# Appendix C-8: Shadow Flicker Analysis (June 4, 2013)

# Memorandum

Date: June 4, 2013

To: EDF Energy Renewables (EDF)

From: Kory Sandven, Burns & McDonnell

Subject: Stoneray Wind Farm – Worst-Case Shadow Flicker Analysis using Siemens SWT 2.3-108 Turbine. (v1)
BMcD Project No. 62823

Burns & McDonnell performed a worst-case analysis of shadow flicker at the proposed Stoneray Wind Farm in Minnesota. Shadow flicker occurs when wind moving turbine blades cast shadows upon stationary objects, such as occupied residences. Such shadows occur only under very specific conditions, including sun position, wind direction, time of day, and other similar factors.

The analysis was modeled using WindPRO, an industry-leading software package for the design and planning of wind energy projects. The following is a brief summary of the assumptions and inputs utilized in the shadow flicker analysis:

**Turbine Layout**
A quantity of 44 Siemens SWT 2.3-108 turbines was modeled at the project site, using the coordinates shown in Attachment A, Table 1. All coordinates were furnished by EDF. Each turbine was modeled with a hub height of 100 meters, a rotor diameter of 108 meters, and maximum rotor speed of 16 rpm.

**Occupied Residences**
A quantity of 139 occupied residences was modeled at the project site, using the coordinates shown in Attachment A, Table 2. All coordinates were furnished by EDF. Each receptor was modeled as a "greenhouse", i.e. a worst-case approach wherein every home is modeled as having windows on all sides.

**Terrain**
The terrain data was provided by EDF using privately flown data from 2011 composed by Westwood Engineering.

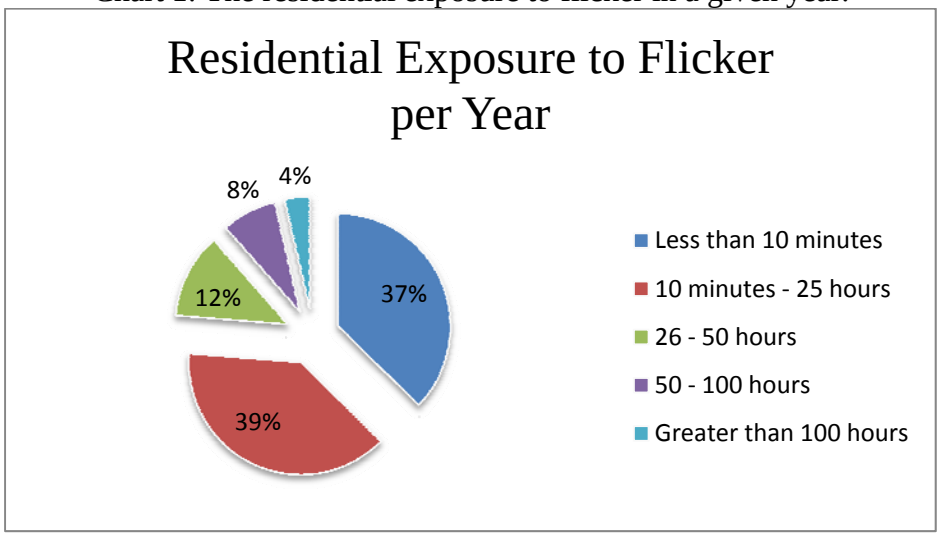
Using the aforementioned assumptions and inputs, WindPRO was used to calculate how often and during what periods each receptor would be affected by shadows generated by one or more wind turbines. To produce a conservative output, the model was run under a worst-case scenario, including the following:

- The sun was assumed to always be shining from sunrise to sunset (i.e., no cloud cover, no rainy days, etc. that would reduce flicker effects);

- The turbines were assumed to always be operating (i.e., constantly spinning, and no downtime due to very low or very high wind speeds);
- The turbine rotors were assumed to always be perpendicular to the individual homes;
- A conservative distance of 2,000 meters was estimated as the maximum distance at which flicker was considered relevant (i.e., shadows cast beyond this distance were considered immaterial); and
- A value of three (3) degrees was utilized for the height below which the sun would not cause noticeable flicker (due to atmospheric diffusion, low radiation, sheltering, etc.).

The residential results of the worst-case flicker analysis are included in Attachment A, Table 2. This information was produced directly from the WindPRO model, and using the aforementioned inputs and assumptions. The following chart describes the results from the worst-case flicker analysis:

Chart 1: The residential exposure to flicker in a given year.




