Section 26
Shadow Flicker

Memo

To:	Brooke Barnes Stantec Consulting Ltd. Topsham, ME	From:	Theo Kindermans Stantec Planning and Landscape Architecture, PC Boston, MA
File:	Oakfield Wind Project	Date:	June 9, 2011

Reference: Shadow-Flicker Modeling
Oakfield Wind Project Amendment, Oakfield, Maine

Introduction

This memorandum provides a brief explanation of the shadow-flicker phenomenon, the modeling approach employed for the amended site in Oakfield, ME and relevant explanations and results. The site layout was provided by Stantec Consulting Ltd. located in Topsham, ME. The layout shows a total of 50 turbine locations; all turbines will be Vestas V-112 3.0 MW, with an 84 meter high hub and a 112 meter diameter rotor, and a total height of approximately 140 meters.

Shadow-Flicker Background

Shadow-flicker from wind turbines results from brief reductions in light intensities caused by the rotating blades of the turbine casting shadows on receptors on the ground and stationary objects, such as a window at a residence. When the sun is obscured by clouds or storms, or when the turbine is not operating, no shadows will be cast.

Shadow-flicker can occur on project area receptors when the wind turbine is located near the receptor and when the turbine blades interfere with the angle of the sunlight. The most typical effect is the visibility of an intermittent light reduction on the receptor facing the wind turbine and subject to the shadow-flicker. Obstacles such as terrain, trees, or buildings between the wind turbine and a potential shadow-flicker receptor significantly reduce or eliminate shadow-flicker effects. No shadow flicker is present when the rotor of the turbine is perpendicular to the receptor

Shadow flicker intensity is defined as the difference in brightness at a given location in the presence and absence of a shadow. Shadow flicker intensities diminish with increased distance from turbine to receptor and with lower visibility weather or atmospheric conditions such as haze or fog. Closer to a turbine the shadow will appear to be darker and wider as the rotors will block out a larger portion of sunrays. The shadow line will also be more defined. Further from the turbine the shadow will be less intense or lighter, and less distinct.

The spatial relationship between a wind turbine and a receptor, as well as wind direction are key factors related to the amount of time any location might experience shadow-flicker. Shadow-flicker time is most commonly expressed in hours per year. Shadow flicker is most pronounced at distances from the turbine of less than 1000 ft and during sunrise and sunset when the sun's angle is lower and the resulting shadows are longer. Shadow flicker is typically present at a receptor for short periods each day – rarely more than a half-hour at sunrise and at sunset. The phenomenon is more prevalent in the winter than the summer due to the sun's lower position on the horizon in winter months in North America (NAS, 2007).

The analysis provided in this report does not evaluate the flicker intensity, but rather focuses on the total amount of time (hours and minutes per year) that shadow flicker can potentially occur at receptors regardless if the shadow flicker is barely noticeable or clearly distinct. As a result, it is likely that receptors will experience less shadow-flicker impact than modeled and reported,

especially those that are further away from the turbines. It is likely that marginally affected receptors may not be able to identify shadow-flicker at all as the shadows become more diffuse with increased distance.

The speed of the rotor and the number of blades determine the frequency of the flicker of the shadow. The shadow-flicker results in this memo are based on Vestas 3-blade model V-112 3.0 MW, with a turbine height of 84 meters. The diameter of the rotors is 112 meters. The nominal rotor speed of 16 RPM translates to a blade frequency of .8 Hz (less than 1 alternation per second).

Modeling Approach

For the shadow flicker modeling a module of the WindPRO software was used. The computer model simulates the path of the sun over the course of the year and assesses at regular intervals the potential shadow flicker across a receptor. The color coded map produced by the computer model is a conservative estimate of the number of hours per year that shadows could be cast by the rotation of the turbine blades. This report presents a flicker analysis for both worst case and meteorologically adjusted conditions.

