SHADOW FLICKER ASSESSMENT

ADELAIDE WIND ENERGY CENTRE

January 2012

GL Garrad Hassan

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RENEWABLE ENERGY APPROVAL APPLICATION - SHADOW FLICKER ASSESSMENT

ADELAIDE WIND ENERGY CENTRE, ONTARIO

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REVISION HISTORY

Issue	Issue Date	Summary
A	15 December 2011	Initial issue for review
B	9 January 2012	Requested changes for Client in Appendix B

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1 INTRODUCTION

GL Garrad Hassan Canada, Inc. (GL GH), a member of the GL Group and part of the GL Garrad Hassan brand, has been commissioned by NextEra Energy Canada, ULC ("Client" or "NextEra") to independently assess the impact of the shadow flicker events experienced in the vicinity of the proposed Adelaide Wind Energy Centre (the "Project"), which will use the General Electric GE1.6-100 with a blade tip height of 130 m, a hub height of 80 m and a rotor diameter of 100 m. Given that a shadow flicker analysis is not required under Ontario reg. 359/09, this report is presented as complementary information to the Renewable Energy Approval (REA) application for this Project.

Shadow flicker is defined as the modulation of light levels resulting from the periodic passage of a rotating wind turbine blade between the sun and a viewer. The duration of shadow flicker experienced at a specific location can be determined using a purely geometric analysis which takes into account the relative positions of the sun throughout the year, the wind turbines at the site, and the viewer. This method has been used to determine the duration of shadow flicker events at sensitive locations in the vicinity of the Project.

It should be noted, however, that this analysis method tends to be conservative and therefore typically results in an over-estimation of the number of hours of shadow flicker experienced at a given dwelling.

This report includes a brief presentation of the Project site, a description of the shadow flicker assessment methodology, results of the analysis including a map illustrating areas prone to shadow flicker, and concluding comments.

2 DESCRIPTION OF THE WIND FARM SITE

2.1 Site Description

The proposed Adelaide Wind Energy Centre is located in south-western Ontario, in the Township of Adelaide-Metcalfe, Middlesex County, Ontario. More specifically, the area being studied for the wind farm components is located south of Townsend Line, west of Centre Road, north of Napperton Drive and east of Sexton Road. Project components will be installed on privately-owned agricultural lots within this area.

The proposed wind farm is situated in relatively simple terrain, consisting of mostly flat areas and some rolling hills, with elevations ranging from 230 m to 255 m. The landscape in the study area is predominantly characterized by agricultural fields and associated farms punctuated with numerous hedgerows, isolated woodlands, and the occasional watercourse.

2.2 Wind Farm Layout

The proposed turbine layout, which consists of 38 General Electric GE1.6-100 wind turbine generators, has been supplied by the Client. The precise coordinates of each turbine are presented in Appendix A; coordinates are presented in this report in UTM Zone 17N, NAD 1983 datum [1].

2.3 Receptor Locations

Dwellings for the Project area were identified using base data from Canvec and MNR and were validated during a site visit in June 2011. Pursuant to this site visit, 284 dwellings were identified within a 1.5 km radius of the wind turbines. The ID numbers and coordinates of these dwellings are listed in Appendix B. The receptor locations (dwellings) for this flicker analysis are the same as the Points of Reception and participating receptor locations used in the Noise Impact Assessment.

3 SHADOW FLICKER ASSESSMENT

3.1 Overview

Shadow flicker may occur under certain combinations of circumstances with regards to the sun's position and wind direction; when the sun passes behind the rotating blades of a wind turbine, a moving shadow is cast in front of or behind the turbine. When viewed from a stationary position, the moving shadows cause periodic flickering of the sunlight, otherwise known as the "shadow flicker" phenomenon.

