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Revision 1

ENT – Exposure Index Calculation

**Exposure Index Analysis Using MACCS2 and CALMET:
Sensitivity Study Supporting the Pilgrim Station SAMA Analysis**

Revision 1

January 2011

Revision History

Revision	Date	Major Change(s)
Initial	December 2010	Original Issue
1	January 2011	Correct heading in third column of Table 1 and delete confidentiality markings on pages 7-13.

Exposure Index Analysis Using MACCS2 and CALMET: Sensitivity Study Supporting the Pilgrim Station SAMA Analysis

Introduction and Summary

The exposure index is a metric used by the U.S. Nuclear Regulatory Commission in the Generic Environmental Impact Statement for License Renewal of Nuclear Plants, and is applied in the assessment of future plant operation risk impacts from atmospheric release pathways. In a License Renewal Application, Severe Accident Mitigation Alternatives (SAMA) analysis, the two metrics of interest are annual- and spatially-averaged consequences that are dependent on wind-directed radiological exposures to the population distributed in a 50-mile radius domain around the subject plant. The exposure index (EI) is calculated in this study as a surrogate for the SAMA analysis metrics to better understand the sensitivity of using localized wind trajectories throughout the 50-mile radius domain around the Pilgrim Nuclear Power Station, as compared to a single set of annual wind trajectories based on measurements for the Pilgrim site. For this analysis, the single set of wind trajectories is based on the 2001 annual wind rose for the Pilgrim Station as processed by the MACCS2 computer model, and the localized trajectory roses are calculated using the CALMET model.

Using the same population distribution for the fifty-mile spatial domain around the Pilgrim Station in each case, the total EI is calculated using the MACCS2-based wind rose, the CALMET-based 500 m trajectory rose, and the CALMET-based 100 m trajectory rose. The MACCS2-based EI is calculated to be 282,429. The total EI based on the CALMET trajectory roses for the 500-m elevation is equal to 291,589, or 3.24% larger than the MACCS2-based EI. The total EI based on the CALMET trajectory roses for the 100-m elevation is equal to 321,396, or 13.80% larger than the MACCS2-based EI (282,429).

Discussion

The Exposure Index (EI) is a metric used by the U.S. Nuclear Regulatory Commission in the Generic Environmental Impact Statement for License Renewal of Nuclear Plants, and is applied in the assessment of future plant operation risk impacts from atmospheric release pathways (NUREG-1437, Vol. 1 page 5-19). As described in NUREG-1437, this pathway includes the exposure of individuals directly from the passage of the cloud of radioactive material released from an accident and from material deposited on the ground, as well as the longer-term effects from other terrestrial pathways such as through food ingestion of crops. The EI is a function of the population distribution surrounding the plant of interest weighted by the site-specific wind direction frequencies for the 16 different principal compass directions. Other factors, such as terrain, precipitation, and stability class have some effect on these risks, but their impact is secondary.

In a nuclear power plant Severe Accident Mitigation Alternatives (SAMA) analysis, the two consequence metrics of interest are the off-site population dose and the off-site economic costs.

Both of these two metrics are evaluated on an annual average basis, and consider population- and spatially-averaged consequences that are strongly dependent on wind-directed radiological exposures to the population distributed in a 50-mile radius spatial domain around the subject plant. In the present SAMA analysis for the Pilgrim Station, the MACCS2 computer code (SNL, 1998a and 1998b) is applied to calculate off-site population dose and economic cost consequences in the 50-mile domain around Pilgrim. This study uses the EI based on the MACCS2 processing of Pilgrim 2001 meteorological data and compares it to an alternative basis using the CALMET model. The EIs calculated between MACCS2 and the alternative CALMET model can thus provide an approximate comparison of likely differences in SAMA analysis impacts if an alternative model were available. In other words, if population and regional economic characteristics are held constant, the relative change in EI, from the MACCS2-based SAMA wind rose in one case to the CALMET based trajectory rose case in the other will indicate the relative change in SAMA PDR and OECR that would result from if a CALMET-based, trajectory rose basis model was available for use with MACCS2.