The worst case analysis assumes that:

-the sun is always shining from sunrise to sunset;

-the rotor plane is always perpendicular to the line from the turbine to the sun;

-the turbine is always operating; and

-there is no topographic or vegetative buffer between the receptor and the turbine.

Furthermore, the analysis assumes windows are situated in direct alignment with the turbine-to-sun line of sight. Even when windows are so aligned, the analysis does not account for the difference between windows in rooms with primary use and enjoyment (e.g. living rooms) and other less frequently occupied or un-occupied rooms or garages.

The worst case shadow-flicker model uses the following inputs:

- Turbine locations
- Shadow flicker receptor (residence or camp) locations (coordinates)
- USGS 1:24,000 topographic and USGS DEM (height contours)
- Turbine rotor diameter
- Turbine hub height

The model calculates detailed shadow flicker results at each assessed receptor location and the amount of shadow-flicker (hours and minutes per year) everywhere surrounding the project. A receptor in the model is defined as a 1 square meter area that is 1 meter above ground level, approximating a window. This omni-directional approach produces shadow-flicker results at a receptor regardless of the direction of windows and provides similar results as a model with windows on various sides of the receptor.

The sun's path with respect to each turbine location is calculated by the software to determine the cast shadow paths every minute, daily over one full year.

Output from the model includes the following information:

- Calculated shadow-flicker time at selected receptors,
- Tabulated and plotted time of day with shadow flicker at receptors,
- Tabulated time of impact from each turbine at a receptor, and
- Map showing turbine locations, selected shadow-flicker receptors and color-coded contour lines indicating projected shadow-flicker time (hours per year).

In addition to the models worst case evaluation, we also evaluated the model results using data that is reflective of typical conditions at the Oakfield Wind Project. The data used is local meteorological information on wind speed and direction, and cloud cover. Other model inputs remained the same. The data came from the following sources:

- Wind speeds and direction frequency distributions were acquired from the on-site meteorological towers,
- Sunshine hours, the time between sunrise and sundown for the area, was obtained from monthly reference data for the annual number of sunny or partly sunny days experienced in Caribou (the closest reporting station for the National Oceanic and Atmospheric Administration) in 2008.

The turbine run-time and direction (seen from the receptor) are calculated from the site's long-term wind speed and direction distribution, while the actual sunshine hours add the probability of sunshine during any given period. This calculation more accurately reflects the expected shadow-flicker time.

In both scenarios it is assumed that no trees or other obstacles are placed between the turbine and the receptor. Inclusion of vegetation or obstructions would further minimize the effects of shadow-flicker.

Analysis

As previously stated, the shadow-flicker model assumptions applied to this project are very conservative and as such, both the worst case and meteorologically adjusted results are expected to over-predict the impacts. Additionally, many of the modeled shadow flicker hours are expected to be of very low intensity.

Of the modeled 170 receptors, 63 potentially receive shadow flicker. All other modeled receptors do not show any impact of shadow flicker.

The statistics of the potentially impacted receptors are outlined in Table 1 below:

Flicker Receptor	Expected total shadow flicker time per year (hours;minutes) weather corrected	Distance to nearest WTG with impact (feet)
J	2:20	3300 (N12)
K	2:09	3400 (N12)
L	4:30	3100 (N12)
S	3:12	3100 (N12)
AA	1:55	3150 (N10)
AB	5:12	3250 (N10)
AH	6:20	3300 (N13)

