An Introduction to Shadow Flicker and its Analysis

Thomas Priestley, Ph.D., AICP/ASLA

CH2M HILL

Tom.Priestley@ch2m.com

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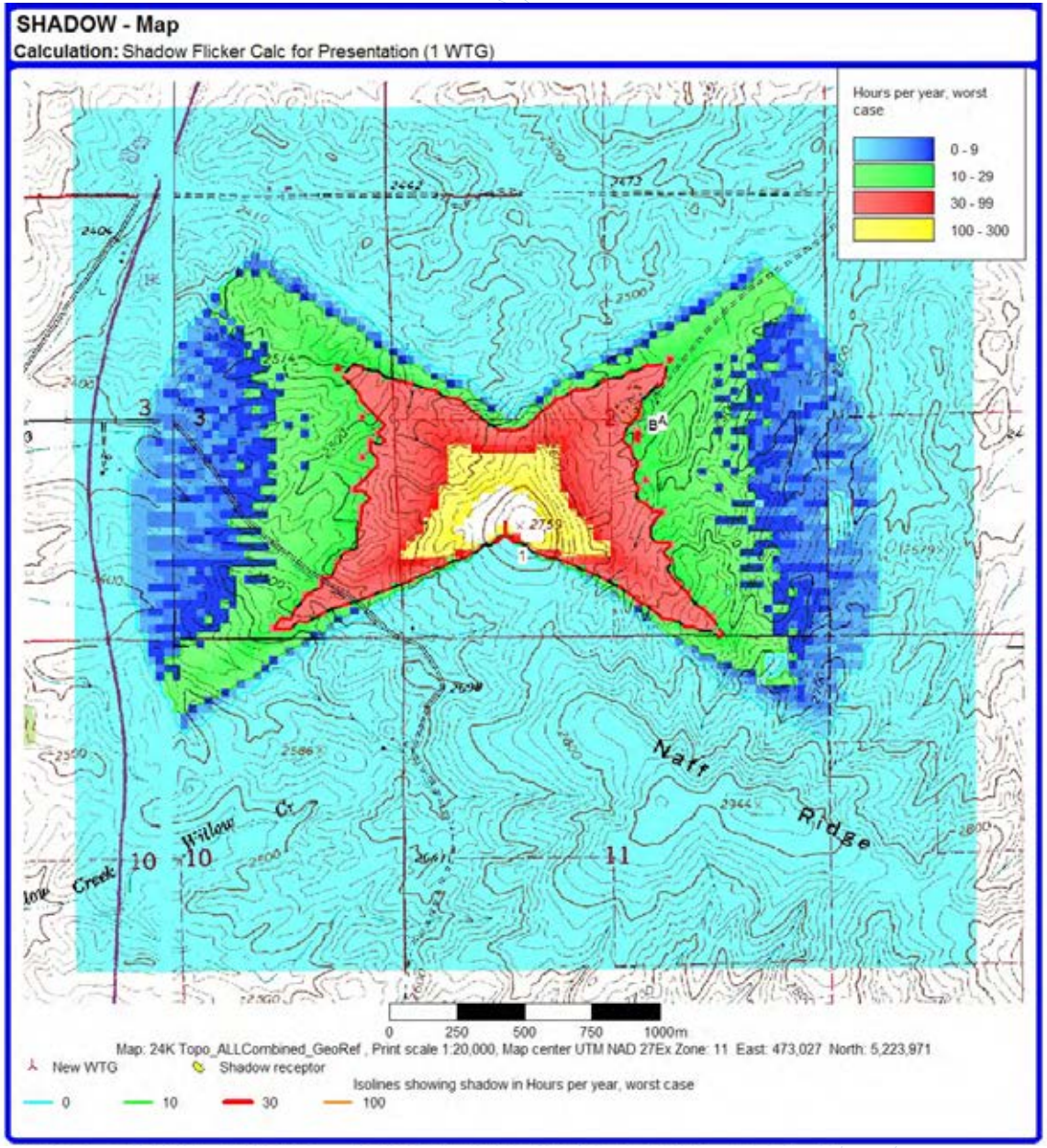
Shadow Flicker

The alternating changes in light intensity that can occur at times when the rotating blades of wind turbines cast moving shadows on the ground or on structures.