The present analysis uses the MACCS2 calculated EI, i.e., that obtained from using the wind rose output from the MACCS2 code when processing the 2001 data for Pilgrim and the population distribution developed for the SAMA analysis (NRC, 2007). This exposure index is compared to that obtained using the CALMET model (Hanna and Hendrick, 2010), and a set of trajectory rose data evaluated at the 100-m and 500-m elevations for different sites within the same Pilgrim 50-mile radius domain.

Methodology

For the Pilgrim Plant exposure index analysis, the same methodology is followed as is described in NUREG-1437, Volume 1, where the exposure index is the product of the wind rose for sector i , interval j , and the population for the corresponding grid element in sector i , interval j .

$$\text{Exposure Index} = \sum_{i=1}^{16} \sum_{j=1}^5 \text{Wind rose (sector } i, \text{ interval } j) \times \text{Population in grid element (sector } i, \text{ interval } j), \quad (\text{Eqn. 1})$$

where i is the directional sector index that ranges from 1 to 16 denoting principal compass directions N, NNE, NE, ENE, E, ESE, SE, SSE, S, SSW, SW, WSW, W, WNW, NW, and NNW, and j is the 10-mile interval index that ranges from 1 to 5 for 0-10 miles, 10 miles to 20 miles, 20 miles to 30 miles, 30 miles to 40 miles, and 40 miles to 50 miles intervals, respectively.

The tables in this document support the exposure index calculation shown above using a MACCS2-based method with one set of wind roses, and then using a set of CALMET-based wind roses, or trajectory roses.

Population

The same population distribution is used in the exposure index analysis by both MACCS2-based and CALMET based methods. Development of these data is discussed in NRC (2007). Table 1 shows the population for the 50-mile radius around the Pilgrim Station. Column 3 of Table 1 shows the population for each of the 16 wind direction sectors and column 4 shows the percentage of the total population within each of the 16 different wind direction sectors. The next five columns list population data for 80 polar grid elements composed of five ten-mile intervals (0-10 miles, 10 miles to 20 miles, 20 miles to 30 miles, 30 miles to 40 miles, and 40 miles to 50 miles) and 16 radial sectors of 22.5° width center in each of the principal compass directions (N, NNE, NE, ENE, E, ESE, SE, SSE, S, SSW, SW, WSW, W, WNW, NW, and NNW). The last column gives the 20 – 50 mile population by sector. Summary statistics are given in the last row of Table 1 showing the percentage of population by 10-mile increment from 0 to 50 miles of the total population of 7,490,644.

MACCS2-Based Calculation of Exposure Index

Table 2 shows the MACCS2-based wind rose and resulting exposure index calculation. The first three columns contain the same index, polar direction, and total population by sector as Table 1. The fourth column shows the MACCS2 wind rose as processed by the code after reading in 8,760 hours of Pilgrim site-specific weather data including wind direction. The code bins all of these hourly data into weather types, or categories for subsequent calculation of SAMA consequences. The MACCS2 model also processes all input data from 8,760 hourly records into a set of annual wind direction frequencies, shown in the fourth column, and is based on Pilgrim data for the 2001 calendar year. The fifth through ninth column contain the EI product of the wind rose (fourth column) for that sector and the population for the grid element, for that direction sector and that interval. For example, the fifth column lists the EI calculation for the 0 to 10-mile interval beginning with the N sector. The population of that sector and interval (Table 1) is 0 and this is multiplied by the wind rose for this sector and interval, which is 0.088. The product is $0 \times 0.088 = 0.0$. The process continues for each of 16 direction sectors for the 0 to 10-mile interval and the outcome listed in the fifth column. The sum for this column is 6,263 persons. The process continues for the next four intervals of 10 to 20 miles (sixth column), 20 to 30 miles (seventh column), 30 to 40 miles (eighth column), and 40 to 50 miles (ninth column). The corresponding interval sums by interval are: 22,516 (10-20 miles), 66,220 (20-30 miles), 120,502 (30-40 miles), and 66,927 (40-50 miles). The total EI for the MACCS2-based calculation is 282,429, with percentages of the five intervals shown in the last line of Table 2.

