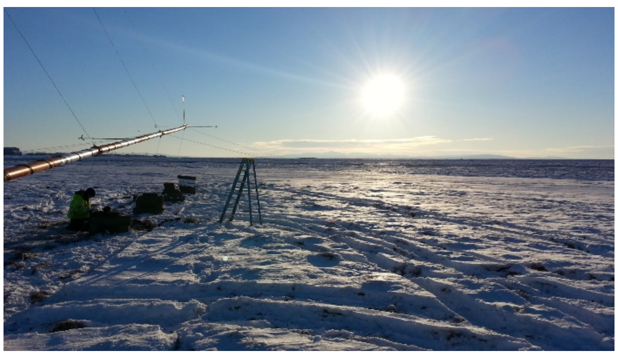
Met tower site photographs

Site view to north

Site view to northeast

Site view to east

Site view to southeast



Site view to south

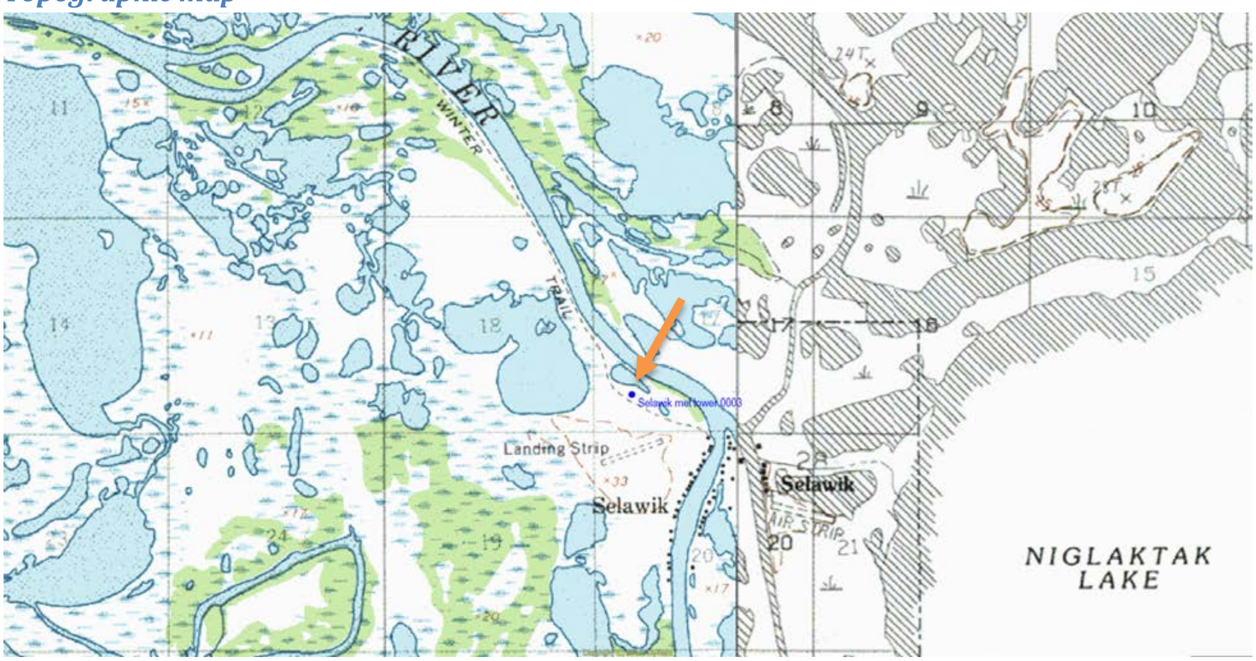
Site view to southwest

Site view to west

Site view to northwest

Google Earth image, Selawik

Topographic map



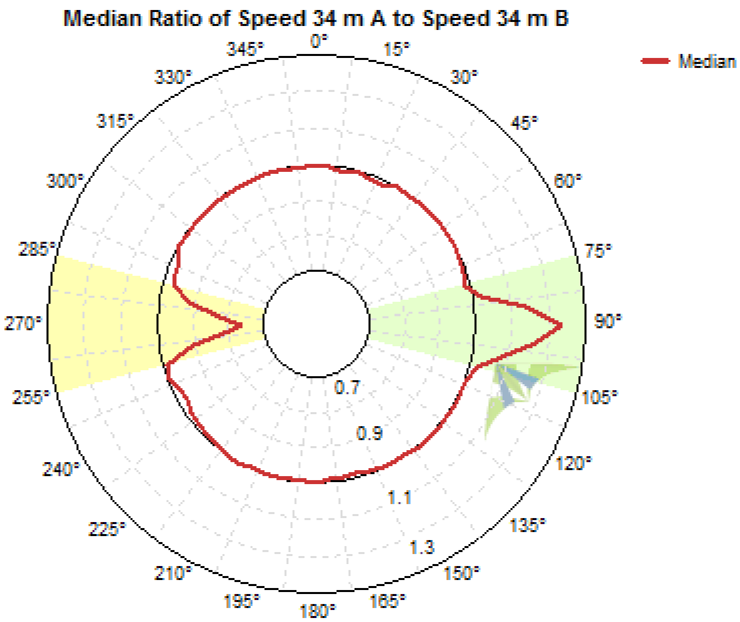
Data Quality Control

Data was filtered to remove presumed icing events that yield false zero wind speed data and non-variant wind direction data. Data that met criteria listed below were automatically filtered. In addition, data was manually filtered for obvious icing that the automatic filter didn't identify, and invalid or low quality data for situations such as logger initialization and other situations.

- 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

In general, icing conditions were infrequent indicating minimal concern for wind turbine energy production loss due to ice. With semi-frequent westerly winds, tower shadow affected anemometer 34 m A (channel 1) more often than anemometer 34 m B (channel 2).

Tower shading plot



Sensor data recovery table

Data Column	Possible Records	Valid Records	Recovery Rate (%)	Icing	Invalid	Tower shading
Speed 34 m A	61,478	48,887	79.5%	1,803	783	10,005
Speed 34 m B	61,366	53,055	86.5%	542	786	6,983
Speed 20 m	61,268	60,015	98.0%	470	783	0
Direction 34 m	61,268	57,515	93.9%	2,971	782	0
Temperature	61,268	60,486	98.7%	0	782	0
Pyranometer	61,268	60,488	98.7%	0	780	0

Data Column	Possible Records	Valid Records	Recovery Rate (%)	Icing	Invalid	Tower shading
Relative humidity	61,268	60,486	98.7%	0	782	0

Sensor data recovery rate by month

Year	Month	34 m A	34 m B	20 m	Vane	Temp	Pyran.	RH
2014	Nov	99.3	88.6	100.0	88.4	100.0	100.0	100.0
2014	Dec	82.3	90.9	94.6	46.9	100.0	100.0	100.0
2015	Jan	85.4	80.0	98.4	71.1	100.0	100.0	100.0
2015	Feb	88.4	87.2	100.0	83.5	100.0	100.0	100.0
2015	Mar	69.0	91.4	100.0	91.4	100.0	100.0	100.0
2015	Apr	71.0	83.8	96.4	83.8	100.0	100.0	100.0
2015	May	80.8	87.3	100.0	87.3	100.0	100.0	100.0
2015	Jun	70.3	97.5	100.0	97.5	100.0	100.0	100.0
2015	Jul	70.9	91.1	100.0	91.1	100.0	100.0	100.0
2015	Aug	64.6	95.9	100.0	95.9	100.0	100.0	100.0
2015	Sep	84.1	90.4	100.0	90.4	100.0	100.0	100.0
2015	Oct	83.7	81.7	100.0	81.7	100.0	100.0	100.0
2015	Nov	95.6	83.7	100.0	83.7	100.0	100.0	100.0
2015	Dec	83.2	71.9	92.1	71.9	92.2	92.2	92.2
2016	Jan	0.0	0.0	0.0	0.0	0.0	0.0	0.0
All Data		79.8	86.6	98.0	82.5	98.7	98.7	98.7

Wind Speed

Anemometer data obtained from the met tower, from the perspectives of both mean wind speed and mean wind power density, indicate a moderate wind resource. Note that cold temperatures contributed to a higher wind power density than standard conditions would yield for the measured mean wind speeds. This is reflected in the CRMC (cubed root mean cubed) wind speed, which reflects a calculation of a steady wind speed, at the measured mean air density, that would yield the measured mean wind power density. In other words, the winds in Selawik punch above their weight.