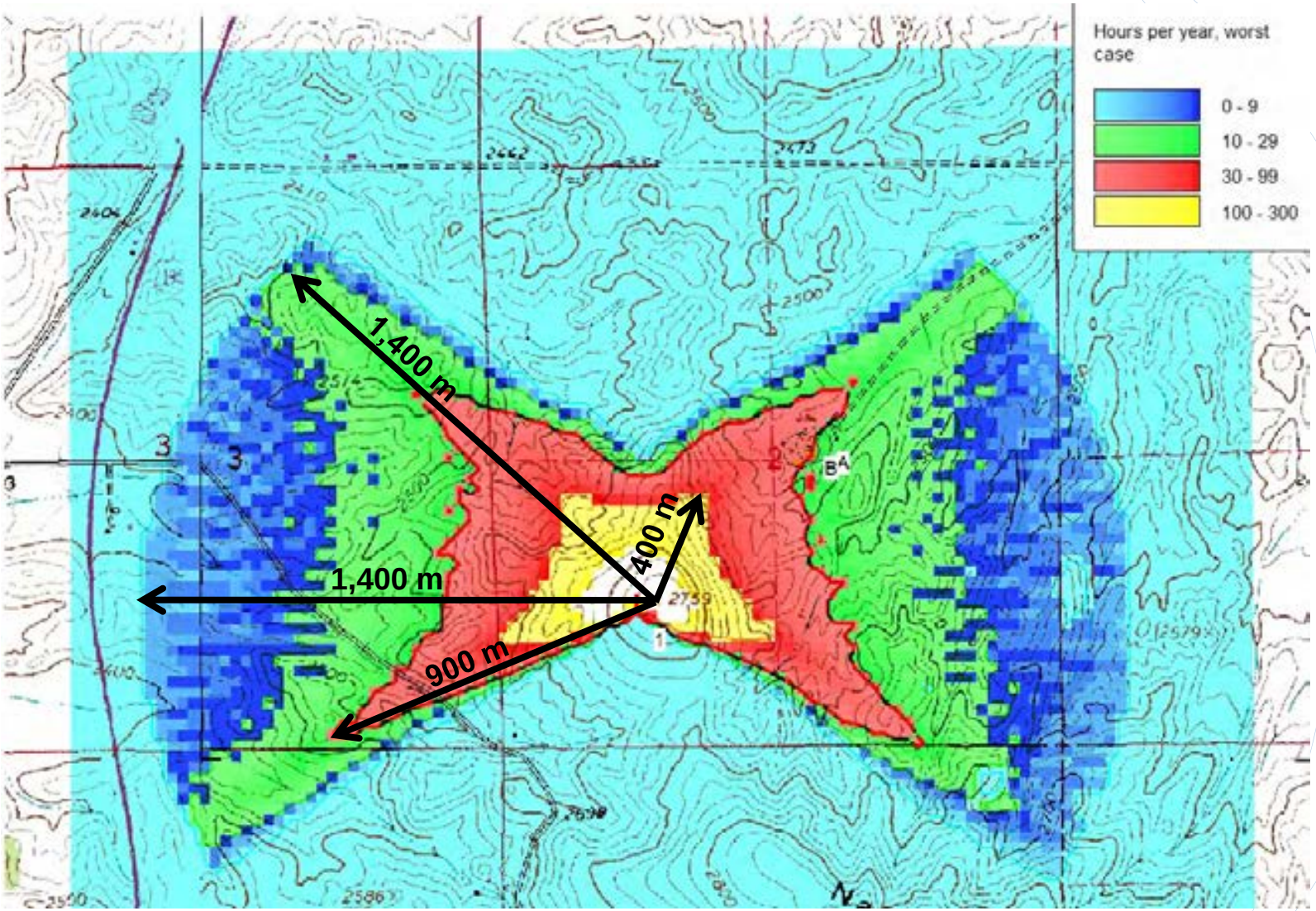
Important Things to Know About Shadow Flicker

Shadow flicker is limited in time and location