The effect is most noticeable inside buildings, where the flicker appears through a window opening. The likelihood and duration of the effect depends on a number of variables, namely:

- Orientation of the building relative to the turbine;
- Wind direction: the shape and intensity of the shadow are determined by the position of the sun relative to the blades (the turbine rotor continuously yaws to face the wind so the rotor plane will always be perpendicular to the wind direction;
- Distance from turbine: the farther the observer from the turbine, the less pronounced the effect;
- Turbine height and rotor diameter: a larger turbine rotor diameter will cast a larger shadow, meaning a larger area will be prone to incidences of shadow flicker;
- Time of year and day: position of sun relative to the horizon;
- Weather conditions: cloud cover reduces the occurrence of shadow flicker;
- Vegetation and other obstacles that help to mask shadows; and
- Operational status of turbines.

3.2 Assessment Methodology

The number of hours of shadow flicker experienced annually at a given location can be calculated using a geometrical model which takes into account the sun's position, topography of the wind farm site and wind turbine specifications such as rotor diameter and hub height. The modeling of shadow flicker at the Project has been conducted for the General Electric GE1.6-100 wind turbine generator model using the method described below.

The wind turbine has been modeled assuming all wind turbines are disc objects oriented perpendicular to the sun-turbine vector, representing the maximum duration for which there is potential for shadow flicker to occur.

Shadow flicker has been calculated at the receptors (i.e. dwellings) at a height of 2 m to represent ground floor windows. Rather than facing a particular direction, shadow flicker receptors (windows) are simulated as horizontal planes, meaning they experience shadow flicker over 360°; this assumption therefore represents a worst case scenario. Simulations have been carried out with a resolution of 1 minute; if shadow flicker occurs in any 1-minute period, the model registers this as 1 minute of shadow flicker.

It is generally accepted that shadow flicker from wind turbines does not occur beyond a distance, D, from a given wind turbine. The UK wind industry considers this distance to be equivalent to 10 rotor diameters [2], while the Danish wind industry suggests a value of between 500 and 1000 m [3]. GL GH has adopted a conservative approach and has assumed the length, D, that a shadow can be cast to be defined as follows:

D = 10 x (hub height + rotor radius)

For the GE1.6-100 wind turbine generator, this equates to 1.3 km. Beyond this distance, a viewer does not perceive the turbine blade to be interrupting the light, but rather as an object passing in front of the sun.

For this study, shadow flicker calculations were adjusted using an annual cloud coverage figure which is based on historical meteorological data and statistics. According to data gathered from the London Airport meteorological station, it has been estimated that the cloud cover is sufficient to nullify shadow flicker occurrence 66.8% of the time. Results both with and without consideration of cloud cover are presented in Section 4 and Appendix B. Further, using the site-specific wind rose to consider the probability of the turbines being oriented in a given direction could lead to significant further reduction in the annual shadow flicker occurrence.

No attempt has been made to account for vegetation or other shielding effects around each shadow receptor in the calculations of shadow flicker duration. Similarly, turbine shut-down occurrences have not been considered.

3.3 Conservative Assumptions

Shadow flicker duration calculated in the manner described above typically over-estimates the annual number of hours of shadow flicker experienced at a specified location for several reasons, namely:

1 The modeling of the wind turbine blades as discs rather than individual blades results in an overestimate of shadow flicker duration.

   Turbine blades are of non-uniform thickness with the thickest part of the blade (maximum chord) close to the hub and the thinnest part (minimum chord) at the tip. Diffusion of sunlight, as discussed above, results in a limit to the maximum distance that a shadow can be perceived. This maximum distance will also be dependent on the thickness of the turbine blade and the human threshold for perception of light intensity variation. As such, a shadow cast by the blade tip will be shorter than the shadow cast by the thickest part of the blade [4].

2 The wind turbine will not always be yawed such that its rotor is perpendicular to the sun-turbine vector. Any other rotor orientation will reduce the area of the projected shadow, and thus the incidence of shadow flicker. Additionally, the orientation of windows on a given house has not been taken into account, i.e. the model assumes that a window is always facing the turbine(s).

   The wind speed frequency distribution, or wind rose, at the site can be used to determine probable turbine orientation in order to calculate the resulting reduction in shadow flicker duration, however this has not been done in this study.

3 Aerosols (moisture, dust, smoke, etc.) in the atmosphere have the ability to influence shadows cast by a wind turbine.

The length of the shadow cast by a wind turbine is dependent on the degree that direct sunlight is diffused, which in turn is dependent on the amount of dispersants (humidity, smoke, and other aerosols) in the path between the light source (sun) and the receiver [4].