CALMET-Based Calculation of Exposure Index

Two sets of CALMET data were used to obtain two separate calculations of the EI based, i.e., one specific to the 500-m elevation and another specific to the 100-m elevation. Tables 3 and 4 show the information used in the trajectory rose input data processing and subsequent output for the EI analysis specific to the 500-m elevation. Tables 5 and 6 show the information used in the trajectory rose input data processing and subsequent output for the EI analysis specific to the 100-m elevation. The basis calculation performed again uses Eqn. 1, with the exception of the trajectory rose term being substituted for the wind rose term for interval *i*, and sector *j*.

a. CALMET-based Exposure Index at 500 m

The CALMET-based calculation of the exposure index uses the same population distribution (Table 1) as does the MACCS2-based EI analysis but incorporates additional, finer resolution measures of wind directions provided by the trajectory roses. Before applying the CALMET trajectory roses to the five-interval, 16-sector population grid an averaging process is used. CALMET trajectory roses are averaged for the 10-mile interval in question as follows:

- 0 – 10 mile interval: wind trajectories at 1 mile, 2 miles, 3 miles, 4 miles, 5 miles, 6 miles, 7 miles, 8 miles, 9 miles, and 10 miles (The 0 to 10 mile range is the only one where trajectory roses are available every 1-mile increment).
- 10 – 20 mile interval: wind trajectories at 10 miles and 20 miles
- 20 – 30 mile interval; wind trajectories at 20 miles and 30 miles
- 30 – 40 mile interval; wind trajectories at 30 miles and 40 miles; and
- 40 – 50 mile interval; wind trajectories at 40 miles and 50 miles.

The first set of CALMET trajectory rose data are for the 500-m elevation and are taken from Appendix E of Hanna and Hendrick (2010). The data for 1 mile, 2 miles, 3 miles, 4 miles, 5 miles, 6 miles, 7 miles, 8 miles, 9 miles, and 10 miles are listed by direction in Table 3. The 0 to 10 mile interval average by direction is shown in the row with the label, “0-10 ave.” For example, the ten entries under the North direction are summed and divided by 10 to yield the 0 – 10 mile interval average of 0.1156. Other direction averages for this interval follow from NNE through NNW.

The 10 - 20 mile interval averages are then computed by averaging the trajectory roses at 10 miles and 20 miles. For example, for the North direction, the 10-mile and 20-mile trajectory roses are 0.1173 and 0.1179, respectively are averaged to obtain the value of 0.1176. Other values for this same interval are calculated in the same manner for each direction and the results are listed in the row “10-20 ave.”. The same process is repeated for the 20- and 30-mile, the 30- and 40-mile, and 40- and 50-mile trajectory roses to obtain trajectory rose interval averages for the 20 – 30 mile, 30 – 40 mile, and 40 – 50 miles intervals, that are listed in rows with the labels of “20-30 ave.”, “30-40 ave.” and “40-50 ave.”, respectively.

The five rows of direction-specific, ten-mile interval average trajectory rose data (“0-10 ave.”, “10-20 ave.”, “20-30 ave.”, “30-40 ave.” and “40-50 ave.”) are carried forward into the following table (Table 4) as the fourth column (CALMET average of 1-, 2-, 3-, 4-, 5-, 6-, 7-, 8-, 9-, and 10-mile trajectory roses), sixth column (CALMET average of 10-mile and 20-mile trajectory rose), eighth column (CALMET average of 20-mile and 30-mile trajectory rose), tenth column (CALMET average of 30-mile and 40-mile trajectory rose), and twelfth column (CALMET average of 40-mile and 50-mile trajectory rose) for calculation of the exposure index based on the 500-m elevation CALMET trajectory rose data. The same Equation 1 product of trajectory rose (for that sector and interval) and population from Table 1 (for the same sector and interval) was taken for the CALMET case as was performed for the MACCS2 wind rose by ten-mile interval for the following intervals: 1.) 0 to 10 miles Population Exposure Index (fifth column), 10 miles to 20 miles Population Exposure Index (seventh column), 20 miles to 30 miles Population Exposure Index (ninth column), 30 miles to 40 miles Population Exposure Index, and thirteenth column (40 miles to 50 miles Population Exposure Index). For example, for the North direction in the 40- to 50-mile interval, the trajectory rose is 0.1123 and the population from Table 1 is 80,474, with the product then being $0.1123 \times 80,474 = 9,033$. This process is completed for all 16 directions for each ten-mile interval.