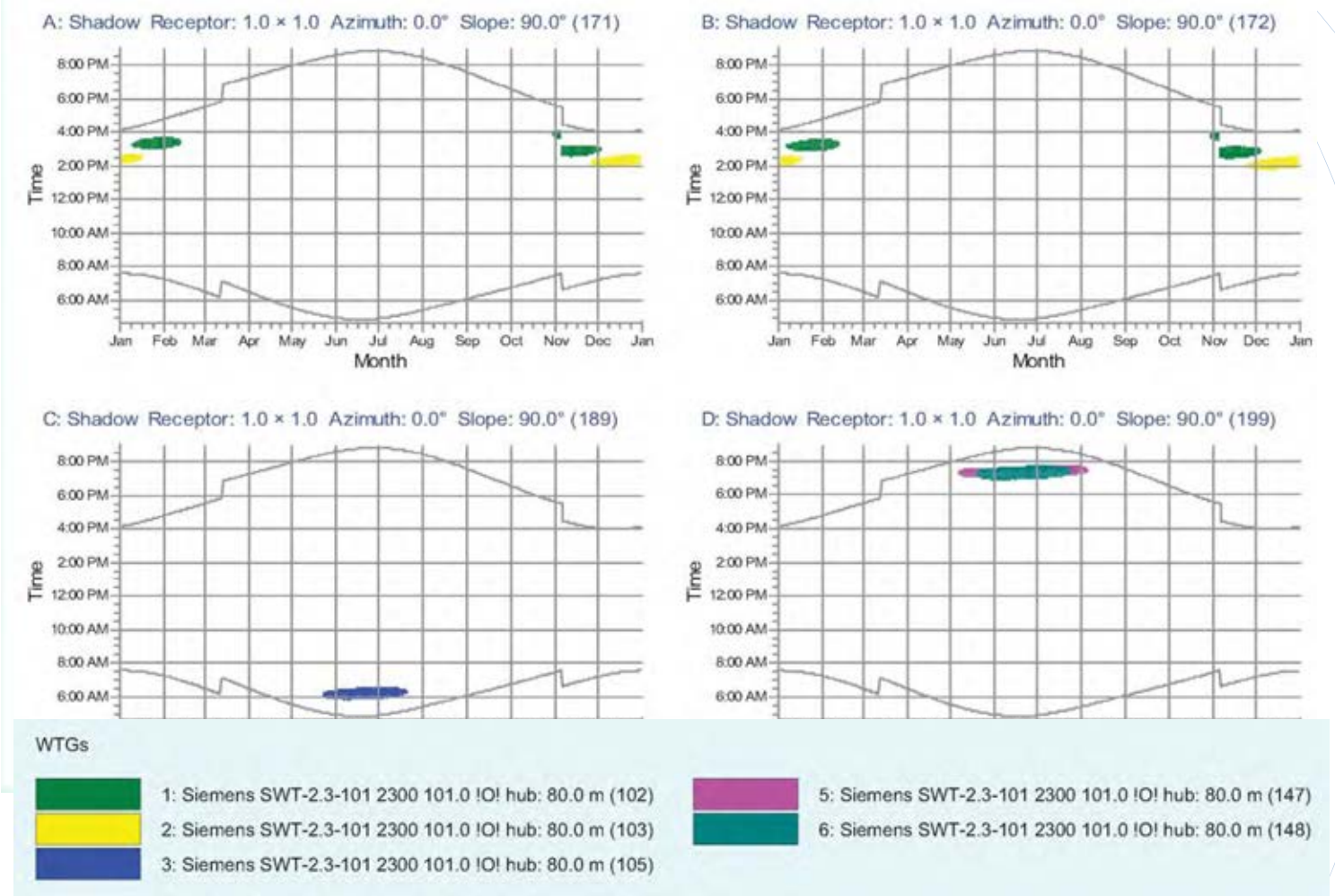
Flickering Occurs in a Butterfly-Like Pattern Around Each Turbine