A table following that below presents the same data but with anemometer icing and tower shadow data removed from the data set and then synthesized with Windographer software's gap-filling subroutine. The advantage of gap-filling is that a more representative data set is achieved, especially with inclusion of data from the opposing anemometer when data is filtered for tower shadow (gap-filling synthesizes tower shadow data by this method).

Anemometer data summary (filtered for icing and tower shadow)

Variable	Speed 34 m A	Speed 34 m B	Speed 20 m
Measurement height (m)	33.9	33.7	20.9
Mean wind speed (m/s)	5.78	5.68	5.10
MoMM wind speed (m/s)	5.65	5.62	5.03

Variable	Speed 34 m A	Speed 34 m B	Speed 20 m
Median wind speed (m/s)	5.70	5.60	4.90
Max 10 min avg. wind speed (m/s)	17.60	20.80	18.40
Max gust wind speed (m/s)	23.30	25.50	23.50
CRMC wind speed (m/s)	7.32	7.20	6.52
Weibull k	1.65	1.65	1.68
Weibull c (m/s)	6.38	6.27	5.66
Mean power density (W/m²)	258	245	182
MoMM power density (W/m²)	242	236	172
Mean energy content (kWh/m²/yr)	2,260	2,147	1,591
MoMM energy content (kWh/m²/yr)	2,118	2,065	1,503
Energy pattern factor	2.0	2.0	2.1
Frequency of calms (%) (< 4 m/s)	33.1	33.5	39.4

MoMM = mean of monthly means

CRMC = cubed root mean cubed

Anemometer data summary (gap-filled)

Variable	Speed 34 m A	Speed 34 m B	Speed 20 m
Measurement height (m)	33.9	33.7	20.9
Mean wind speed (m/s)	5.59	5.61	5.10
MoMM wind speed (m/s)	5.49	5.52	5.03
Median wind speed (m/s)	5.50	5.50	4.90
Max 10 min avg. wind speed (m/s)	20.80	20.80	18.40
Max gust wind speed (m/s)	23.30	25.50	23.50
CRMC wind speed (m/s)	7.14	7.18	6.52
Weibull k	1.60	1.60	1.68
Weibull c (m/s)	6.15	6.18	5.66
Mean power density (W/m²)	239	243	182
MoMM power density (W/m²)	225	229	172
Mean energy content (kWh/m²/yr)	2,096	2,128	1,590
MoMM energy content (kWh/m²/yr)	1,972	2,005	1,502
Energy pattern factor	2.1	2.1	2.1
Frequency of calms (%)	34.8	34.6	39.4

MoMM = mean of monthly means

CRMC = cubed root mean cubed

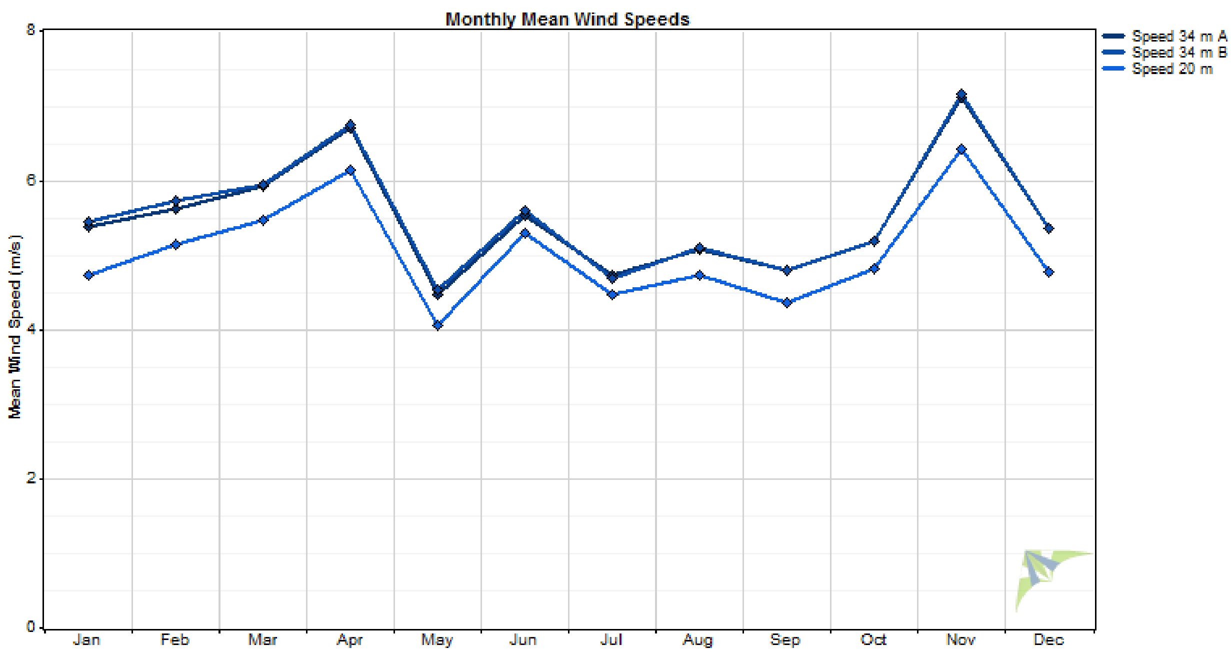
Time Series

Time series calculations indicate higher wind speeds during the winter months compared to the summer months. This correlates well with Selawik's 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 night hours.

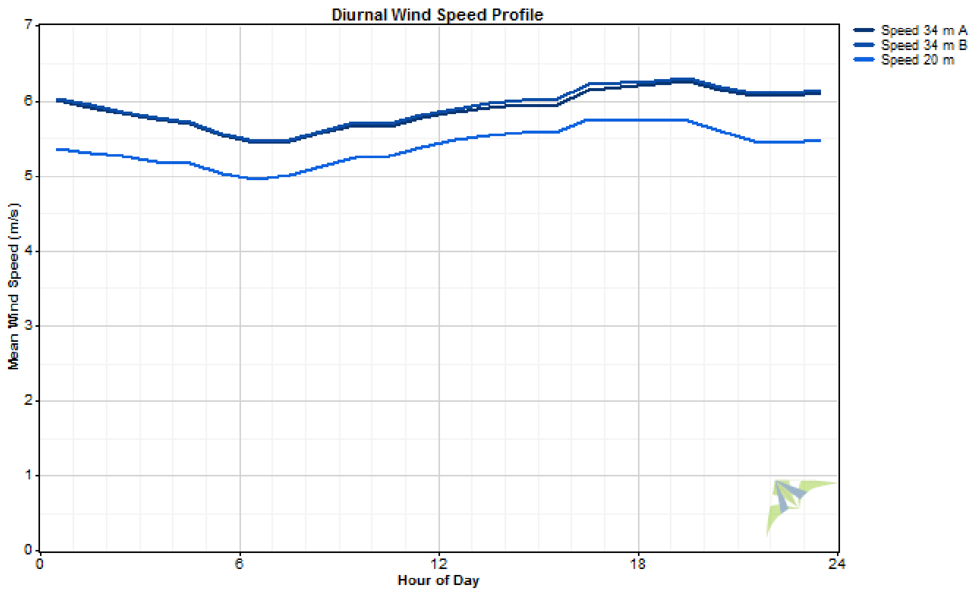
34 m A anemometer data summary

Year	Month	Raw Mean (m/s)	Filtered Mean (m/s)	Gapfilled Mean (m/s)	Max (m/s)	Gust (m/s)	Std. Dev. (m/s)	Weibull k	Weibull c (m/s)
2014	Nov	7.97	8.02	7.97	14.9	17.3	2.56	3.53	8.79
2014	Dec	5.41	6.46	5.84	15.6	19.6	3.38	1.62	6.44
2015	Jan	5.19	5.64	5.39	15.7	20.5	3.51	1.34	5.79
2015	Feb	5.56	5.76	5.63	20.8	21.4	3.95	1.10	5.78
2015	Mar	5.82	6.43	5.94	16.5	18.8	3.20	1.89	6.66
2015	Apr	6.33	7.07	6.70	15.9	18.0	3.25	2.12	7.52
2015	May	4.37	4.50	4.48	13.0	16.6	2.46	1.85	5.03
2015	Jun	5.32	5.42	5.55	14.0	17.3	2.56	2.27	6.24
2015	Jul	4.53	4.30	4.73	11.8	15.2	2.31	2.10	5.31
2015	Aug	4.80	4.47	5.08	15.7	18.0	2.79	1.87	5.71
2015	Sep	4.71	4.76	4.81	12.2	15.9	2.28	2.19	5.41
2015	Oct	5.03	5.92	5.19	12.6	15.9	3.09	1.33	5.51
2015	Nov	6.37	6.53	6.39	17.6	23.3	3.96	1.43	6.92
2015	Dec	4.84	5.20	4.88	16.1	19.6	4.03	0.88	4.59
All Data		5.42	5.78	5.59	20.8	23.3	3.26	1.60	6.15
MoMM		5.32	5.65	5.49					