AI	6:41	3000 (N14)
AJ	3:16	3200 N14)
AK	9:35	3000 (N14)
AL	8:11	3200 (N14)
AM	10:03	3200 N14)
AN	9:25	2600 (N15)
AO	13:55	2400 (N15)
AP	13:17	2500 (N15)
AQ	11:09	2000 (N15)
AR	2:53	3000 (N16)
AS	6:27	2500 (N16)
AT	4:43	2600 (N16)
AZ	9:11	2900 (S04)
BA	6:56	3000 (S04)
BB	7:27	2850 (S04)
BC	14:16	2600 (S03)
BD	11:16	2400 (S03)
BE	20:52	2200 (S03)
BF	15:54	2000 (S01)
BM	6:04	3200 (S04)
BP	45:19	800 (S01)
BQ	23:48	1250 (S01)
BR	10:41	2100 (S01)
BS	26:00	1150 (S02)
BT	18:34	1800 (S03)
BU	16:06	2100 (S02)
BV	27:41	1500 (S03)
CB	9:52	2200 (E03)
CE	5:05	3000 (N05)
CL	109:29	700 (N02)
CP	32:28	1200 (S06)
CQ	24:30	1800 (S04)
CR	0:09	2700 (S01)
CS	83:09	600 (N06)
CT	31:18	1100 (N15)
CV	4:38	3300 (N15)
CW	11:03	2850 (N01)
DX	2:06	3300 (N12)
EA	11:14	2600 (N08)
EI	19:15	3050 (N01)
EJ	15:47	2000 (N16)
EK	17:36	1900 (N15)
EN	6:42	2900 (N16)
EQ	26:46	800 (S01)
ES	2:23	3000 (S08)

ET	66:08	800 (N08)
FD	7:39	2500 (E10)
FE	10:02	2000 (E01)
FH	16:15	1900 (E08)
FI	14:24	1650 (E03)
FJ	16:22	1900 (E03)
FK	13:05	2100 (E03)
FL	9:46	2400 (E04)
FN	14:49	1650 (E03)
FO	13:47	2150 (N14)

Table 1. Potentially impacted receptors.

Standards

There are no regulatory standards in the State of Maine, or federal limits, for acceptable shadow flicker impacts. In previous regulatory decisions, including the original Oakfield Wind Project approval, a general standard of 30 hours of expected shadow flicker per year has been cited (see also the Rollins Wind Project; Record Hill Wind Project).

Discussion

The statistics of the potentially impacted receptors that have calculated shadow flicker effects over 30 hours per year are outlined in Table 1 below, illustrating the worst case prediction of the model, and an expected actual outcome.

Table 2. Locations with the potential for greater than 30 hours per year of shadow flicker