The Important Role of Distance



Shadow Flicker is Time-Limited



Why Do We Need to be Concerned About Shadow Flicker?

Health Effects

- **Epilepsy**
- **Epileptic seizures precipitated by light flashes in the range from 5 to 30 Hertz**
- **Flickering created by modern wind turbines is in the range of 0.6 to 1.0 Hertz**
- **Thus shadow flicker effects created by wind turbines do not have the potential to trigger epileptic seizures**
- **http://www.epilepsyfoundation.org/about/photosensitivity/index.cfm**

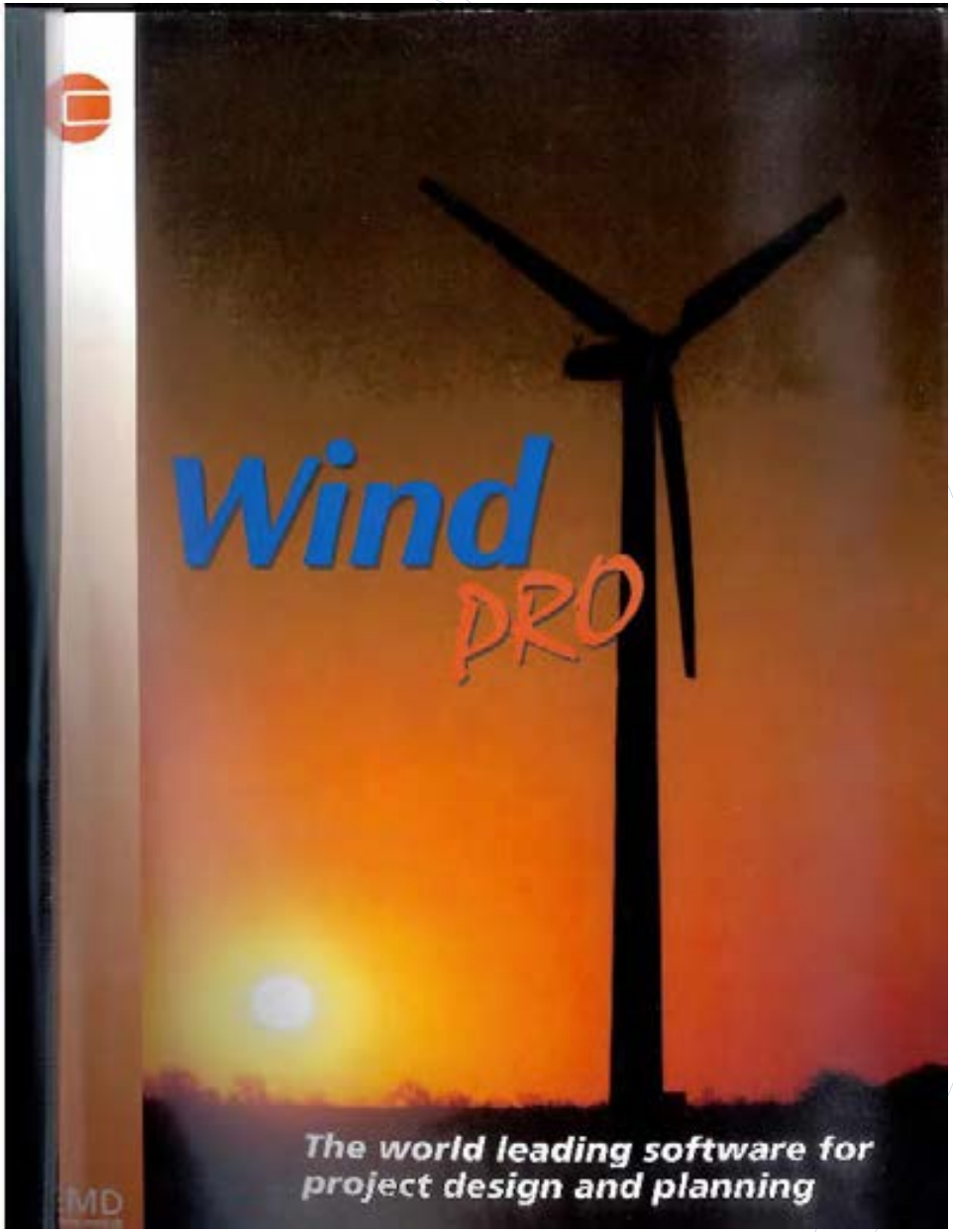
Other Health Effects

- **In some cases when wind power projects are being considered for permitting, concerns are raised that turbine-related shadow flicker has the potential to cause nausea, dizziness, and disorientation.**
- **Proponents of wind power argue that the empirical evidence does not support these assertions**

The Potential for Nuisance Effects the Primary Basis for Concern About Shadow Flicker

Analysis of Shadow Flicker Effects

Wind Pro or Similar Software Programs



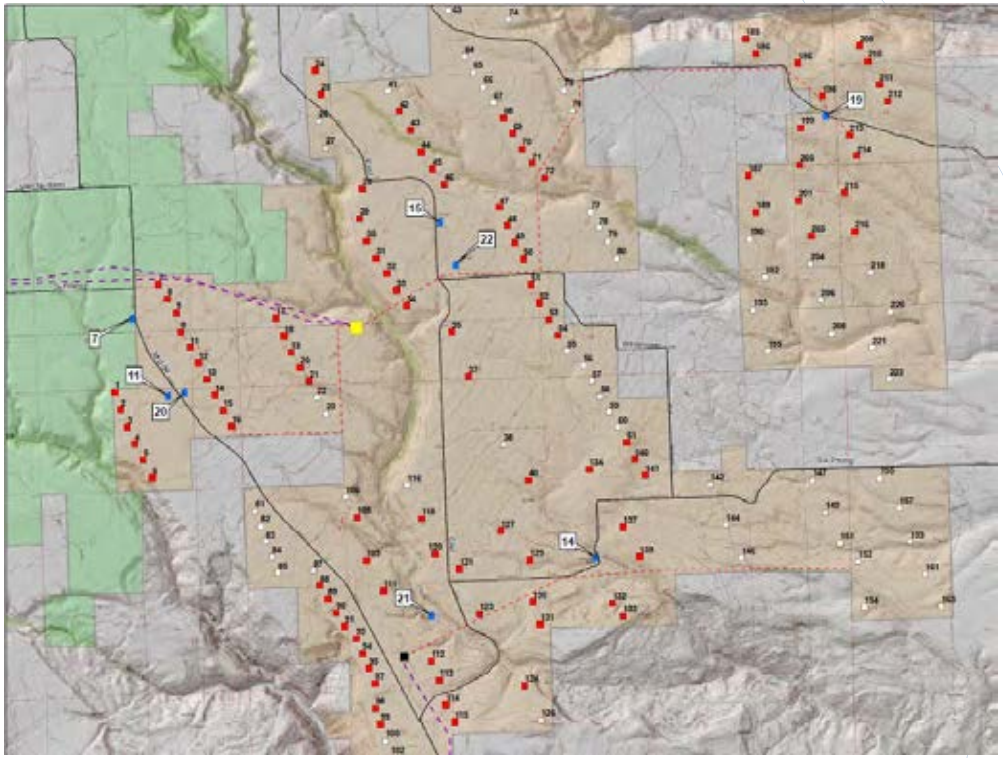
Model Inputs

define analysis area to extend 2 km from turbines

turbine locations (xyz coordinates)

turbine design parameters

residence locations (xyz coordinates) and characteristics



Worst Case vs Real Case Analysis

- **Worst case assumes: sun during all daylight hours, blades always spinning, and wind direction aligned with direction from turbine to receptor**