Monthly time series, mean wind speeds (gap-filled wind data)



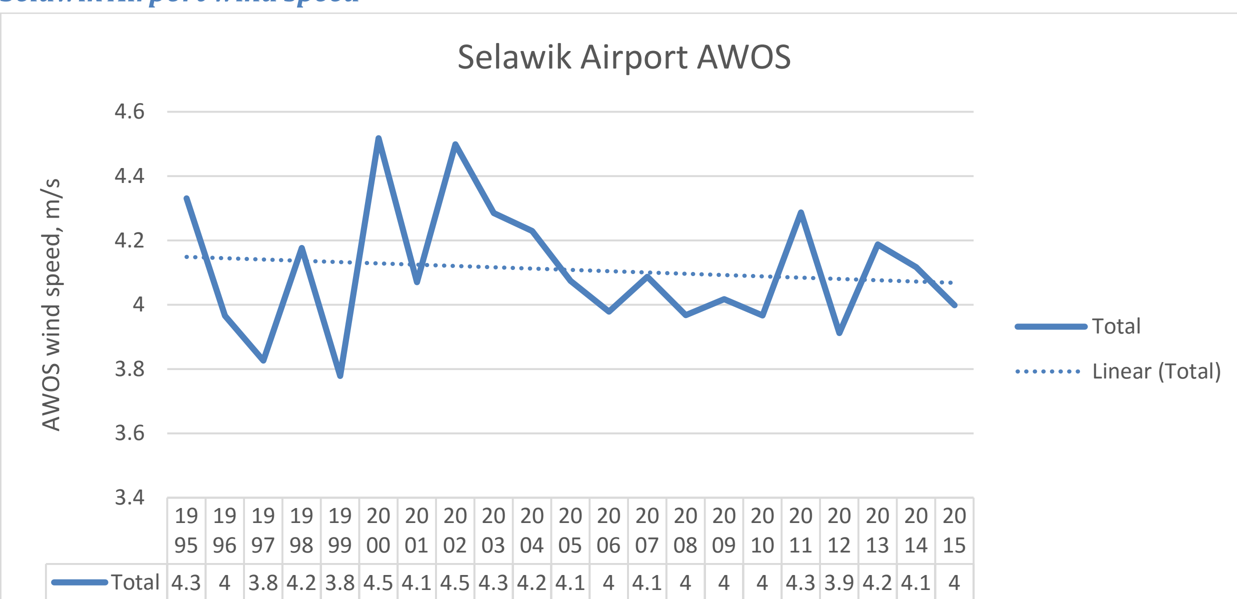
Daily wind profile (annual)



Long-term Wind Speed Average

Comparing the fourteen months of measured wind speed data at the Selawik met tower is possible by reference to the nearby Selawik Airport automated weather station. Data for this station was obtained for the time period of Jan. 1, 1995 through Dec. 31, 2015. For this 21 year time period, the AWOS station recorded an average wind speed of 4.09 m/s (at a 10 meter measurement height). In 2015, which comprises the bulk of the Selawik met tower operating time period, the AWOS station wind speed average was 4.00 m/s, which is 2.2 percent less than the long-term average. Note also a slight declining trend in wind speed over the 21 year period, although this may be misleading given the higher variability encountered year-to-year.

Selawik Airport wind speed

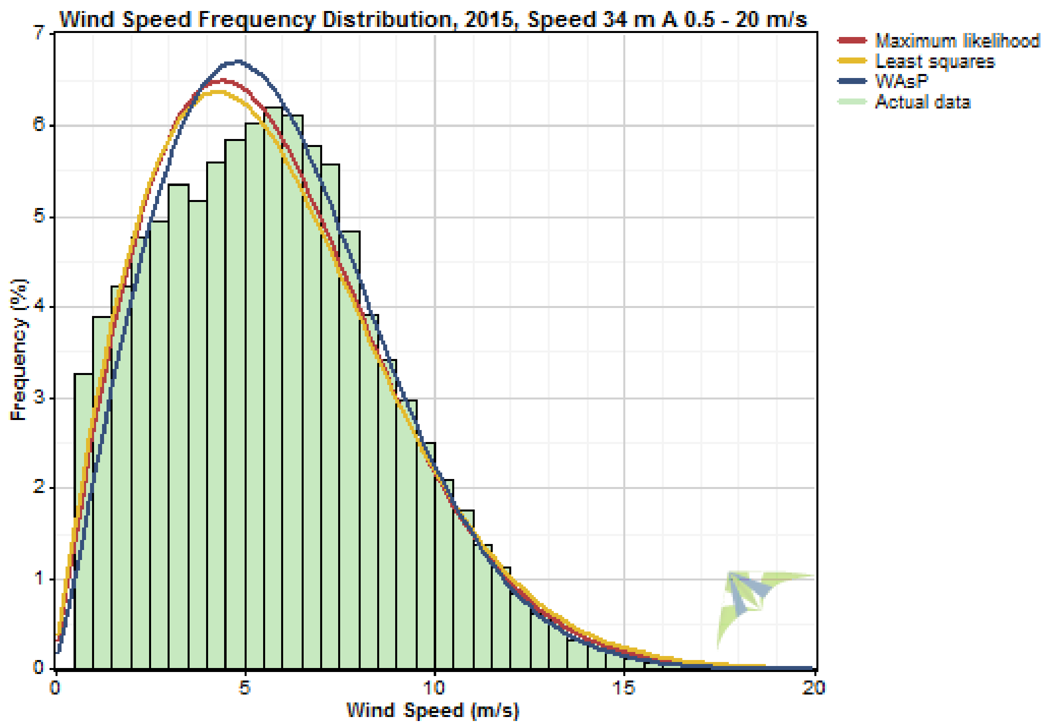


	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Total	4.3	4	3.8	4.2	3.8	4.5	4.1	4.5	4.3	4.2	4.1	4	4.1	4	4	4	4.3	3.9	4.2	4.1	4

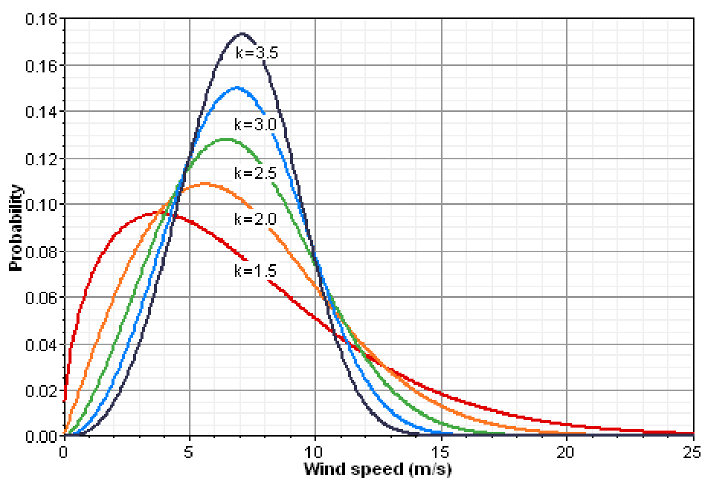
Probability Distribution Function

The probability distribution function (PDF), or histogram, of the Selawik 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. As seen below in the wind speed distribution of the 34 meter A anemometer, the most frequently occurring wind speeds are between 3 and 8 m/s with very few wind events exceeding 20 m/s (note that the cutout speed of most wind turbines is 25 m/s; see following Occurrence by wind speed bin table).