The final exposure indices by ten-mile interval are listed in the Total Exposure Index row in Table 4 and are:

0 – 10 miles EI:	6,433
10 – 20 miles EI:	24, 230
20 – 30 miles EI:	64,871
30 – 40 miles EI:	123,038
40 – 50 miles EI:	73,016.

The total EI based on the CALMET trajectory roses is the sum of these five interval EIs and is equal to 291,589. This is larger by the MACCS2-based EI (282,429) by 3.24%. This ratio is shown at the bottom of Table 4 as well as the (CALMET EI)/(MACCS2 EI) ratio by ten-mile intervals, and are shown in the row with the label, “CALMET/MACCS2 Ratio for Interval”.

b. CALMET-based Exposure Index at 100 m

The second set of CALMET trajectory rose data are for the 100-m elevation and are taken from Appendix C of Hanna and Hendrick (2010). The data for 1 mile, 2 miles, 3 miles, 4 miles, 5 miles, 6 miles, 7 miles, 8 miles, 9 miles, and 10 miles are listed by direction in Table 5. The 0 to 10 mile interval average by direction is shown in the row with the label, “0-10 ave.”. For example, the ten entries under the North direction are summed and divided by 10 to yield the 0 – 10 mile interval average of 0.0922. Other direction averages for this interval follow from NNE through NNW.

The 10 - 20 mile interval averages are then computed by averaging the trajectory roses at 10 miles and 20 miles. For example, for the North direction, the 10-mile and 20-mile trajectory roses are 0.0941 and 0.0869, respectively are averaged to obtain the value of 0.0905. Other values for this same interval are calculated in the same manner for each direction and the results are listed in the row “10-20 ave.”. The same process is repeated for the 20- and 30-mile, the 30- and 40-mile, and 40- and 50-mile trajectory roses to obtain trajectory rose interval averages for the 20 – 30 mile, 30 – 40 mile, and 40 – 50 miles intervals, that are listed in rows with the labels of “20-30 ave.”, “30-40 ave.” and “40-50 ave.”, respectively.

The five rows of direction-specific, ten-mile interval average trajectory rose data (“0-10 ave.”, “10-20 ave.”, “20-30 ave.”, “30-40 ave.” and “40-50 ave.”) are carried forward into the following table (Table 6) as the fourth column (CALMET average of 1-, 2-, 3-, 4-, 5-, 6-, 7-, 8-, 9-, and 10-mile trajectory roses), sixth column (CALMET average of 10-mile and 20-mile trajectory rose), eighth column (CALMET average of 20-mile and 30-mile trajectory rose), tenth column (CALMET average of 30-mile and 40-mile trajectory rose), and twelfth column (CALMET average of 40-mile and 50-mile trajectory rose) for calculation of the exposure index based on the 500-m elevation CALMET trajectory rose data. The same Equation 1 product of trajectory rose (for that sector and interval) and population from Table 1 (for the same sector and interval) was calculated for the CALMET 100-m elevation case as was performed for the CALMET 500-m trajectory rose by ten-mile interval for the following intervals: 1.) 0 to 10 miles Population Exposure Index (fifth column), 10 miles to 20 miles Population Exposure Index (seventh column), 20 miles to 30 miles Population Exposure Index (ninth column), 30 miles to 40 miles Population Exposure Index, and thirteenth column (40 miles to 50 miles Population Exposure Index). For example, for the North direction in

the 40- to 50-mile interval, the trajectory rose is 0.0907 and the population from Table 1 is 80,474, with the product then being $0.0907 \times 80,474 = 7,299$. This process is completed for all 16 directions for each ten-mile interval. The final exposure indices by ten-mile interval are listed in the Total Exposure Index row in Table 6 and are:

0 – 10 miles EI:	6,698
10 – 20 miles EI:	25,567
20 – 30 miles EI:	69,530
30 – 40 miles EI:	139,719
40 – 50 miles EI:	79,883.

The total EI based on the CALMET trajectory roses is the sum of these five interval EIs and is equal to 321,396. This is larger by the MACCS2-based EI (282,429) by 13.80%. This ratio is shown at the bottom of Table 6 as well as the (CALMET EI)/(MACCS2 EI) ratio by ten-mile intervals, and are shown in the row with the label, “CALMET/MACCS2 Ratio for Interval”.