4 Modeling the sun as a point light source rather than a disc results in an overestimate of the shadow flicker duration. The fact that the light source is a disc results in a shadow which is less well defined and of lower intensity as compared to a point light source.

The occurrence of cloud cover has the potential to significantly reduce the number of hours of shadow flicker.

Cloud cover measurements recorded at nearby meteorological stations may be used to estimate probable levels of cloud cover, and to provide an indication of the resulting reduction in shadow flicker duration (see Section 3.2).

5 The presence of vegetation or other physical barriers around a shadow receptor location may shield the view of the wind turbine, and therefore reduce the incidence of shadow flicker.

6 Periods where the wind turbine is not in operation due to low winds, high winds, or for operational and maintenance reasons will also reduce shadow flicker occurrence.

In light of the reasons listed above, it is likely that the shadow flicker durations presented in Section 4 can be regarded as conservative.

4 RESULTS

The predicted shadow flicker duration at receptors in the vicinity of the Adelaide Wind Energy Centre is presented in the form of a shadow flicker map in Figure 4-1. The map takes into account average annual cloud cover.

This analysis indicates that flicker occurrence is highest at Receptors 213 and 113, where a total of 18 hours/year of flicker was calculated, when taking into account cloud cover. These receptors could also experience a maximum of 55 and 57 minutes/day of flicker, respectively. Appendix B presents the predicted shadow flicker durations (maximum minutes per day and total hours per year) at all receptor locations. It should be noted however, that this analysis method tends to be conservative and therefore typically results in an over-estimation of the number of hours of shadow flicker experienced at a given dwelling.