PDF of 34 m A anemometer (all data)



Weibull k shape curve table



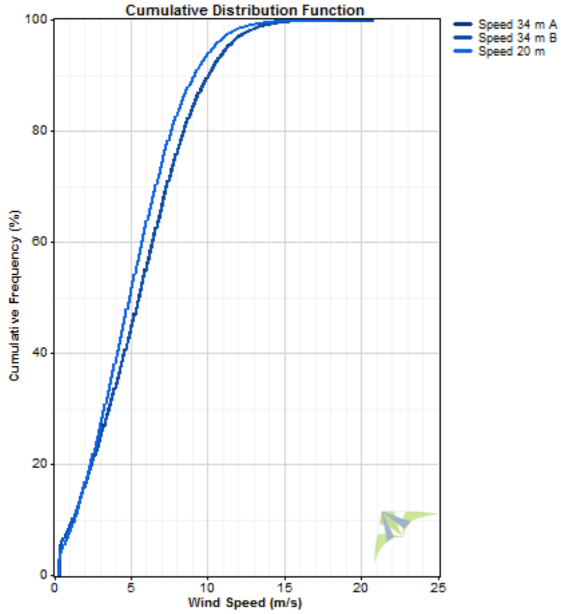
Weibull values table, 34m A anemometer, 2015, 0.5 to 20 m/s

Algorithm	Weibull k	Weibull c (m/s)	Mean (m/s)	Proportion Above 5.711 m/s	Power Density (W/m2)	R Squared
Maximum likelihood	1.923	6.427	5.701	0.451	225.7	0.9672
Least squares	1.868	6.450	5.726	0.451	236.0	0.9696
WAsP	2.070	6.553	5.805	0.471	221.3	0.9556
Actual data			5.711	0.471	221.2	

Occurrence by wind speed bin (34 m A anemometer)

Bin Endpoints (m/s)		Occurrences		Cumulative
Lower	Upper	No.	Percent	Percent
0	1	5,132	8.55%	8.55%
1	2	4,360	7.26%	15.82%
2	3	5,224	8.70%	24.52%
3	4	5,608	9.34%	33.86%
4	5	6,117	10.19%	44.06%
5	6	6,684	11.14%	55.19%
6	7	6,489	10.81%	66.00%
7	8	6,065	10.11%	76.11%
8	9	4,691	7.82%	83.92%
9	10	3,555	5.92%	89.85%
10	11	2,575	4.29%	94.14%
11	12	1,739	2.90%	97.04%
12	13	888	1.48%	98.52%
13	14	457	0.76%	99.28%
14	15	253	0.42%	99.70%
15	16	106	0.18%	99.88%
16	17	40	0.07%	99.94%
17	18	24	0.04%	99.98%
18	19	2	0.00%	99.99%
19	20	7	0.01%	100.00%
20	21	2	0.00%	100.00%

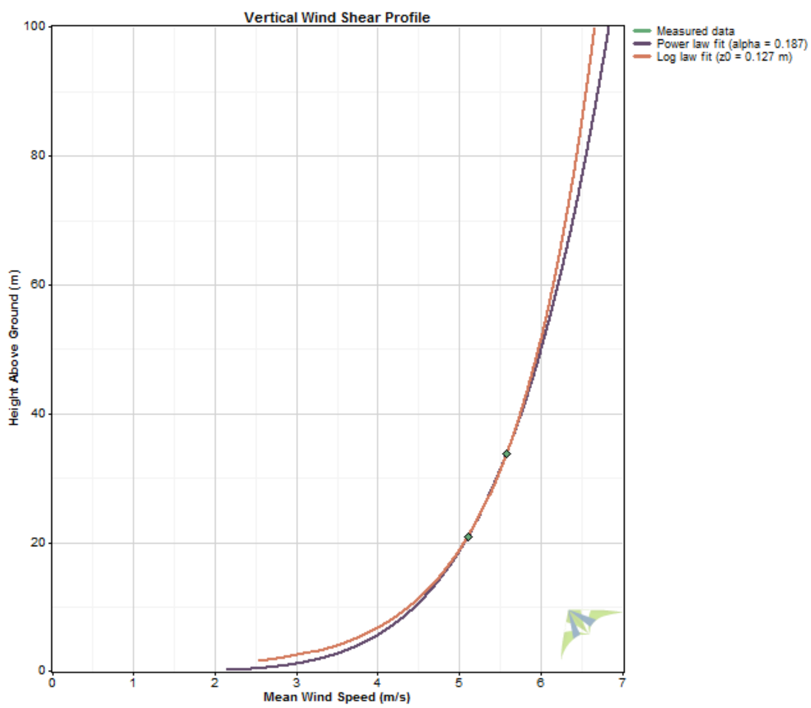
Cumulative distribution function



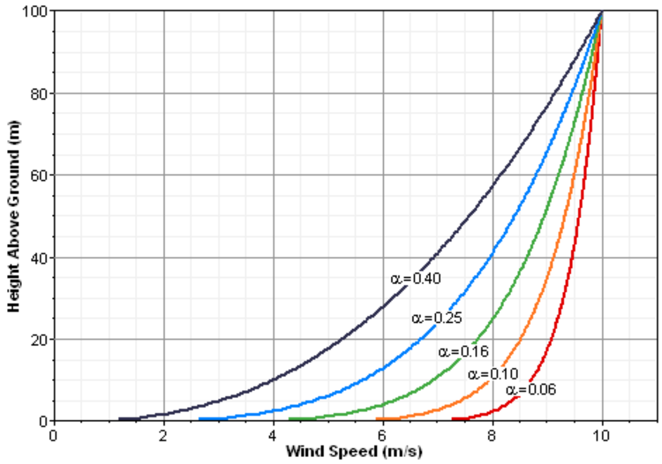
Wind Shear and Roughness

Wind shear at the Selawik met tower site was calculated with the 34 m A and 20 m anemometers, both of which were oriented toward 090° T. The calculated power law exponent of 0.187 indicates a fairly low wind shear at the site. Calculated surface roughness at the site is 0.15 m (the height above ground where wind speed would be zero) for a roughness class of 2.34 (description: agricultural land).

Vertical wind shear profile



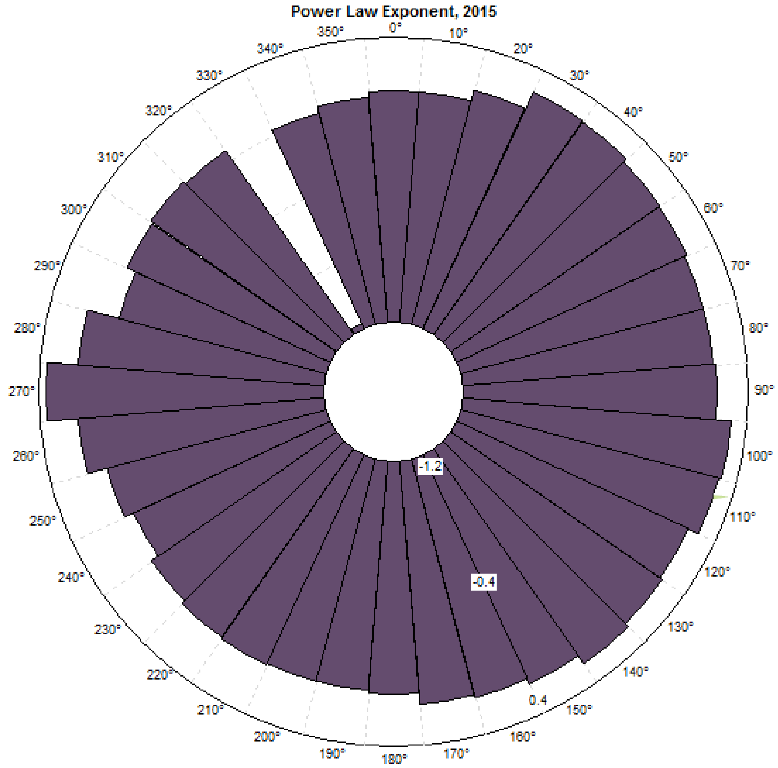
Comparative wind shear profiles



Wind shear by direction sector table

Direction Sector	Time Steps	Mean Wind Speed (m/s) Speed 34 m A	Speed 20 m	Best Fit Power Law Exp.	Surface Roughness (m)
345° - 15°	1,082	3.17	3.03	0.097	0.0009
15° - 45°	3,710	5.38	4.77	0.249	0.4803
45° - 75°	12,127	6.83	6.14	0.222	0.2956
75° - 105°	6,201	4.92	4.38	0.241	0.4165
105° - 135°	2,338	5.00	4.39	0.270	0.6479
135° - 165°	1,379	4.86	4.35	0.231	0.3517
165° - 195°	1,578	5.01	4.72	0.126	0.0095
195° - 225°	2,002	5.13	4.89	0.099	0.0011
225° - 255°	7,509	5.61	5.44	0.065	0.0000
255° - 285°	9,752	5.16	4.60	0.236	0.3794
285° - 315°	2,115	3.69	3.63	0.032	0.0000
315° - 345°	1,561	1.93	2.53	-0.558	