Results

Using the same population distribution for the fifty-mile spatial domain around the Pilgrim Station in each case, the total EI is calculated using the MACCS2-based wind rose, the CALMET-based 500 m trajectory roses, and the CALMET-based 100 m trajectory roses. The MACCS2-based EI is calculated to be 282,429. The total EI based on the CALMET trajectory roses for the 500-m elevation is equal to 291,589, or larger than the MACCS2-based EI by 3.24%. The total EI based on the CALMET trajectory roses for the 100-m elevation is equal to 321,396, or larger than the MACCS2-based EI (282,429) by 13.80%.

While neither MACCS2 to CALMET difference is large, the 500-m elevation results provided by CALMET are judged to be a better comparison over those calculated for the 100-m elevation, also with CALMET. This is because most atmospheric plumes released from the Pilgrim station will mix vertically as they move downwind and generally will extend to the full mixing layer height after twenty miles of travel downwind where most of the population is found in the 50-mile domain around the Pilgrim site. Thus, the CALMET 500 m result is more appropriate as a mid-plume height basis than 100-m basis elevation for the trajectory roses.

Table 1. Population Distribution Used in the Pilgrim SAMA Analysis

Index	Direction	Total Population by Sector	Sector Population as Percentage of Total	0 to 10 mile Population	10 miles to 20 mile	20 miles to 30 miles	30 miles to 40 miles	40 miles to 50 miles	20 to 50 mile Population
1	N	80,474	1.07%	0	0	0	0	80,474	80,474
2	NNE	3	0.00%	3	0	0	0	0	0
3	NE	3	0.00%	3	0	0	0	0	0
4	ENE	33,124	0.44%	3	0	33,121	0	0	33,121
5	E	56,311	0.75%	5	0	33,121	23,185	0	56,306
6	ESE	142,445	1.90%	23	0	49,682	92,740	0	142,422
7	SE	149,996	2.00%	950	9,936	115,925	23,185	0	139,110
8	SSE	165,647	2.21%	13,289	69,555	82,803	0	0	82,803
9	S	383,324	5.12%	23,695	99,364	132,485	84,383	43,397	260,265
10	SSW	142,037	1.90%	23,695	49,762	23,696	23,185	21,699	68,580
11	SW	836,194	11.16%	23,695	71,088	277,374	349,491	114,546	741,411
12	WSW	904,685	12.08%	23,695	71,088	277,374	349,491	183,037	809,902
13	W	1,046,851	13.98%	23,695	71,088	277,374	388,324	286,370	952,068
14	WNW	899,663	12.01%	16,494	71,088	118,481	303,450	390,150	812,081
15	NW	2,212,205	29.53%	11,269	71,088	195,075	1,529,212	405,561	2,129,848
16	NNW	437,682	5.84%	5,599	35,544	43,350	31,295	321,894	396,539
Total Population		7,490,644	100.00%	166,113	619,601	1,659,861	3,197,941	1,847,128	6,704,930
		Percent of Total Population		2.22%	8.27%	22.16%	42.69%	24.66%	89.51%
		7,490,644					0 - 50 mile population	100.00%	

Table 2. MACCS2-Based Wind Rose and Exposure Index

Index	Direction	Total Population by Sector	MACCS2 Wind Rose	0 to 10 miles Population Exposure Index	10 miles to 20 miles Population Exposure Index	20 miles to 30 miles Population Exposure Index	30 miles to 40 miles Population Exposure Index	40 miles to 50 miles Population Exposure Index
1	N	80,474	0.088	0	0	0	0	7,082
2	NNE	3	0.161	0	0	0	0	0
3	NE	3	0.120	0	0	0	0	0
4	ENE	33,124	0.101	0	0	3,345	0	0
5	E	56,311	0.093	0	0	3,080	2,156	0
6	ESE	142,445	0.065	1	0	3,229	6,028	0
7	SE	149,996	0.045	43	447	5,217	1,043	0
8	SSE	165,647	0.031	412	2,156	2,567	0	0
9	S	383,324	0.037	877	3,676	4,902	3,122	1,606
10	SSW	142,037	0.052	1,232	2,588	1,232	1,206	1,128
11	SW	836,194	0.038	900	2,701	10,540	13,281	4,353
12	WSW	904,685	0.036	853	2,559	9,985	12,582	6,589
13	W	1,046,851	0.036	853	2,559	9,985	13,980	10,309
14	WNW	899,663	0.032	528	2,275	3,791	9,710	12,485
15	NW	2,212,205	0.037	417	2,630	7,218	56,581	15,006
16	NNW	437,682	0.026	146	924	1,127	814	8,369
Total Population		7,490,644						
Total Exposure Index		282,429	0.998	6,263	22,516	66,220	120,502	66,927
Percentage of Total Exposure Index				2.22%	7.97%	23.45%	42.67%	23.70%
								100.00%