Real Case Analysis

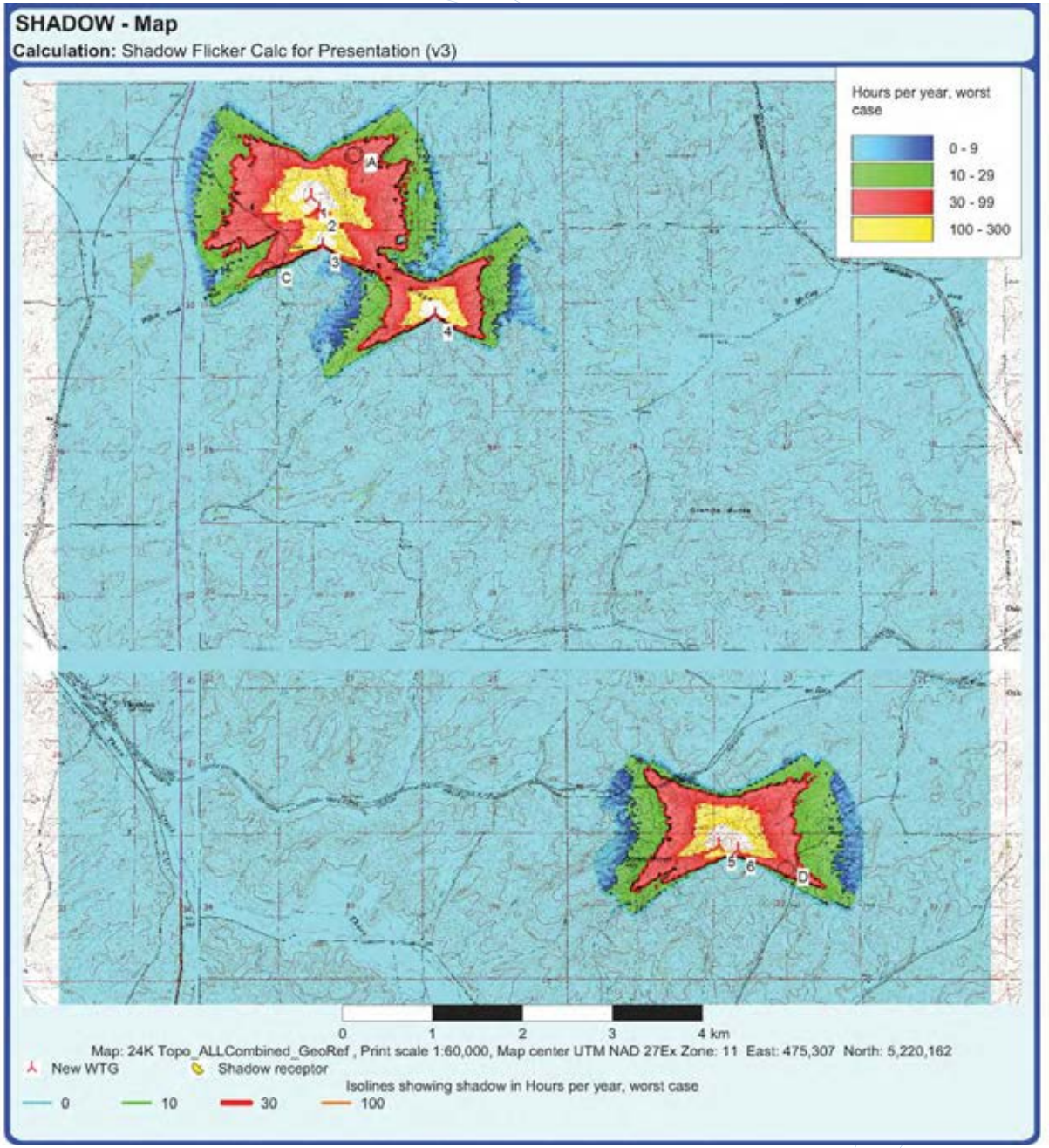
refine results based on consideration of:

operational hours and wind directions

monthly sunshine probabilities

Shadow Module Outputs

Maps Indicating Locations and Incidence of Shadow Flicker



Calculations of Daily Minutes and Annual Hours of Shadow Flicker by Residence

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CH2M HILL
1295 Northland Drive, Suite 200
US-MENDOTA HEIGHTS, MN 55120

Dana West / dana.west@ch2m.com

Calculated:
1/27/2011 9:01 AM/2.7.473

SHADOW - Main Result

Calculation: Shadow Flicker Calc for Presentation (v3)

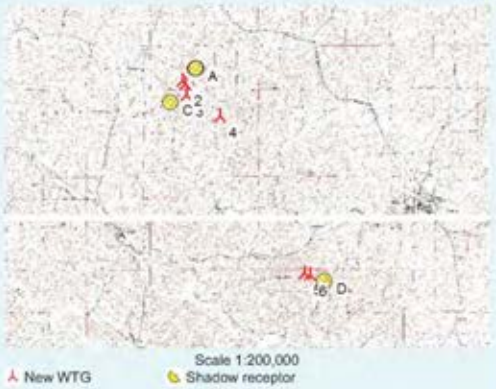
Assumptions for shadow calculations

Maximum distance for influence
Calculate only when more than 20 % of sun is covered by the blade
Please look in WTG table

Minimum sun height over horizon for influence	3 °
Day step for calculation	1 days
Time step for calculation	1 minutes

The calculated times are "worst case" given by the following assumptions:
- The sun is shining all the day, from sunrise to sunset
- The rotor plane is always perpendicular to the line from the WTG to the sun
- The WTG is always operating

A ZVI (Zones of Visual Influence) calculation is performed before flicker calculation so non visible WTG do not contribute to calculated flicker values. A WTG will be visible if it is visible from any part of the receiver window. The ZVI calculation is based on the following assumptions:
Height contours used: Height Contours: TEST2.MAP (9)
Obstacles used in calculation
Eye height: 1.5 m
Grid resolution: 10 m