Wind shear by direction sector graph



Extreme Winds

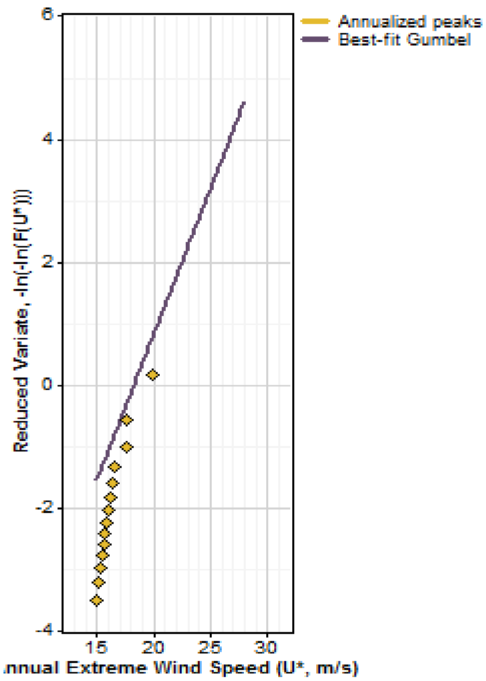
One method to estimate V_{ref}, or the maximum 50 year (10 minute average) wind speed, is a Gumbel distribution analysis modified for monthly maximum winds vice annual maximum winds. Fourteen months of data however are minimal at best and hence results should be viewed with considerable caution. Nevertheless, with data available the predicted Vref in a 50 year return period (in other words, predicted to occur once every 50 years) by this method is 25.8 m/s. This result classifies the site as Class III by International Electrotechnical Commission 61400-1, 3rd edition (IEC3) criteria.

Site extreme wind probability table, 34 m A data

Period (years)	V_{ref} (m/s)	Gust (m/s)	IEC 61400-1, 3rd ed. Class	V_{ref}, m/s
3	19.7	24.4	I	50.0
10	22.8	28.2	II	42.5
20	23.6	29.2	III	37.5
30	24.9	30.8	S	designer-specified
50	25.8	32.0		
100	27.2	33.6		
average gust factor:	1.24			

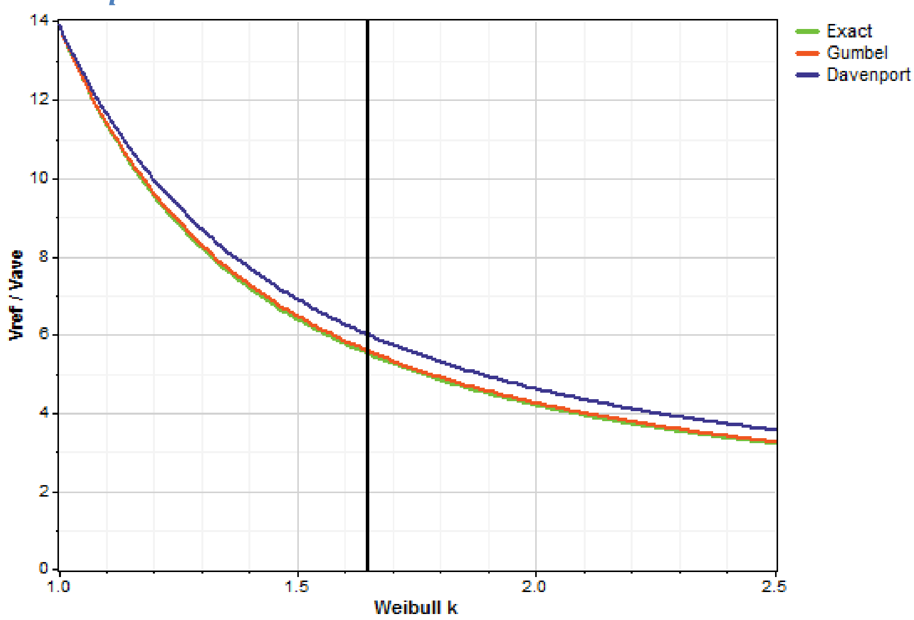
A second technique, Method of Independent Storms, yields a similar calculation for V_{ref} – 26.5 m/s.

Method of Independent Storms



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 for the Selawik wind data V_{ref} is calculated between 30.8 and 33.6 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 Selawik. Note again however the minimal measured wind data for these calculations.

EWTS II plot



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 moderate winds and that turbines installed at this location can be rated as IEC3 Class III.

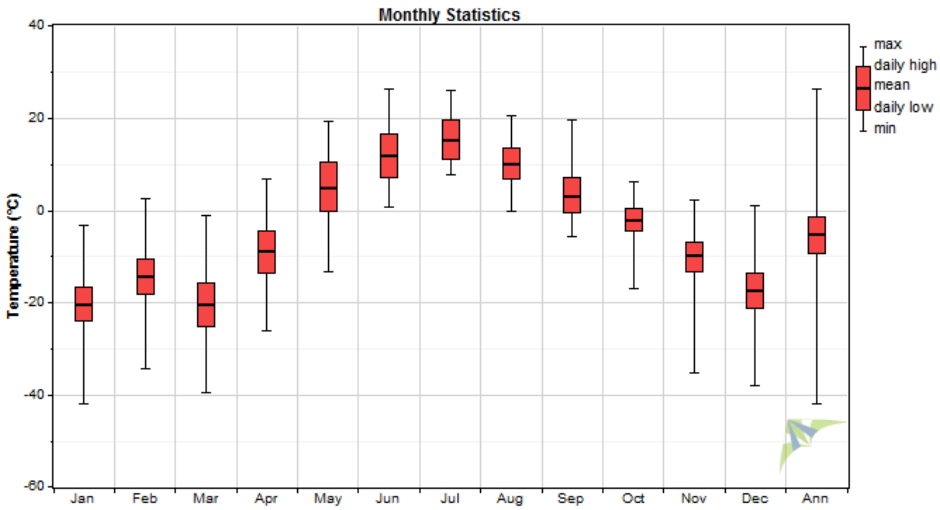
Temperature, Density, and Relative Humidity

Selawik experiences cool summers and cold winters with resulting higher than standard air density. Calculated mean-of-monthly-mean (or annual) air density during the met tower test period exceeds the 1.225 kg/m^3 standard air density for a sea level elevation by 5.8 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.