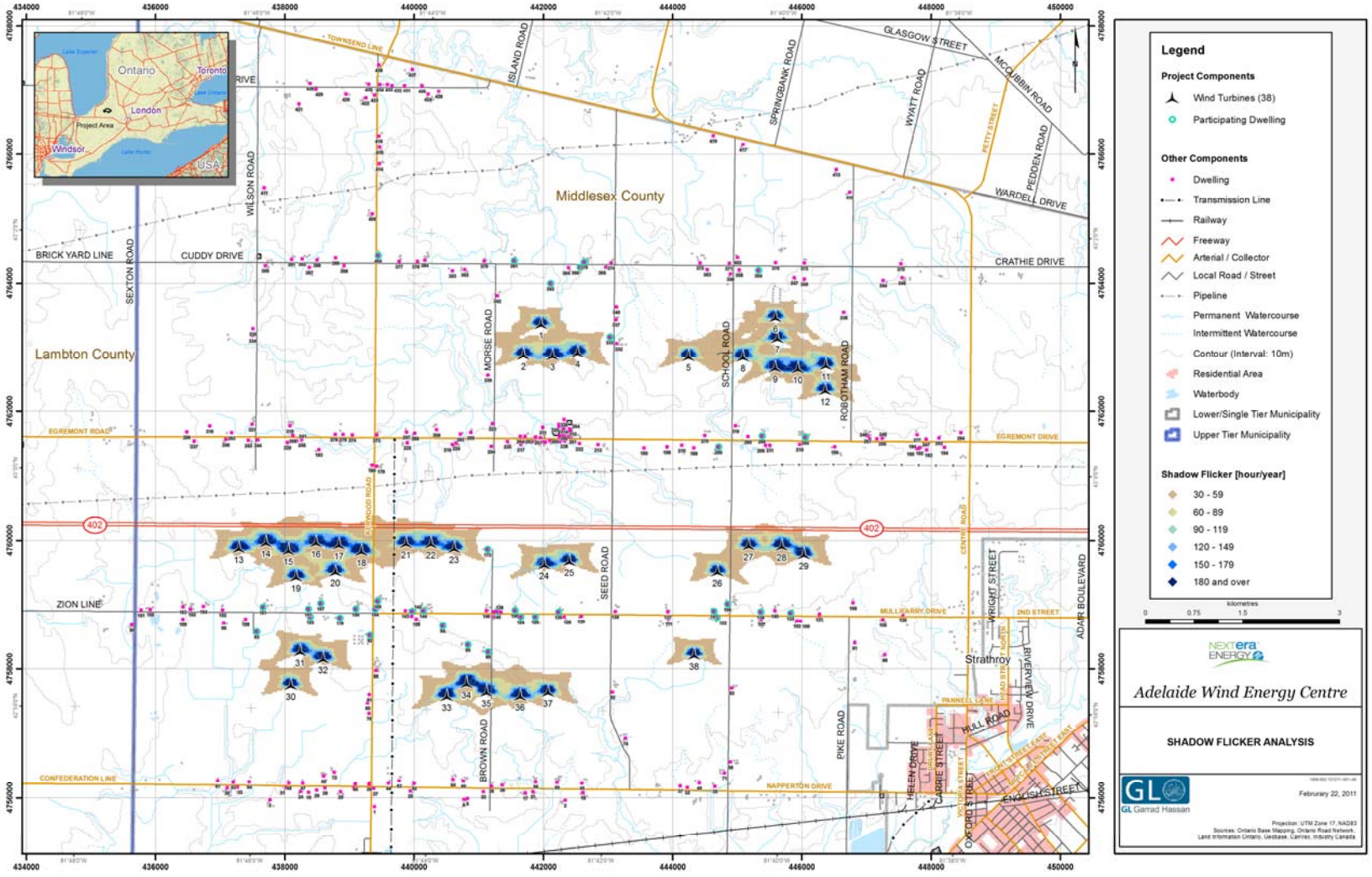

Figure 4-1: Modeled hours of shadow flicker for the Adelaide Wind Energy Centre

5 CONCLUSION

An analysis has been conducted to determine the duration of shadow flicker events likely to be experienced at receptors in the vicinity of the Adelaide Wind Energy Centre in Middlesex County, Ontario. This analysis was realized specifically for the General Electric GE1.6-100 wind turbine with a blade tip height of 130 m. Given that a shadow flicker analysis is not required under Ontario reg. 359/09, this report is presented as complementary information to the Renewable Energy Approval (REA) application for this Project.

6 REFERENCES

[1] Turbine layout locations sent by email, by Jaclyn Vogliano, NextEra, to Jonathan Murphy, GL GH, November 11, 2011.
"CAN_Adelaide_Optimized_59_9MW_GExle1_6_100RD_80HH_37T_1Alts_2011_09_19.shp"

[2] Department for Business Enterprise & Regulatory Reform, UK, "Onshore Wind: Shadow Flicker", http://www.berr.gov.uk/whatwedo/energy/sources/renewables/planning/onshore-wind/shadow-flicker/page18736.html , viewed 23 July 2010.

[3] Danish Wind Industry Association, "Shadow variations from Wind turbines", http://guidedtour.windpower.org/en/tour/env/shadow/shadow2.htm, viewed 22 July 2010.

[4] Freud H-D, Kiel F.H., "Influences of the opaqueness of the atmosphere, the extension of the sun and rotor blade profile on the shadow impact of wind turbine", DEWI Magazine No. 20 pp 43-51, February 2002.

APPENDIX A TURBINE LAYOUT

Coordinates of turbines

Turbine ID	Easting [m][1]	Northing [m][1]
1	441963	4763345
2	441693	4762865
3	442142	4762857
4	442529	4762899
5	444245	4762845
6	445590	4763450
7	445620	4763125
8	445087	4762836
9	445586	4762665
10	445939	4762651
11	446370	4762704
12	446360	4762314
13	437290	4759864
14	437710	4759955
15	438055	4759832
16	438483	4759952
17	438837	4759917
18	439187	4759817
19	438176	4759414
20	438783	4759497
21	439875	4759939
22	440261	4759935
23	440623	4759864
24	442013	4759608
25	442404	4759661
26	444694	4759496
27	445175	4759905
28	445687	4759898
29	446031	4759766
30	438092	4757738
31	438237	4758255
32	438593	4758143
33	440506	4757566
34	440812	4757764
35	441120	4757631