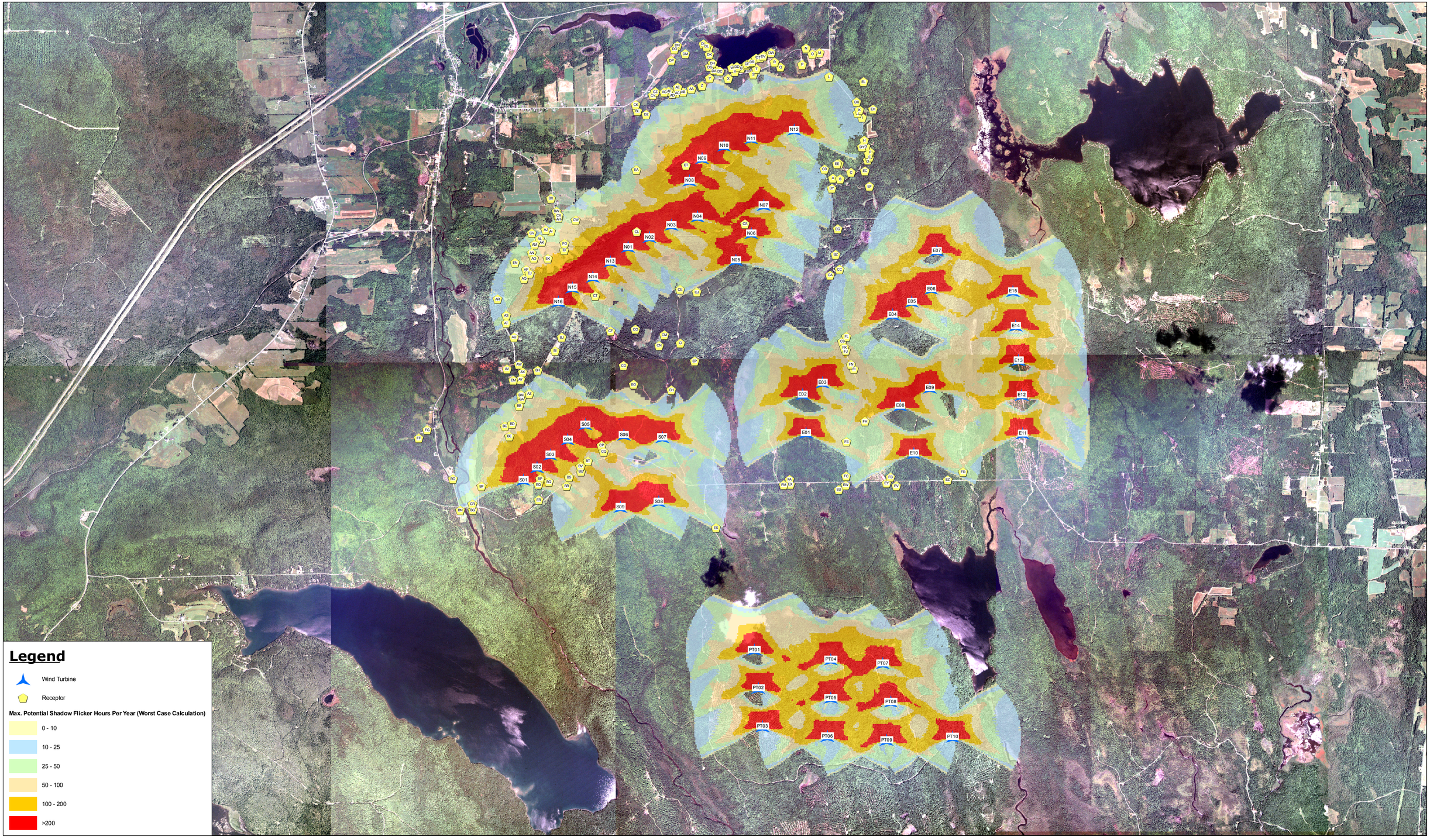
LOCATION	UNADJUSTED POTENTIAL IMPACT	EXPECTED POTENTIAL IMPACT	PROPERTY STATUS
BP	228:46	45:19	Lease
CL	580.56	109.29	Lease
CS	401.33	83.09	Lease
CT	152:56	31:18	Purchase and Sale
ET	371:26	66:08	Purchase and Sale

The five properties expected to have flicker impact above 30 hours per year are all part of the project through purchase, lease or easement. Based on the WindPRO analysis, adjusted for actual wind and sun conditions, no other property that is not part of the project, is calculated to receive flicker in excess of 30 hours per year.

Reference: Shadow-Flicker Modeling

Conclusion

The actual flicker effect on the 63 listed receptors is expected to be below the range of Maine's accepted standards, and will not pose an unreasonable adverse shadow flicker impact on the receptors identified in this report. For clarifications and more detailed analysis of expected influence at selected receptors, please do not hesitate to contact me.



Oakfield Wind Project
Oakfield, Maine

Created by: ZYY
Filename: V:\1956\active\195600152\design\gis\24x36-newlayout-2010-November.mxd