Temperature and density table

	Temp			Temp			Density		
Month	Mean (°C)	Min (°C)	Max (°C)	Mean (°F)	Min (°F)	Max (°F)	Mean (kg/m3)	Min (kg/m3)	Max (kg/m3)
Jan	-20.2	-41.8	-3.1	-4.4	-43.2	26.4	1.380	1.219	1.523
Feb	-14	-34.1	2.5	6.8	-29.4	36.5	1.362	1.276	1.474
Mar	-20.1	-39.5	-1.1	-4.2	-39.1	30.0	1.393	1.294	1.508
Apr	-8.8	-25.9	6.8	16.2	-14.6	44.2	1.333	1.256	1.425
May	5.2	-13.1	19.5	41.4	8.4	67.1	1.264	1.199	1.354
Jun	12.1	0.7	26.4	53.8	33.3	79.5	1.232	1.169	1.285
Jul	15.5	7.7	26.1	59.9	45.9	79.0	1.217	1.170	1.252
Aug	10.1	-0.1	20.5	50.2	31.8	68.9	1.241	1.194	1.289
Sep	3.2	-5.6	19.6	37.8	21.9	67.3	1.273	1.198	1.316
Oct	-1.8	-16.8	6.3	28.8	1.8	43.3	1.298	1.259	1.374
Nov	-9.7	-35.1	2.4	14.5	-31.2	36.3	1.338	1.277	1.480
Dec	-17.3	-37.8	1.1	0.9	-36.0	34.0	1.372	1.219	1.497
Annual	-3.8	-41.8	26.4	25.1	-43.2	79.5	1.308	1.169	1.523

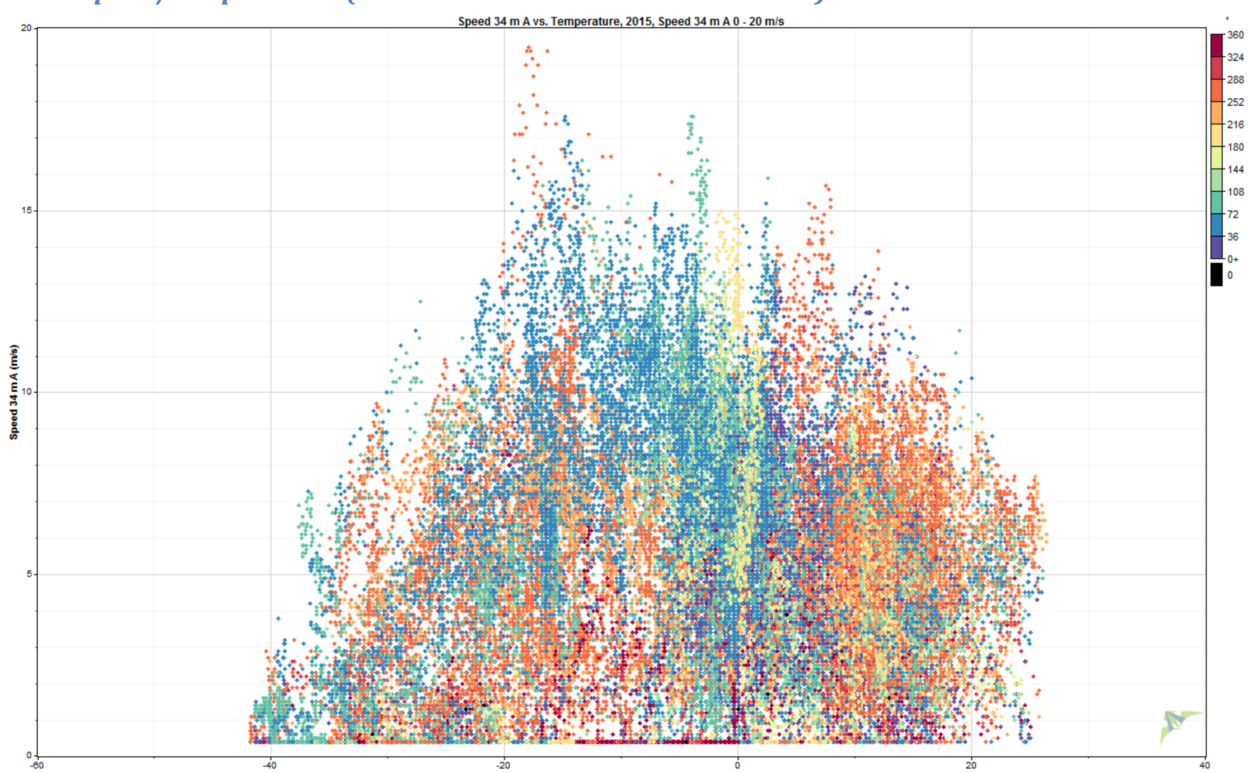
Selawik temperature boxplot graph



Wind Speed Scatterplot

The wind speed versus temperature scatterplot below indicates cold temperatures at the Selawik met tower site with a preponderance of below freezing temperatures. During the met tower test period, temperatures frequently were colder than -20° C (-4° F), the minimum operating temperature for most standard-environment wind turbines. Note that arctic-capable (operational rating to -40°C) wind turbines would be required in Selawik, but note that extreme cold temperatures, although not infrequent, are generally associated with lower wind speeds.

Wind speed/temperature (color code indicates wind direction)



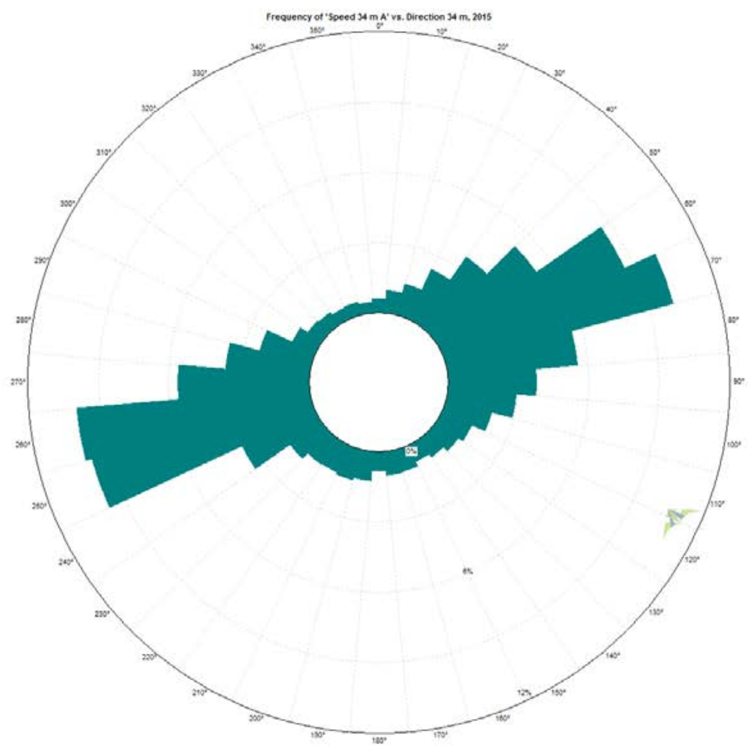
Wind Direction

Wind frequency rose data indicates that winds at the Selawik met tower site are primarily bi-directional, with east-northeasterly and west-southwesterly winds predominating. The mean value rose indicates that ENE winds are of relatively higher intensity than WSW winds, but with more frequent ENE winds, the dominant energy winds are from that direction.

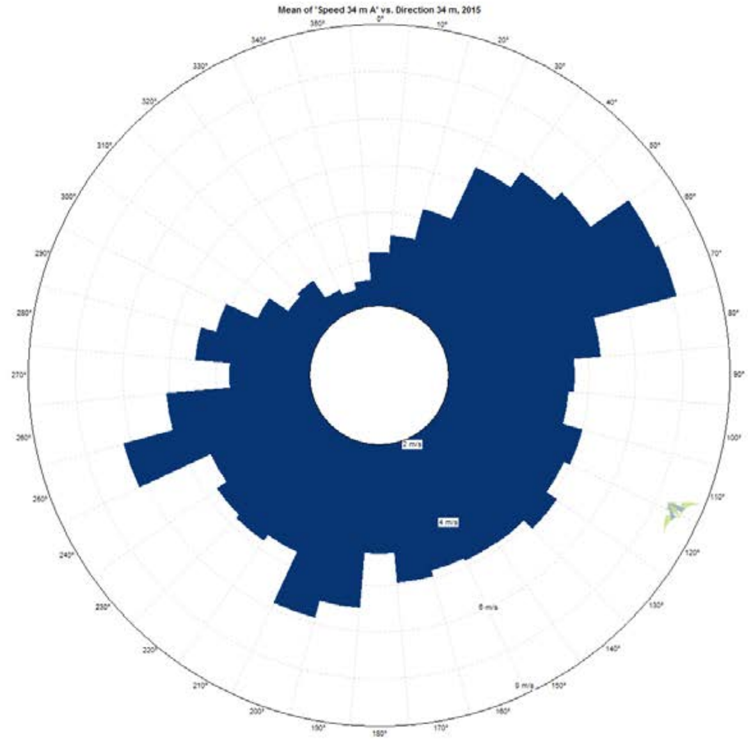
Calm frequency, the percent of time that winds at the 34 meter level are less than 4 m/s, a typical cut-in speed of larger wind turbines, was 34 percent during the 14 month test period.