Turbine ID	Easting [m][1]	Northing [m][1]
36	441641	4757570
37	442072	4757631
38	444335	4758200

1. Coordinate system is UTM Zone 17N, NAD83 datum.

APPENDIX B HOUSE LOCATIONS AND ASSOCIATED SHADOW FLICKER

Shadow flicker at dwellings

Receptors		UTM Coordinates		Participating	Max Minutes per Day [min/day]	Total Hours in Year [hrs/yr]		Turbine ID Contributing to Events	Nearest Turbine	
#	ID	Easting [m]	Northing [m]			without Cloud Cover	with Cloud Cover		Distance [m]	ID
213	333	443029	4763156	No	55	53	18	1 3 4 5	563	4
113	173	441138	4759859	Yes	57	53	18	21 22 23 24 25	515	23
216	337	443128	4763430	No	31	38	13	1 3 4 5	801	4
212	332	443140	4763057	No	62	34	11	1 3 4 5	631	4
211	330	441146	4762567	No	32	30	10	2 3	623	2
104	156	439096	4758927	Yes	22	29	10	19 31	651	20
219	342	441292	4763805	No	31	25	8	1	1021	2
59	93	437566	4758576	Yes	40	20	7	31 32	743	31
58	92	439319	4758521	Yes	28	20	7	31 32	818	32
53	86	439409	4757971	No	30	19	6	31 32 33	834	32
106	161	437664	4758958	Yes	22	19	6	18 20 32	686	19
72	119	438850	4758790	Yes	28	15	5	31	696	32
94	143	439870	4758901	No	17	15	5	19 20 31 32	1038	21
218	340	443131	4763628	No	20	15	5	1 3	945	4
100	152	437038	4758917	No	19	15	5	19 31 32	980	13
112	169	439437	4759052	Yes	15	13	4	15 19 31	791	20
93	142	439969	4758896	Yes	16	13	4	20 32	1047	21
217	338	446649	4763542	No	19	12	4	6 7	883	11
68	108	437395	4758770	No	25	12	4	31	987	31
50	81	439309	4757608	No	18	12	4	30 31 33	894	32
55	89	441145	4758266	Yes	21	11	4	37	602	34
84	133	445824	4758864	Yes	15	10	3	26 38	925	29
48	76	439303	4757317	No	19	10	3	30 33	1089	32
49	80	439285	4757478	No	17	9	3	30 33	959	32
85	134	445361	4758884	Yes	18	9	3	38	906	26
102	154	439398	4758926	No	15	9	3	19 31	839	20

79	128	439964	4758816	No	11	8	3	20 32	1127	21
51	82	443072	4757647	No	22	8	2	37	1000	37
90	139	443113	4758889	No	15	7	2	26 38	1048	25
67	107	445375	4758770	No	18	6	2	38	996	26
108	164	436743	4758970	No	13	5	2	19 31	1048	13
95	144	440144	4758901	Yes	11	5	1	20 32	1041	22
62	96	437056	4758714	No	16	4	1	31	1174	13
203	319	444973	4761778	No	13	4	1	12	1064	8
96	145	445584	4758903	No	13	3	1	38	972	29
128	202	444822	4761459	No	7	3	1	12	1402	8
181	277	447785	4761642	No	9	3	1	12	1575	12
88	137	443929	4758886	No	8	2	1	25	797	38
129	203	444866	4761460	No	6	2	1	12	1394	8
101	153	436541	4758926	No	10	2	1	19	1201	13
82	131	446272	4758848	No	9	2	1	26	950	29
71	114	446273	4758782	No	8	2	1	26	1014	29
170	260	445167	4761612	No	6	2	1	12	1133	9
158	247	447924	4761573	No	7	2	0	12	1731	12
123	192	447823	4761442	No	4	1	0	12	1704	12
81	130	447562	4758842	No	3	1	0	29	1788	29
97	146	441122	4758903	No	4	1	0	25	1083	23
119	184	447806	4761430	No	2	0	0	12	1695	12
1	1	439388	4755862	No	0	0	0	-	2038	33
2	2	442341	4755960	No	0	0	0	-	1692	37
3	3	437770	4755964	No	0	0	0	-	1803	30
4	4	440774	4755972	No	0	0	0	-	1616	33
5	5	440829	4755988	No	0	0	0	-	1611	33
6	8	439390	4756038	No	0	0	0	-	1892	33
7	17	441720	4756075	No	0	0	0	-	1497	36
8	18	442615	4756079	No	0	0	0	-	1644	37
9	19	438368	4756084	No	0	0	0	-	1677	30
10	20	438865	4756093	No	0	0	0	-	1818	30
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12	22	441075	4756094	No	0	0	0	-	1538	35