Table 3. CALMET Trajectory Rose by Direction and Distance (Based on 500-m elevation)

Distance or Ave.	Trajectory Rose at Distance																
	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
1 mile	0.1143	0.1278	0.0898	0.0939	0.0929	0.0730	0.0586	0.0500	0.0524	0.0506	0.0377	0.0308	0.0204	0.0325	0.0341	0.0411	0.9999
2 miles	0.1148	0.1279	0.0893	0.0939	0.0924	0.0730	0.0585	0.0499	0.0526	0.0506	0.0377	0.0311	0.0202	0.0327	0.0345	0.0410	1.0001
3 miles	0.1146	0.1283	0.0891	0.0940	0.0922	0.0725	0.0586	0.0498	0.0525	0.0504	0.0381	0.0307	0.0206	0.0327	0.0346	0.0415	1.0002
4 miles	0.1147	0.1287	0.0890	0.0937	0.0923	0.0724	0.0581	0.0496	0.0529	0.0501	0.0381	0.0307	0.0211	0.0327	0.0341	0.0418	1.0000
5 miles	0.1152	0.1288	0.0893	0.0935	0.0919	0.0725	0.0574	0.0495	0.0530	0.0503	0.0378	0.0304	0.0212	0.0327	0.0343	0.0421	0.9999
6 miles	0.1159	0.1293	0.0892	0.0939	0.0917	0.0722	0.0566	0.0497	0.0536	0.0497	0.0379	0.0302	0.0210	0.0328	0.0351	0.0413	1.0001
7 miles	0.1161	0.1291	0.0900	0.0934	0.0915	0.0721	0.0562	0.0499	0.0536	0.0491	0.0380	0.0302	0.0212	0.0329	0.0352	0.0416	1.0001
8 miles	0.1167	0.1293	0.0897	0.0932	0.0911	0.0720	0.0561	0.0498	0.0533	0.0496	0.0385	0.0295	0.0209	0.0329	0.0357	0.0418	1.0001
9 miles	0.1165	0.1297	0.0898	0.0929	0.0918	0.0718	0.0562	0.0491	0.0531	0.0491	0.0381	0.0295	0.0214	0.0328	0.0360	0.0423	1.0001
10 miles	0.1173	0.1301	0.0892	0.0926	0.0919	0.0718	0.0569	0.0485	0.0528	0.0484	0.0379	0.0297	0.0212	0.0333	0.0361	0.0421	0.9998
0-10 ave.	0.1156	0.1289	0.0894	0.0935	0.0920	0.0723	0.0573	0.0496	0.0530	0.0498	0.0380	0.0303	0.0209	0.0328	0.0350	0.0417	
10 miles	0.1173	0.1301	0.0892	0.0926	0.0919	0.0718	0.0569	0.0485	0.0528	0.0484	0.0379	0.0297	0.0212	0.0333	0.0361	0.0421	0.9998
20 miles	0.1179	0.1337	0.0891	0.0921	0.0919	0.0694	0.0557	0.0484	0.0499	0.0481	0.0321	0.0288	0.0219	0.0333	0.0418	0.0458	0.9999
10-20 ave.	0.1176	0.1319	0.0892	0.0924	0.0919	0.0706	0.0563	0.0485	0.0514	0.0483	0.0350	0.0293	0.0216	0.0333	0.0390	0.0440	
20 miles	0.1179	0.1337	0.0891	0.0921	0.0919	0.0694	0.0557	0.0484	0.0499	0.0481	0.0321	0.0288	0.0219	0.0333	0.0418	0.0458	0.9999
30 miles	0.1167	0.1341	0.0929	0.0908	0.0883	0.0666	0.0585	0.0489	0.0507	0.0466	0.0319	0.0266	0.0225	0.0338	0.0436	0.0476	1.0001
20-30 ave.	0.1173	0.1339	0.0910	0.0915	0.0901	0.0680	0.0571	0.0487	0.0503	0.0474	0.0320	0.0277	0.0222	0.0336	0.0427	0.0467	
30 miles	0.1167	0.1341	0.0929	0.0908	0.0883	0.0666	0.0585	0.0489	0.0507	0.0466	0.0319	0.0266	0.0225	0.0338	0.0436	0.0476	1.0001
40 miles	0.1146	0.1307	0.0932	0.0908	0.0897	0.0668	0.0609	0.0498	0.0520	0.0465	0.0324	0.0236	0.0225	0.0353	0.0444	0.0468	1.0000
30-40 ave.	0.1157	0.1324	0.0931	0.0908	0.0890	0.0667	0.0597	0.0494	0.0514	0.0466	0.0322	0.0251	0.0225	0.0346	0.0440	0.0472	
40 miles	0.1146	0.1307	0.0932	0.0908	0.0897	0.0668	0.0609	0.0498	0.0520	0.0465	0.0324	0.0236	0.0225	0.0353	0.0444	0.0468	1.0000
50 miles	0.1099	0.1369	0.0944	0.0903	0.0889	0.0666	0.0619	0.0508	0.0514	0.0481	0.0322	0.0226	0.0216	0.0357	0.0440	0.0445	0.9998
40-50 ave.	0.1123	0.1338	0.0938	0.0906	0.0893	0.0667	0.0614	0.0503	0.0517	0.0473	0.0323	0.0231	0.0221	0.0355	0.0442	0.0457	