A summary of the results from the worse-case flicker analysis are described below:

- 87 of the 139 homes considered (62.6%) experienced at least 10 total minutes of worst-case flicker over the course of a year.
- 106 of the 139 homes considered (76.3%) experienced less than 25 total hours of worst-case flicker over the course of a year.
- 123 of the 139 homes considered (88.5%) experienced less than 50 total hours of worst-case flicker over the course of a year.

- 134 of the 139 homes considered (96.4%) experienced less than 100 total hours of worst-case flicker over the course of a year.
- Only 5 of the 139 homes considered (3.6%) experienced more than 100 total hours of worst-case flicker over the course of a year.

KPS

cc: Robert Everard, BMcD
Aaron Anderson, BMcD

# Attachment A

## Table 1: Wind Turbine Coordinates

| Turbine Number | Easting [m] | Northing [m] | Elevation [masl] | Turbine Number | Easting [m] | Northing [m] | Elevation [masl] |
|---|---|---|---|---|---|---|---|
| SWT-1 | 727518 | 4879385 | 531.4 | SWT-23 | 726570 | 4883807 | 538.8 |
| SWT-2 | 727439 | 4884269 | 542.3 | SWT-24 | 726826 | 4877174 | 521.5 |
| SWT-3 | 731563 | 4883578 | 552.9 | SWT-25 | 727402 | 4878061 | 529.3 |
| SWT-4 | 728310 | 4883513 | 542.5 | SWT-26 | 737749 | 4873491 | 546.4 |
| SWT-5 | 732632 | 4875735 | 547.7 | SWT-27 | 736418 | 4871769 | 548.6 |
| SWT-6 | 737633 | 4872773 | 545.5 | SWT-28 | 729947 | 4882892 | 545.6 |
| SWT-7 | 729330 | 4876126 | 524.8 | SWT-29 | 733534 | 4871748 | 539.5 |
| SWT-8 | 736688 | 4872424 | 545.6 | SWT-30 | 730882 | 4875693 | 532.5 |
| SWT-9 | 727455 | 4882646 | 536.4 | SWT-31 | 728520 | 4879003 | 530.4 |
| SWT-10 | 738026 | 4871888 | 533.4 | SWT-32 | 727741 | 4883567 | 545.5 |
| SWT-11 | 732321 | 4882004 | 554.3 | SWT-33 | 726431 | 4876361 | 510.1 |
| SWT-12 | 734241 | 4872764 | 536.7 | SWT-34 | 734762 | 4872721 | 542.5 |
| SWT-13 | 733136 | 4879806 | 554.3 | SWT-35 | 731285 | 4875710 | 539.5 |
| SWT-14 | 729132 | 4879560 | 530.4 | SWT-36 | 733932 | 4882405 | 573 |
| SWT-15 | 727668 | 4877248 | 526.8 | SWT-37 | 728118 | 4881323 | 535.3 |
| SWT-16 | 728140 | 4878785 | 530.4 | SWT-38 | 730653 | 4882171 | 548.6 |
| SWT-17 | 727741 | 4881924 | 533.4 | SWT-39 | 731100 | 4882764 | 551.9 |
| SWT-18 | 735220 | 4872554 | 550.7 | SWT-40 | 732458 | 4880857 | 554.7 |
| SWT-19 | 734162 | 4875824 | 553.7 | SWT-41 | 732556 | 4874636 | 533.4 |
| SWT-20 | 735943 | 4872402 | 551.7 | SWT-42 | 733528 | 4876263 | 549.4 |
| SWT-21 | 735947 | 4870979 | 546.5 | SWT-43 | 730797 | 4876638 | 540.9 |
| SWT-22 | 733095 | 4875778 | 548.6 | SWT-44 | 727081 | 4877278 | 525.9 |