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

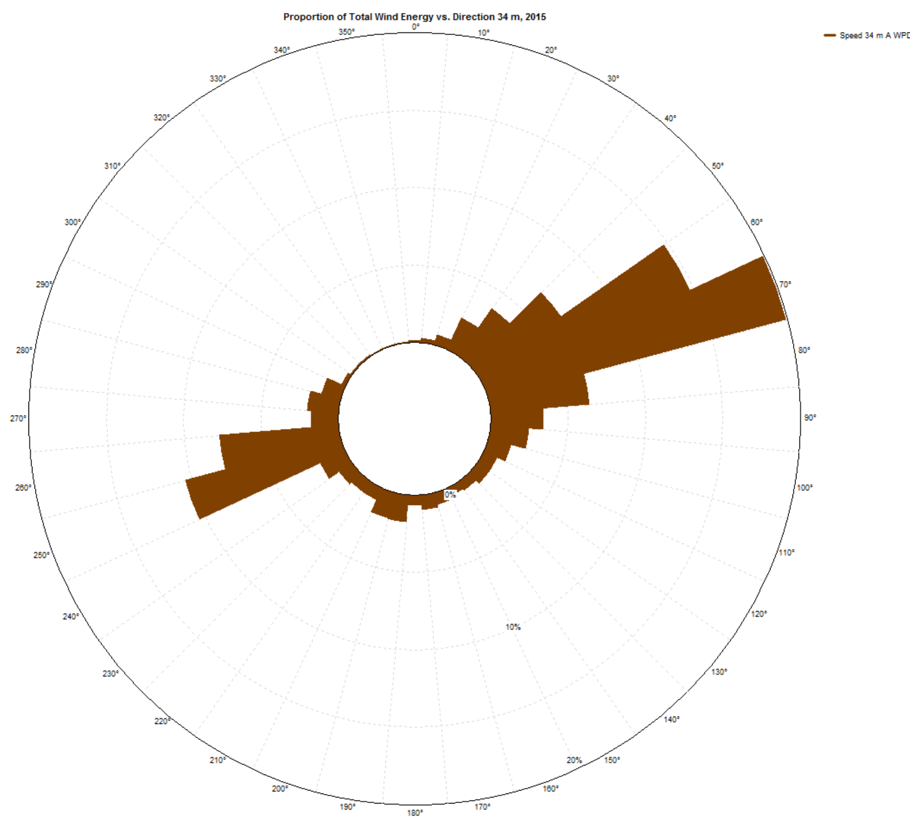
Wind frequency rose



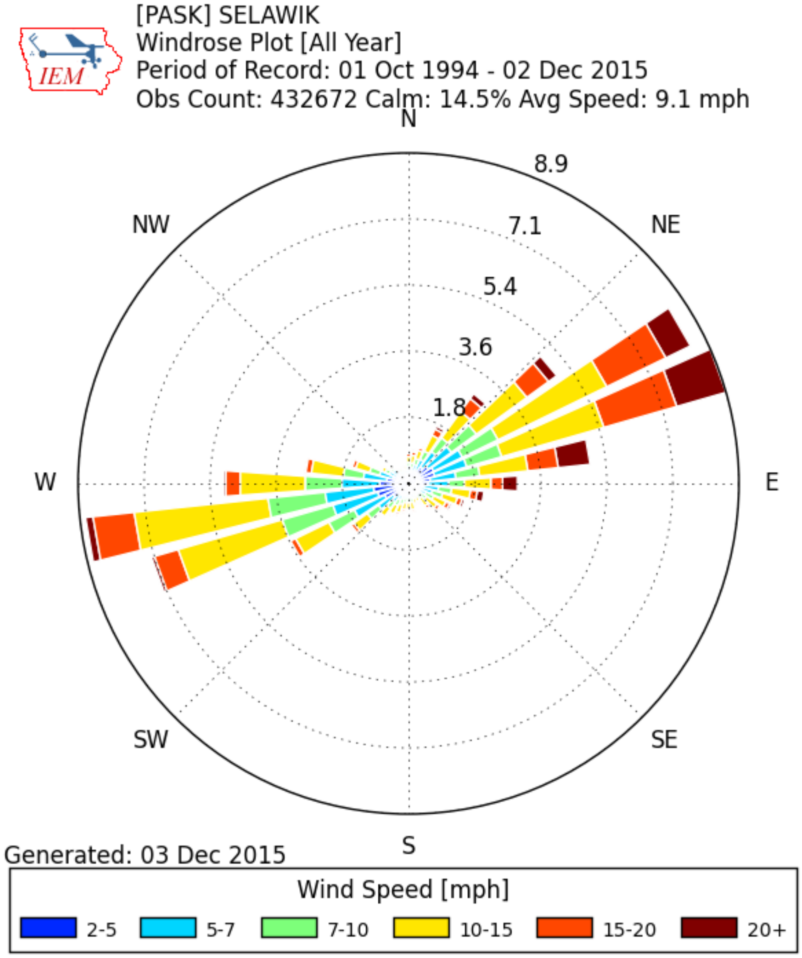
Mean value rose



Wind energy rose



Selawik Airport wind rose



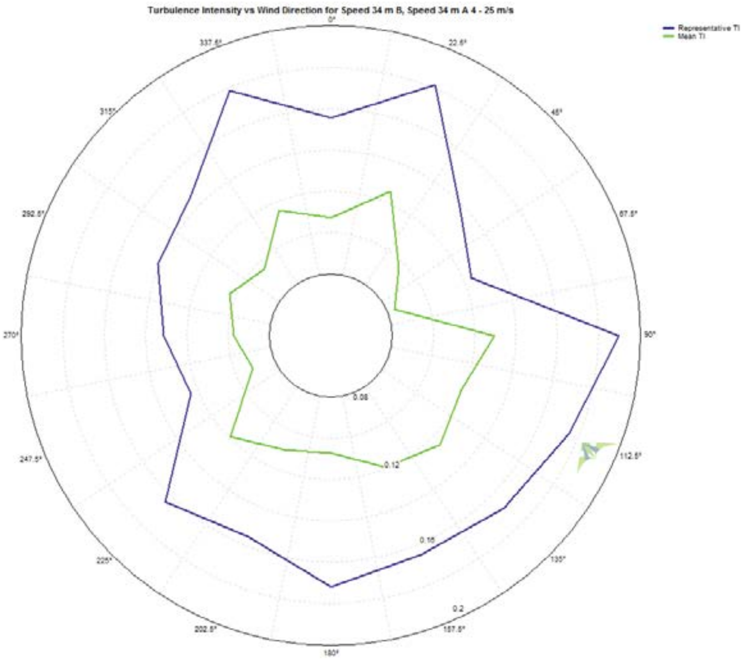
Turbulence

The turbulence intensity (TI) at the Selawik met tower site is very low with a mean turbulence intensity of 0.075 and a representative turbulence intensity of 0.095 at 15 m/s wind speed, indicating smooth air for wind turbine operations. This equates to an International Electrotechnical Commission (IEC) 61400-1, 3rd Edition (2005) turbulence category C, which is the lowest defined category.