WTGs

	UTM NAD27Ex Zone: 11 East	North	Z	Row data/Description	WTG type Valid	Manufact.	Type-generator	Power, rated	Rotor diameter	Hub height	Shadow data Calculation distance	RPM
	UTM NAD27Ex Zone: 11		[m]					[kW]	[m]	[m]	[m]	[RPM]
1	472,878	5,223,974	820.0	Siemens SWT-2.3-1...	Yes	Siemens	SWT-2.3-101-2,300	2,300	101.0	80.0	1,395	16.0
2	472,972	5,223,834	820.0	Siemens SWT-2.3-1...	Yes	Siemens	SWT-2.3-101-2,300	2,300	101.0	80.0	1,395	16.0
3	473,010	5,223,428	835.3	Siemens SWT-2.3-1...	Yes	Siemens	SWT-2.3-101-2,300	2,300	101.0	80.0	1,395	16.0
4	474,256	5,222,646	860.0	Siemens SWT-2.3-1...	Yes	Siemens	SWT-2.3-101-2,300	2,300	101.0	80.0	1,395	16.0
5	477,396	5,216,721	860.0	Siemens SWT-2.3-1...	Yes	Siemens	SWT-2.3-101-2,300	2,300	101.0	80.0	1,395	16.0
6	477,613	5,216,667	860.0	Siemens SWT-2.3-1...	Yes	Siemens	SWT-2.3-101-2,300	2,300	101.0	80.0	1,395	16.0

Shadow receptor-Input

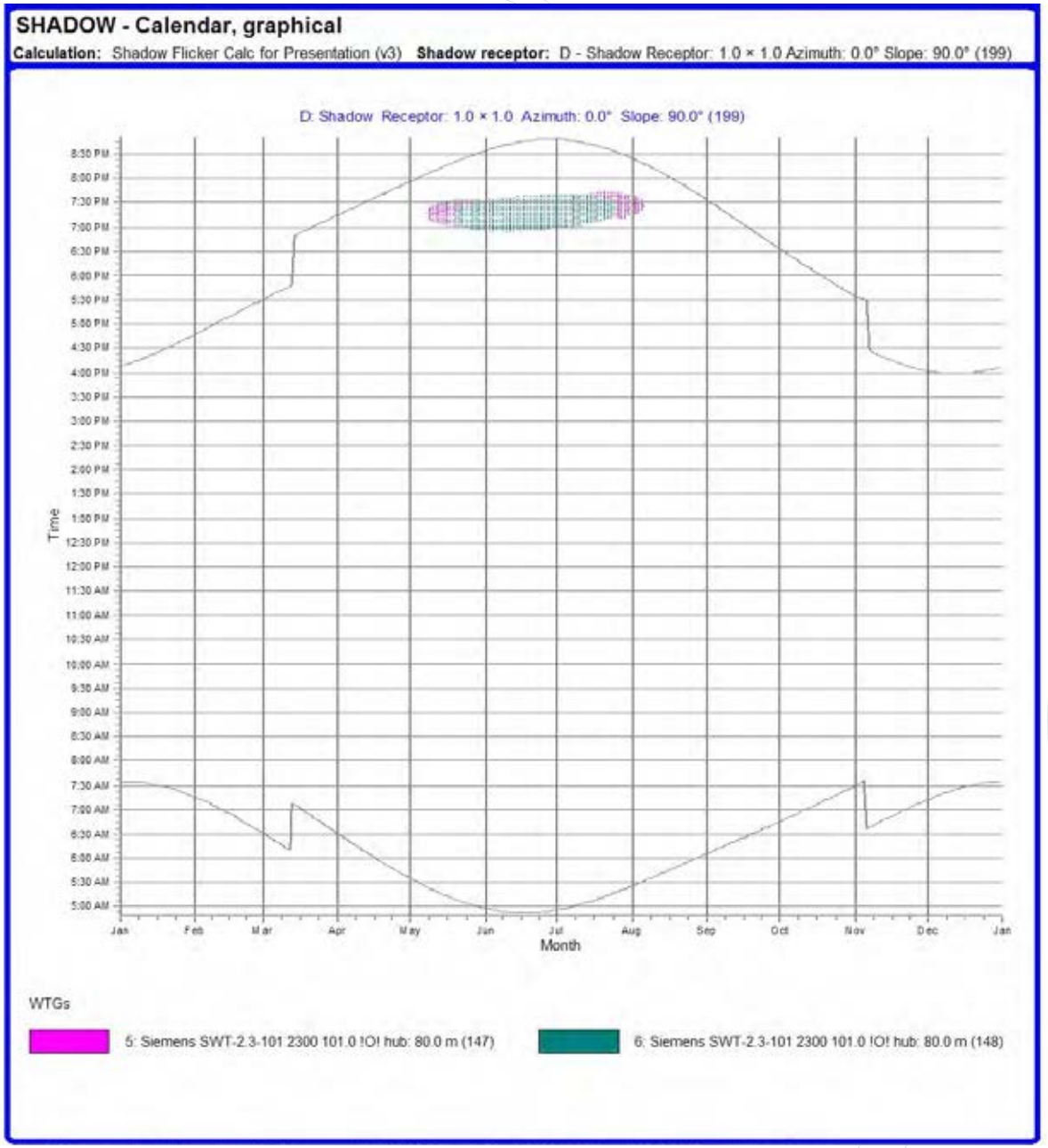
No.	UTM NAD27Ex Zone: 11 East	North	Z	Width	Height	Height a.g.l.	Degrees from south cw	Slope of window	Direction mode
			[m]	[m]	[m]	[m]	[°]	[°]	
A	473,382	5,224,440	760.0	1.0	1.0	0.0	0.0	90.0	"Green house mode"
B	473,345	5,224,424	760.0	1.0	1.0	0.0	0.0	90.0	"Green house mode"
C	472,407	5,223,159	780.0	1.0	1.0	0.0	0.0	90.0	"Green house mode"
D	478,147	5,216,452	800.0	1.0	1.0	0.0	0.0	90.0	"Green house mode"