Table 4. CALMET -Based Exposure Index (Based on 500-m elevation data)

Index	Direction	Total Population by Sector	CALMET average of 1-, 2-, 3-, 4-, 5-, 6-, 7-, 8-, 9-, and 10-mile trajectory roses	0 to 10 miles Population Exposure Index	CALMET average of 10-mile and 20-mile trajectory rose	10 miles to 20 miles Population Exposure Index	CALMET average of 20-mile and 30-mile trajectory rose	20 miles to 30 miles Population Exposure Index	CALMET average of 30-mile and 40-mile trajectory rose	30 miles to 40 miles Population Exposure Index	CALMET average of 40-mile and 50-mile trajectory rose	40 miles to 50 miles Population Exposure Index
1	N	80,474	0.1156	0	0.1176	0	0.1173	0	0.1157	0	0.1123	9,033
2	NNE	3	0.1289	0	0.1319	0	0.1339	0	0.1324	0	0.1338	0
3	NE	3	0.0894	0	0.0892	0	0.0910	0	0.0931	0	0.0938	0
4	ENE	33,124	0.0935	0	0.0924	0	0.0915	3,029	0.0908	0	0.0906	0
5	E	56,311	0.0920	0	0.0919	0	0.0901	2,984	0.0890	2,063	0.0893	0
6	ESE	142,445	0.0723	2	0.0706	0	0.0680	3,378	0.0667	6,186	0.0667	0
7	SE	149,996	0.0573	54	0.0563	559	0.0571	6,619	0.0597	1,384	0.0614	0
8	SSE	165,647	0.0496	659	0.0485	3,370	0.0487	4,028	0.0494	0	0.0503	0
9	S	383,324	0.0530	1,255	0.0514	5,102	0.0503	6,664	0.0514	4,333	0.0517	2,244
10	SSW	142,037	0.0498	1,180	0.0483	2,401	0.0474	1,122	0.0466	1,079	0.0473	1,026
11	SW	836,194	0.0380	900	0.0350	2,488	0.0320	8,876	0.0322	11,236	0.0323	3,700
12	WSW	904,685	0.0303	717	0.0293	2,079	0.0277	7,683	0.0251	8,772	0.0231	4,228
13	W	1,046,851	0.0209	496	0.0216	1,532	0.0222	6,158	0.0225	8,737	0.0221	6,314
14	WNW	899,663	0.0328	541	0.0333	2,367	0.0336	3,975	0.0346	10,484	0.0355	13,850
15	NW	2,212,205	0.0350	394	0.0390	2,769	0.0427	8,330	0.0440	67,285	0.0442	17,926
16	NNW	437,682	0.0417	233	0.0440	1,562	0.0467	2,024	0.0472	1,477	0.0457	14,694
		7,490,644										
Total Exposure Index		291,589	1.0000	6,433	0.9999	24,230	1.0000	64,871	1.0001	123,038	0.9999	73,016
MACCS2 EI (Table 2)		282,429		6,263		22,516		66,220		120,502		66,927
CALMET/MACCS2 Ratio for Interval				1.0271		1.0761		0.9796		1.0210		1.0910
(CALMET EI)/ (MACCS2 EI)		1.0324		3.24%								