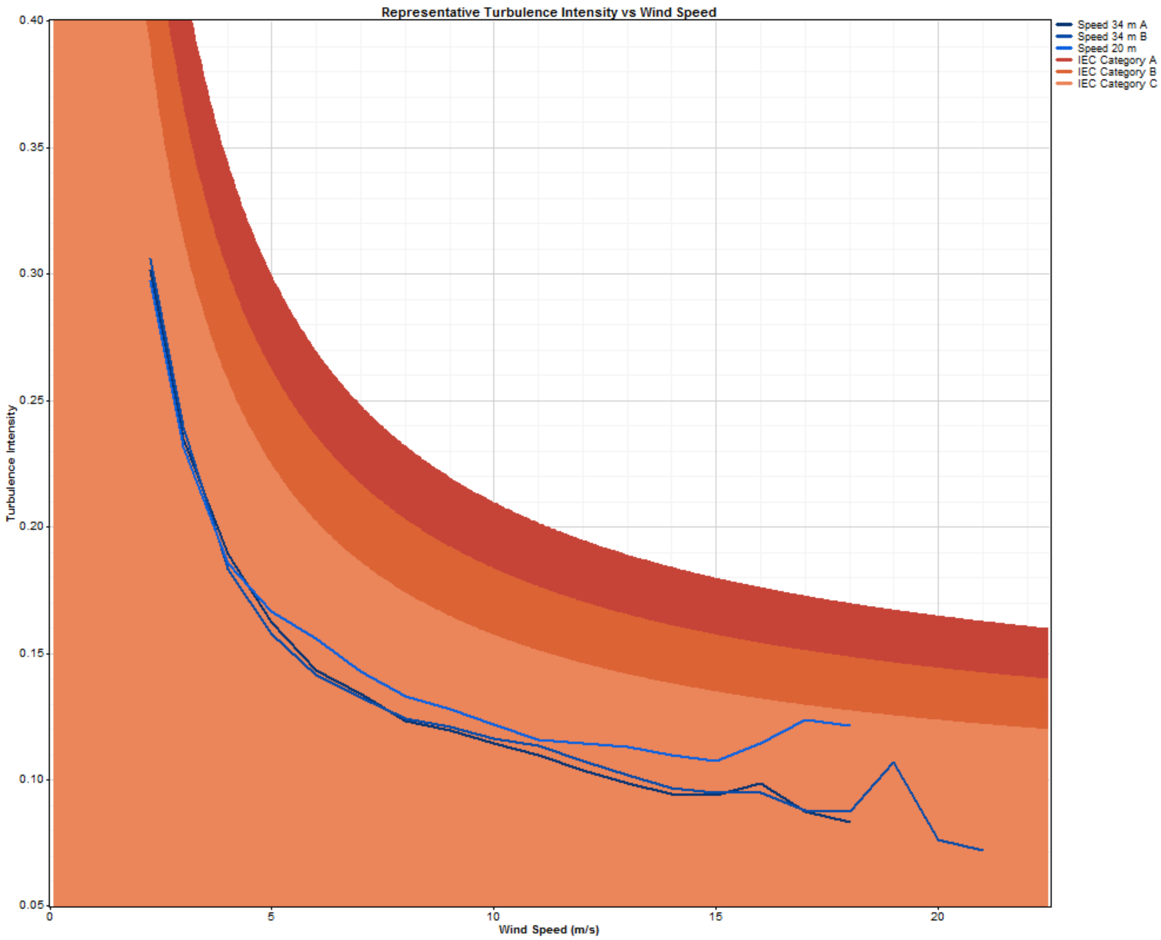
Turbulence synopsis

	34 m A anem.			34 m B anem.			Legend	
Sector	Mean TI at 15 m/s	Repres. TI at 15 m/s	IEC3 Category	Mean TI at 15 m/s	Repres. TI at 15 m/s	IEC3 Category	IEC3 Categ.	Mean TI at 15 m/s
all	0.075	0.094	C	0.075	0.095	C	S	>0.16
315° to 045°	-	-	-	-	-	-	A	0.14-0.16
045° to 135°	0.075	0.095	C	0.073	0.091	C	B	0.12-0.14
135° to 225°	0.071	0.078	C	0.072	0.082	C	C	0-0.12
225° to 315°	0.078	0.090	C	0.084	0.110	C		

Turbulence rose, 34m A anemometer



Turbulence intensity, all direction sectors



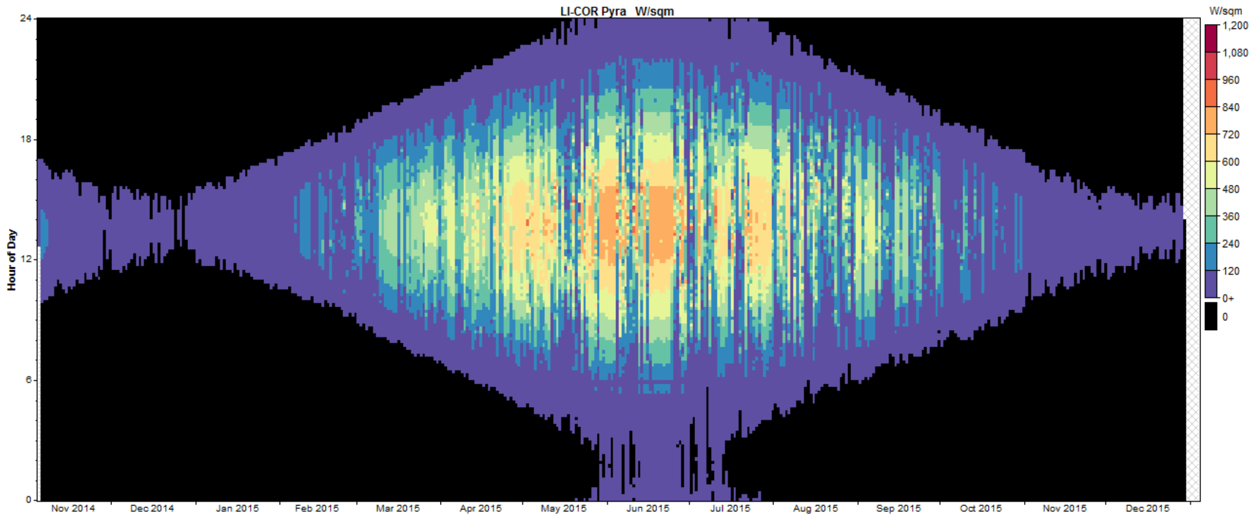
Turbulence table, 34 m A data, all sectors

Bin Midpt. (m/s)	Bin Endpoints Lower (m/s)	Upper (m/s)	Data Points In Bin	Bin Frequency (%)	Mean TI	SD of TI	Represen-tative TI	Peak TI
0.3	0	0.5	2,688	4.581	0.085	0.164	0.294	0.750
1	0.5	1.5	3,905	6.655	0.458	0.148	0.647	1.500
2	1.5	2.5	4,895	8.342	0.244	0.087	0.355	0.833
3	2.5	3.5	5,705	9.722	0.166	0.056	0.237	0.815
4	3.5	4.5	5,825	9.926	0.137	0.045	0.195	0.629
5	4.5	5.5	6,558	11.175	0.118	0.039	0.168	0.566
6	5.5	6.5	6,534	11.135	0.106	0.035	0.150	0.393
7	6.5	7.5	5,929	10.104	0.099	0.032	0.139	0.358
8	7.5	8.5	5,069	8.638	0.091	0.029	0.128	0.276
9	8.5	9.5	4,058	6.915	0.087	0.029	0.124	0.264
10	9.5	10.5	2,929	4.991	0.085	0.026	0.117	0.316
11	10.5	11.5	2,112	3.599	0.082	0.023	0.112	0.257
12	11.5	12.5	1,265	2.156	0.078	0.022	0.107	0.190
13	12.5	13.5	645	1.099	0.077	0.022	0.105	0.178
14	13.5	14.5	298	0.508	0.074	0.018	0.097	0.152
15	14.5	15.5	162	0.276	0.076	0.017	0.098	0.130
16	15.5	16.5	64	0.109	0.084	0.014	0.102	0.116
17	16.5	17.5	27	0.046	0.078	0.013	0.095	0.112
18	17.5	18.5	9	0.015	0.084	0.023	0.114	0.117
19	18.5	19.5	4	0.007	0.083	0.012	0.099	0.100
20	19.5	20.5	1	0.002	0.071	0.000	0.071	0.071

Solar Resource

Although this report addresses the measured wind resource at the Selawik met tower site, the met tower was equipped with a pyranometer to measure solar radiation. With this, one can see that the winter solar power resource in Selawik is very low but has a high peak at summer solstice in late June. Note also that surprisingly high solar power generation in rural Alaska has been obtained in late winter (February thru early May) with sun reflection off foregrounds of snow, in addition to sunlight.

Pyranometer DMap



Pyranometer box plot