Calculation Results

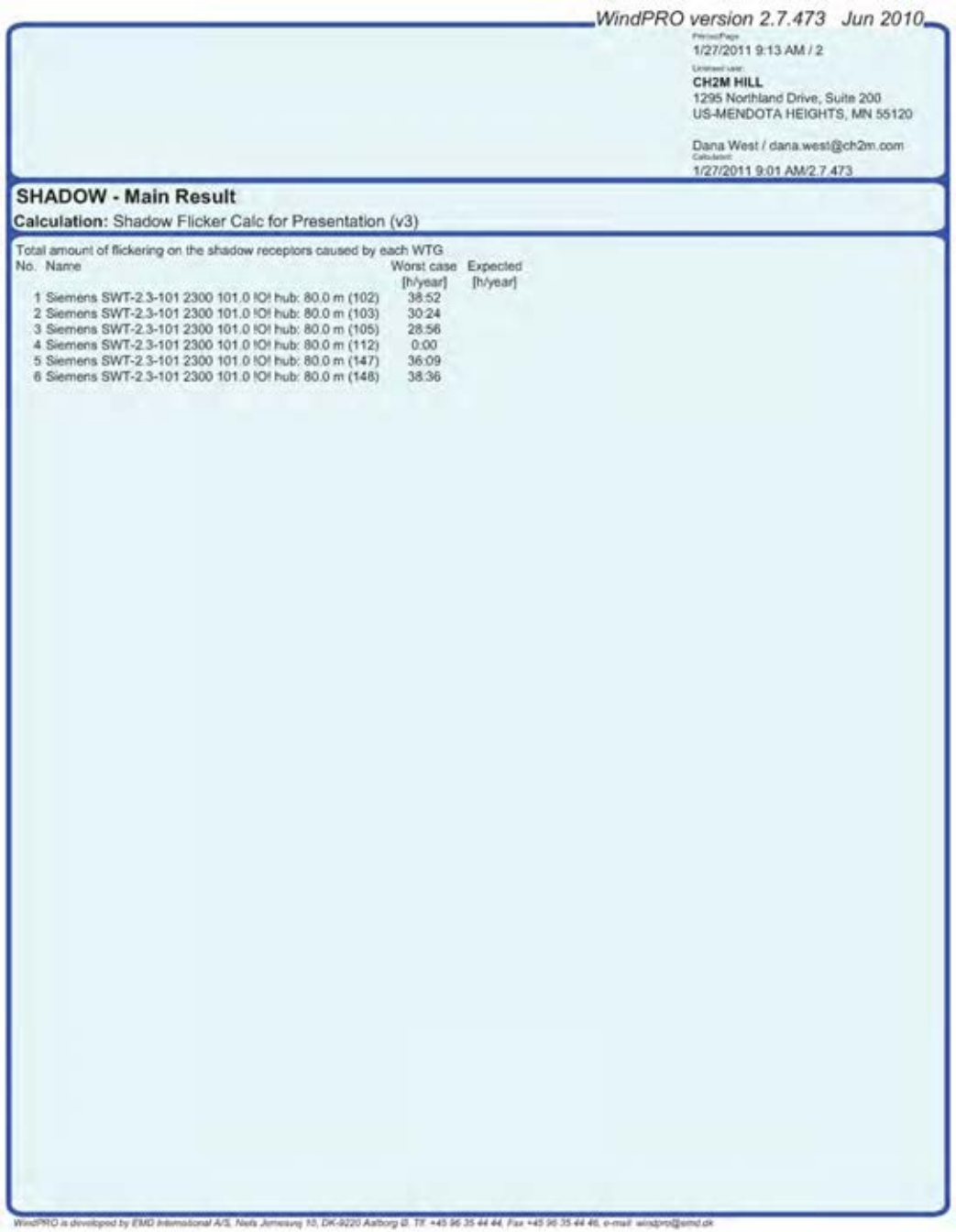
Shadow receptor

No.	Shadow, worst case Shadow hours per year [h/year]	Shadow days per year [days/year]	Max shadow hours per day [h/day]
A	53:36	105	0:38
B	57:32	105	0:42
C	28:56	59	0:36
D	50:32	91	0:42

Graphic Displays of Timing of Shadow Flicker Exposure Episodes for Each Residence



Annual Hours of Shadow Flicker Cast on all Receptors by Each Individual Turbine



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CH2M HILL
1295 Northland Drive, Suite 200
US-MENDOTA HEIGHTS, MN 55120