*Note: all coordinates provided as UTM NAD83 Zone 14*

**Table 2: Occupied Residence Coordinates and Flicker Results**

| Residence Number | Easting [m] | Northing [m] | Elevation [masl] | Worst-Case Flicker [Hours/Year] |
|---|---|---|---|---|
| A | 728,693 | 4,885,001 | 549 | 5 |
| B | 728,356 | 4,885,174 | 550 | 0 |
| C | 731,819 | 4,884,542 | 564 | 0 |
| D | 730,190 | 4,884,446 | 561 | 5 |
| E | 727,056 | 4,884,807 | 545 | 0 |
| F | 726,222 | 4,884,788 | 543 | 6 |
| G | 728,602 | 4,884,373 | 546 | 19 |
| H | 727,334 | 4,883,949 | 540 | 89 |
| I | 730,186 | 4,884,037 | 556 | 5 |
| J | 731,788 | 4,884,082 | 553 | 0 |
| K | 731,963 | 4,883,685 | 564 | 58 |
| L | 729,179 | 4,883,057 | 543 | 47 |
| M | 730,868 | 4,883,327 | 548 | 45 |
| N | 733,480 | 4,883,419 | 579 | 1 |
| O | 734,503 | 4,883,422 | 573 | 0 |
| P | 730,411 | 4,882,660 | 552 | 49 |
| Q | 730,273 | 4,882,808 | 552 | 152 |
| R | 726,763 | 4,882,365 | 529 | 61 |
| S | 727,355 | 4,882,324 | 531 | 51 |
| T | 736,438 | 4,881,885 | 567 | 0 |
| U | 736,640 | 4,881,829 | 563 | 0 |
| V | 733,270 | 4,881,978 | 559 | 11 |
| W | 730,792 | 4,881,735 | 544 | 7 |
| X | 728,754 | 4,881,851 | 531 | 50 |
| Y | 725,455 | 4,881,848 | 533 | 0 |
| Z | 726,987 | 4,881,298 | 524 | 8 |
| AA | 728,658 | 4,881,401 | 536 | 36 |
| AB | 730,302 | 4,881,628 | 544 | 0 |
| AC | 731,919 | 4,881,473 | 539 | 4 |
| AD | 732,037 | 4,881,304 | 546 | 39 |
| AE | 733,626 | 4,881,077 | 563 | 6 |
| AF | 733,323 | 4,881,089 | 564 | 12 |
| AG | 728,812 | 4,880,750 | 536 | 0 |
| AH | 735,711 | 4,880,265 | 574 | 0 |
| AI | 733,187 | 4,880,244 | 563 | 0 |
| AJ | 731,518 | 4,880,132 | 541 | 3 |
| AK | 730,052 | 4,880,248 | 537 | 16 |
| AL | 729,522 | 4,879,989 | 537 | 52 |
| AM | 727,390 | 4,880,003 | 533 | 2 |
| AN | 733,651 | 4,879,589 | 549 | 43 |
| AO | 734,411 | 4,878,603 | 555 | 0 |
| AP | 734,743 | 4,878,619 | 556 | 0 |
| AQ | 736,990 | 4,878,109 | 572 | 0 |
| AR | 732,924 | 4,877,907 | 549 | 0 |
| AS | 732,125 | 4,877,854 | 552 | 0 |

| | | | | |
|---|---|---|---|---|
| AT | 732,021 | 4,877,692 | 552 | 6 |
| AU | 730,412 | 4,877,912 | 540 | 0 |
| AV | 732,084 | 4,877,289 | 555 | 10 |
| AW | 733,741 | 4,877,520 | 559 | 0 |
| AX | 736,253 | 4,877,010 | 564 | 0 |
| AY | 733,393 | 4,876,851 | 558 | 0 |
| AZ | 731,644 | 4,876,898 | 549 | 16 |
| BA | 732,164 | 4,876,828 | 555 | 8 |
| BB | 732,219 | 4,876,820 | 555 | 11 |
| BC | 732,417 | 4,876,820 | 554 | 11 |
| BD | 732,553 | 4,876,901 | 555 | 17 |
| BE | 732,345 | 4,876,895 | 555 | 12 |
| BF | 732,103 | 4,876,825 | 555 | 7 |
| BG | 732,628 | 4,876,899 | 555 | 23 |
| BH | 732,805 | 4,876,902 | 558 | 14 |
| BI | 732,687 | 4,876,814 | 555 | 27 |
| BJ | 732,909 | 4,876,904 | 558 | 0 |
| BK | 732,914 | 4,876,941 | 558 | 0 |
| BL | 732,960 | 4,876,926 | 558 | 0 |
| BM | 736,865 | 4,876,103 | 556 | 0 |
| BN | 732,423 | 4,875,998 | 551 | 165 |
| BO | 730,522 | 4,875,871 | 528 | 89 |
| BP | 734,558 | 4,875,781 | 560 | 112 |
| BQ | 737,391 | 4,875,467 | 550 | 0 |
| BR | 738,558 | 4,875,126 | 566 | 0 |
| BS | 732,250 | 4,875,212 | 545 | 17 |
| BT | 731,084 | 4,875,277 | 536 | 10 |
| BU | 731,016 | 4,875,274 | 535 | 11 |
| BV | 731,686 | 4,875,129 | 549 | 26 |
| BW | 730,869 | 4,875,304 | 531 | 8 |
| BX | 730,488 | 4,875,292 | 524 | 28 |
| BY | 730,145 | 4,875,262 | 520 | 28 |
| BZ | 730,539 | 4,874,777 | 527 | 0 |
| CA | 738,438 | 4,874,473 | 551 | 0 |
| CB | 735,472 | 4,874,184 | 552 | 0 |
| CC | 735,499 | 4,873,706 | 555 | 5 |
| CD | 739,080 | 4,873,799 | 552 | 7 |
| CE | 737,183 | 4,873,265 | 543 | 90 |
| CF | 733,838 | 4,873,138 | 533 | 76 |
| CG | 733,953 | 4,873,213 | 535 | 29 |
| CH | 735,444 | 4,873,106 | 555 | 31 |
| CI | 739,172 | 4,872,304 | 548 | 9 |
| CJ | 737,183 | 4,872,549 | 533 | 118 |
| CK | 735,601 | 4,872,363 | 549 | 193 |
| CL | 733,962 | 4,872,115 | 543 | 73 |
| CM | 733,973 | 4,871,931 | 541 | 57 |
| CN | 735,597 | 4,871,471 | 540 | 25 |
| CO | 737,246 | 4,871,752 | 538 | 52 |
| CP | 737,139 | 4,871,614 | 543 | 48 |