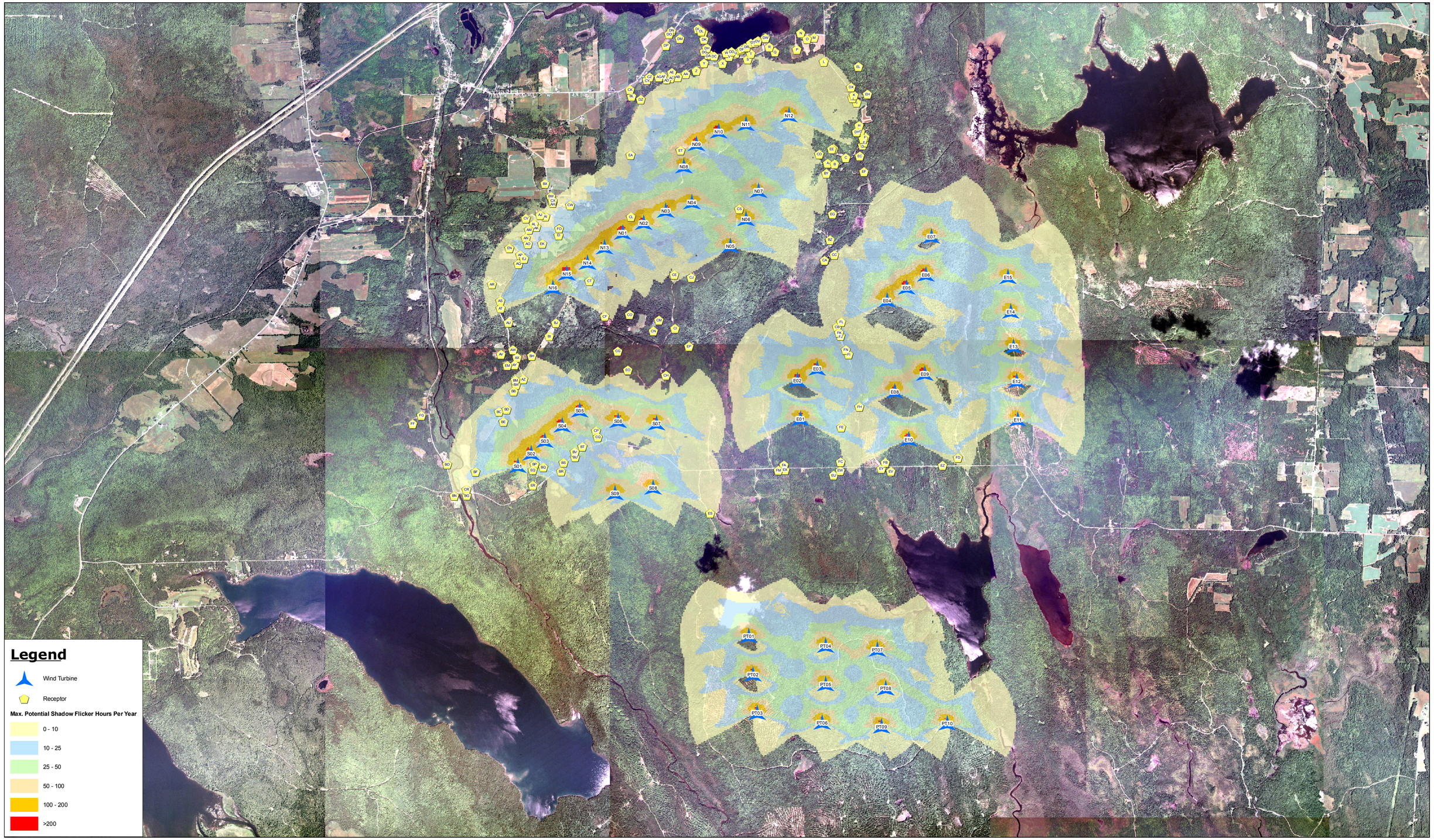
Stantec
Planning and Landscape Architecture, PC
141 Portland Street
Boston, MA 02114

Shadow Flicker Study

May, 2011

N

0 1,000 2,000 4,000 Feet



Oakfield Wind Project
Oakfield, Maine

Meteorologically Adjusted Shadow Flicker Study

May 2011

Created by: ZYY
Filename: V:\1956\active\195600152\design\gis\24x36-newlayout-2010-November-meteorological data.mxd

Stantec
Planning and Landscape Architecture, PC
141 Portland Street
Boston, MA 02114

N

0 1,000 2,000 4,000 Feet