Dana West / dana.west@ch2m.com

Calculated:
1/27/2011 9:01 AM/2.7.473

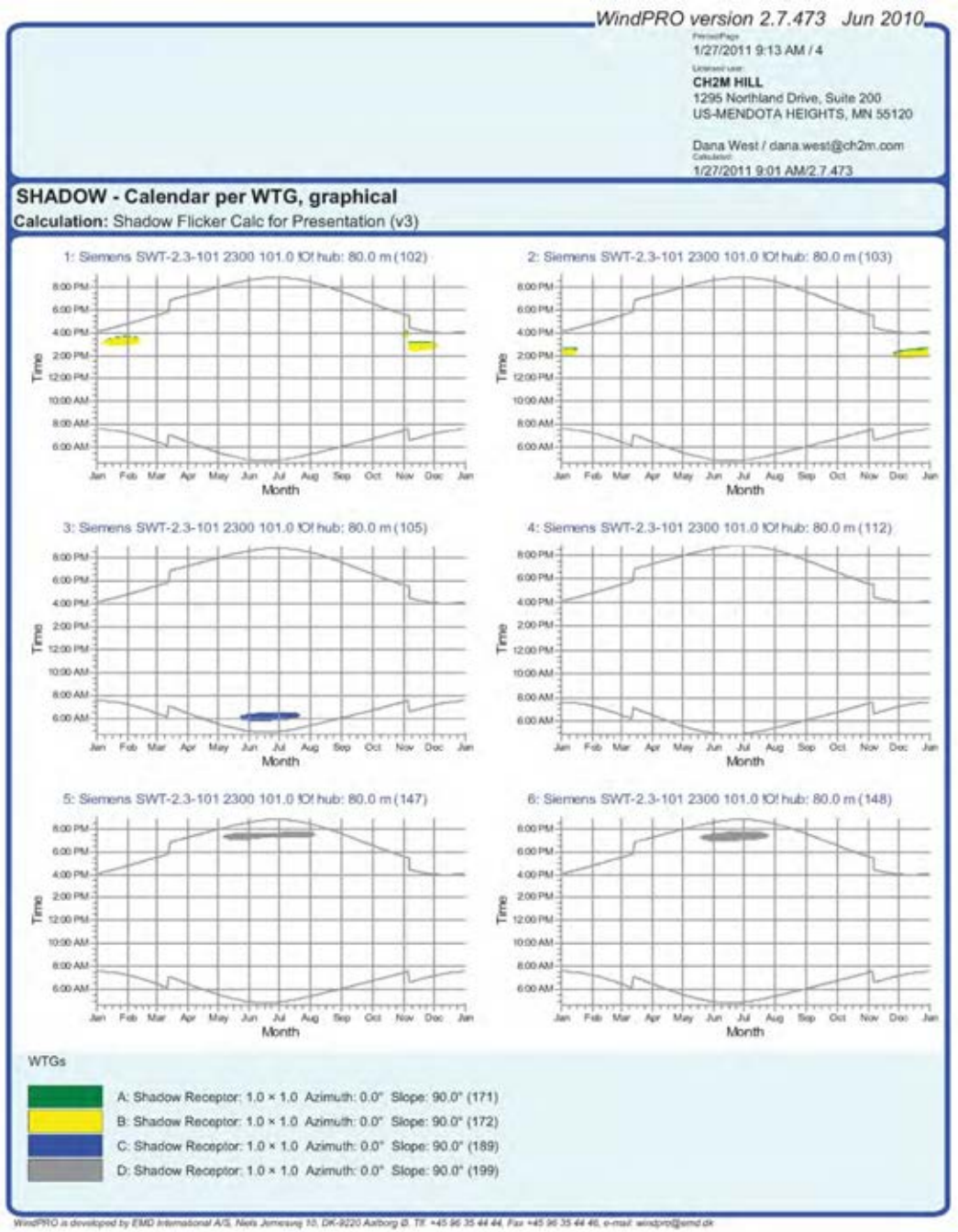
SHADOW - Main Result

Calculation: Shadow Flicker Calc for Presentation (v3)

Total amount of flickering on the shadow receptors caused by each WTG

No.	Name	Worst case [h/year]	Expected [h/year]
1	Siemens SWT-2.3-101 2300 101.0 !O! hub: 80.0 m (102)	38:52	
2	Siemens SWT-2.3-101 2300 101.0 !O! hub: 80.0 m (103)	30:24	
3	Siemens SWT-2.3-101 2300 101.0 !O! hub: 80.0 m (105)	28:56	
4	Siemens SWT-2.3-101 2300 101.0 !O! hub: 80.0 m (112)	0:00	
5	Siemens SWT-2.3-101 2300 101.0 !O! hub: 80.0 m (147)	36:09	
6	Siemens SWT-2.3-101 2300 101.0 !O! hub: 80.0 m (148)	38:36	

For Each Turbine, Displays of Timing of Shadow Flicker Exposure for Specific Residences



Summaries of Data in a Form that is Meaningful to Clients and Decision-Makers

Predicted Shadow Flicker

House	Distance from closest turbine causing flicker effect (meters)	Days per year shadow flicker occurs	Total annual hours of shadow flicker	Days per year of shadow flicker adjusted for cloud cover[1]	Annual hours of shadow flicker adjusted for cloud cover[1]	Duration of longest daily shadow flicker event (minutes)	Average daily shadow flicker event (minutes)	Times of greatest Potential Shadow flicker exposure
7	626	248	99.07	128	54.82	37.8	23.5	mornings, year round
11	671	287	155.2	156	88.58	39.2	25.5	mornings and evenings, year round
14	688	88	32.51	46	18.39	35.7	22.2	evenings, November-February; mornings, spring and fall
15	975	252	73.37	140	40.81	26.6	17.4	evenings, year round: mornings, March, August and September
16	1363 [2]	0	0	0	0	0.0	0.0	No predicted shadow
20	412	255	141.61	123	70.28	49.2	25.4	mornings, year round; evenings winter, spring, and fall