| | | | | |
|---|---|---|---|---|
| CQ | 734,000 | 4,870,899 | 529 | 2 |
| CR | 736,444 | 4,870,583 | 546 | 0 |
| CS | 736,255 | 4,870,427 | 547 | 0 |
| CT | 734,252 | 4,870,392 | 522 | 4 |
| CU | 733,915 | 4,870,268 | 520 | 0 |
| CV | 726,286 | 4,884,670 | 542 | 11 |
| CW | 734,729 | 4,883,355 | 575 | 0 |
| CX | 728,915 | 4,877,901 | 521 | 11 |
| CY | 737,359 | 4,877,097 | 564 | 0 |
| CZ | 737,097 | 4,872,205 | 539 | 42 |
| DA | 736,560 | 4,870,047 | 544 | 0 |
| DB | 728,918 | 4,877,351 | 525 | 16 |
| DC | 732,155 | 4,877,165 | 555 | 9 |
| DD | 732,093 | 4,877,183 | 555 | 8 |
| DE | 729,402 | 4,875,186 | 517 | 7 |
| DF | 729,971 | 4,875,213 | 518 | 34 |
| DG | 725,128 | 4,883,188 | 536 | 5 |
| DH | 725,325 | 4,877,837 | 518 | 6 |
| DI | 725,339 | 4,876,614 | 530 | 10 |
| DJ | 726,386 | 4,876,720 | 512 | 14 |
| DK | 727,255 | 4,876,534 | 521 | 14 |
| DL | 727,579 | 4,876,747 | 524 | 10 |
| DM | 727,247 | 4,875,176 | 509 | 0 |
| DN | 726,791 | 4,875,160 | 509 | 0 |
| DO | 726,359 | 4,875,131 | 521 | 0 |
| DP | 733,797 | 4,874,196 | 539 | 8 |
| DQ | 732,278 | 4,874,316 | 533 | 0 |
| DR | 732,341 | 4,873,597 | 524 | 0 |
| DS | 732,034 | 4,873,693 | 524 | 0 |
| DT | 729,080 | 4,873,567 | 514 | 0 |
| DU | 729,099 | 4,873,450 | 515 | 0 |
| DV | 728,751 | 4,874,291 | 514 | 0 |
| DW | 728,704 | 4,875,076 | 515 | 0 |
| DX | 728,689 | 4,875,171 | 516 | 0 |
| DY | 727,493 | 4,874,116 | 507 | 0 |
| DZ | 727,529 | 4,873,362 | 505 | 0 |
| EA | 727,780 | 4,872,070 | 502 | 0 |
| EB | 728,851 | 4,872,688 | 513 | 0 |
| EC | 727,738 | 4,876,680 | 523 | 14 |
| ED | 729,178 | 4,876,706 | 522 | 11 |
| EE | 726,304 | 4,875,021 | 524 | 0 |
| EF | 727,800 | 4,875,160 | 513 | 3 |
| EG | 732,024 | 4,874,344 | 536 | 35 |
| EH | 732,407 | 4,872,671 | 520 | 8 |
| EI | 732,173 | 4,872,460 | 519 | 6 |

*Note: all coordinates provided as UTM NAD83 Zone 14*

Project:
**Stoneray Wind Project**

Description:
BMcD cannot warrant or guarantee the estimates or forecasts presented herein. These estimates / forecasts are provided on a best-effort basis. Moreover, calculations performed herein by BMcD are based upon information and wind data provided by the Client and are a service of BMcD. BMcD has not conducted independent wind measurements and, therefore, cannot be held responsible for the accuracy of the data it was supplied.