13	24	438246	4756095	No	0	0	0	-	1650	30
14	25	439944	4756106	No	0	0	0	-	1565	33
15	26	438497	4756118	No	0	0	0	-	1670	30
16	27	439379	4756141	No	0	0	0	-	1817	33
17	28	438624	4756152	No	0	0	0	-	1673	30
18	29	439072	4756153	No	0	0	0	-	1864	30
19	30	437113	4756156	No	0	0	0	-	1861	30
20	31	438026	4756157	No	0	0	0	-	1582	30
21	32	444230	4756162	No	0	0	0	-	2041	38
22	33	437270	4756165	No	0	0	0	-	1775	30
23	35	444656	4756179	No	0	0	0	-	2047	38
24	36	441197	4756182	No	0	0	0	-	1452	35
25	37	444119	4756184	No	0	0	0	-	2028	38
26	38	441366	4756200	No	0	0	0	-	1398	36
27	39	439304	4756212	No	0	0	0	-	1811	33
28	40	439095	4756215	No	0	0	0	-	1824	30
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30	44	439605	4756226	No	0	0	0	-	1615	33
31	45	442598	4756229	No	0	0	0	-	1498	37
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35	50	442215	4756239	No	0	0	0	-	1399	37
36	53	437205	4756244	No	0	0	0	-	1738	30
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38	56	441882	4756251	No	0	0	0	-	1341	36
39	60	440766	4756259	No	0	0	0	-	1333	33
40	61	436962	4756260	No	0	0	0	-	1860	30
41	62	439769	4756264	No	0	0	0	-	1497	33
42	64	440605	4756282	No	0	0	0	-	1288	33
43	68	444898	4756557	No	0	0	0	-	1737	38
44	69	438603	4756336	No	0	0	0	-	1492	30
45	71	444804	4756385	No	0	0	0	-	1875	38
46	72	438767	4756399	No	0	0	0	-	1499	30

47	74	443272	4756927	No	0	0	0	-	1392	37
52	83	444912	4757711	No	0	0	0	-	756	38
54	88	447287	4758217	No	0	0	0	-	1994	29
56	90	440833	4758373	Yes	0	0	0	-	609	34
57	91	446821	4758403	No	0	0	0	-	1575	29
60	94	440444	4758669	Yes	0	0	0	-	976	34
61	95	435639	4758681	No	0	0	0	-	2031	13
63	100	445980	4758740	No	0	0	0	-	1028	29
64	102	445928	4758743	No	0	0	0	-	1028	29
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66	106	436426	4758769	No	0	0	0	-	1395	13
69	109	440037	4758770	No	0	0	0	-	1181	21
70	111	443943	4758779	No	0	0	0	-	699	38
73	122	444685	4758797	Yes	0	0	0	-	692	38
74	123	438394	4758806	Yes	0	0	0	-	572	31
75	124	441649	4758806	Yes	0	0	0	-	881	24
76	125	441873	4758807	Yes	0	0	0	-	813	24
77	126	442321	4758808	No	0	0	0	-	857	25
78	127	441227	4758811	No	0	0	0	-	1120	24
80	129	442586	4758816	No	0	0	0	-	864	25
83	132	435944	4758858	No	0	0	0	-	1680	13
86	135	441344	4758884	No	0	0	0	-	986	24
87	136	442235	4758884	Yes	0	0	0	-	757	24
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91	140	441286	4758890	Yes	0	0	0	-	1022	24
92	141	444639	4758896	Yes	0	0	0	-	603	26
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118	183	438531	4761415	No	0	0	0	-	1463	16
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