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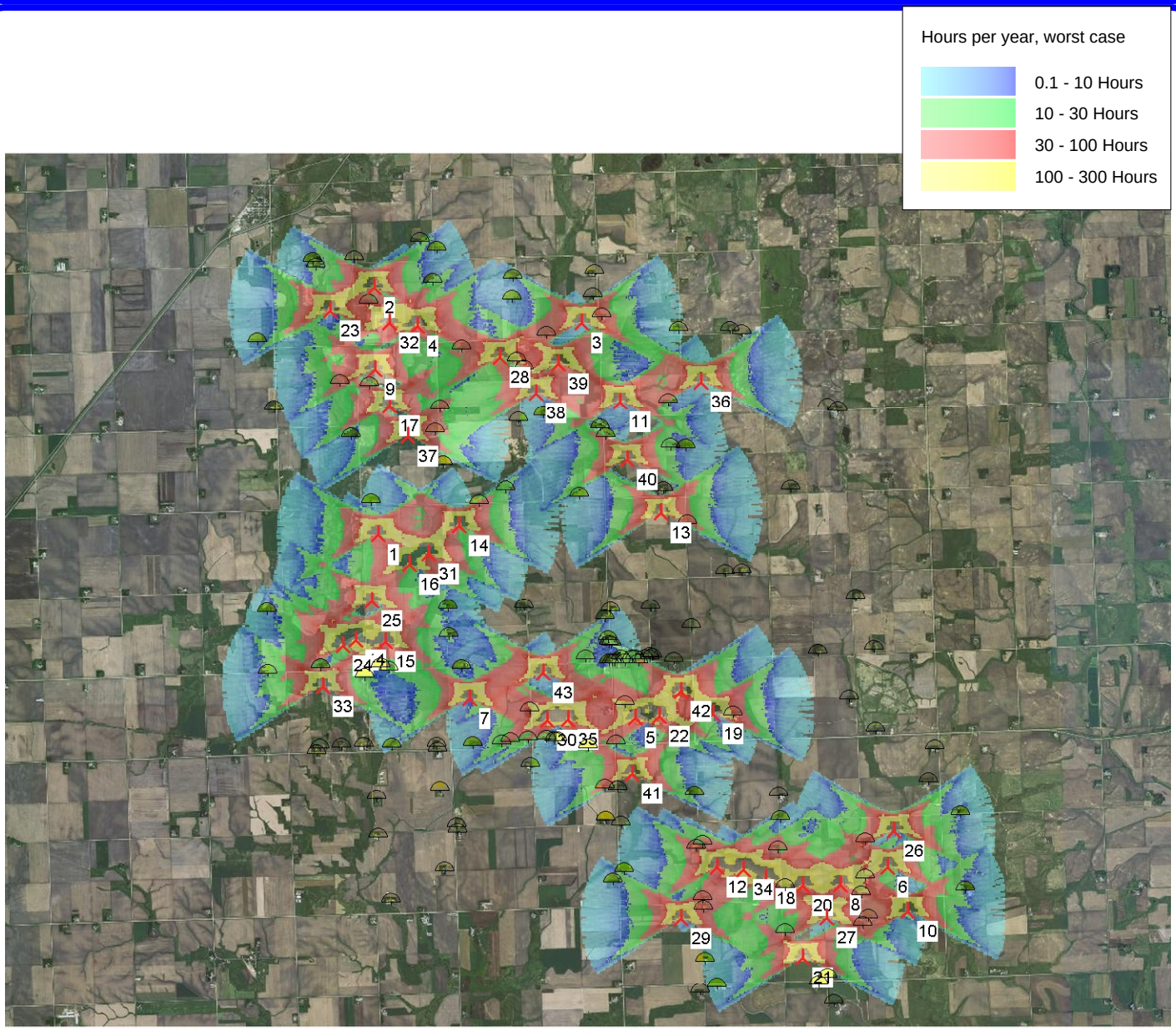
## SHADOW - Map

**Calculation:** Turbine Layout for Siemens 2300-108




Map: Aerial , Print scale 1:125,000, Map center UTM (north)-NAD83 (US+CA) Zone: 14 East: 731,680 North: 4,878,320

New WTG  Shadow receptor

Flicker map level: 0 m above sea level