Table 5. CALMET Trajectory Rose by Direction and Distance (Based on 100-m elevation)

Distance or Ave.	Trajectory Rose at Distance																
	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
1 mile	0.0900	0.1399	0.0940	0.0753	0.0847	0.0914	0.0570	0.0512	0.0493	0.0534	0.0373	0.0327	0.0290	0.0305	0.0453	0.0389	0.9999
2 miles	0.0906	0.1398	0.0941	0.0751	0.0847	0.0911	0.0568	0.0509	0.0492	0.0538	0.0372	0.0325	0.0290	0.0305	0.0453	0.0392	0.9998
3 miles	0.0906	0.1399	0.0944	0.0751	0.0847	0.0910	0.0565	0.0512	0.0489	0.0536	0.0372	0.0324	0.0287	0.0308	0.0455	0.0397	1.0002
4 miles	0.0907	0.1404	0.0940	0.0753	0.0847	0.0911	0.0565	0.0511	0.0488	0.0534	0.0373	0.0321	0.0291	0.0304	0.0451	0.0400	1.0000
5 miles	0.0919	0.1406	0.0939	0.0754	0.0845	0.0911	0.0560	0.0504	0.0493	0.0529	0.0373	0.0317	0.0288	0.0306	0.0458	0.0397	0.9999
6 miles	0.0929	0.1409	0.0942	0.0751	0.0847	0.0911	0.0557	0.0504	0.0481	0.0532	0.0372	0.0312	0.0288	0.0313	0.0457	0.0394	0.9999
7 miles	0.0935	0.1409	0.0944	0.0750	0.0846	0.0908	0.0556	0.0504	0.0477	0.0528	0.0379	0.0305	0.0291	0.0312	0.0463	0.0392	0.9999
8 miles	0.0940	0.1406	0.0949	0.0750	0.0842	0.0910	0.0555	0.0500	0.0474	0.0521	0.0376	0.0306	0.0296	0.0317	0.0464	0.0394	1.0000
9 miles	0.0940	0.1407	0.0948	0.0749	0.0843	0.0907	0.0555	0.0497	0.0475	0.0517	0.0372	0.0305	0.0296	0.0321	0.0461	0.0407	1.0000
10 miles	0.0941	0.1405	0.0944	0.0758	0.0841	0.0898	0.0556	0.0496	0.0479	0.0504	0.0369	0.0310	0.0296	0.0319	0.0468	0.0418	1.0002
0-10 ave.	0.0922	0.1404	0.0943	0.0752	0.0845	0.0909	0.0561	0.0505	0.0484	0.0527	0.0373	0.0315	0.0291	0.0311	0.0458	0.0398	
10 miles	0.0941	0.1405	0.0944	0.0758	0.0841	0.0898	0.0556	0.0496	0.0479	0.0504	0.0369	0.031	0.0296	0.0319	0.0468	0.0418	1.0002
20 miles	0.0869	0.1357	0.0949	0.0794	0.0838	0.0842	0.0541	0.0507	0.0479	0.0522	0.0323	0.0337	0.0267	0.0311	0.0519	0.0546	1.0001
10-20 ave.	0.0905	0.1381	0.0947	0.0776	0.0840	0.0870	0.0549	0.0502	0.0479	0.0513	0.0346	0.0324	0.0282	0.0315	0.0494	0.0482	
20 miles	0.0869	0.1357	0.0949	0.0794	0.0838	0.0842	0.0541	0.0507	0.0479	0.0522	0.0323	0.0337	0.0267	0.0311	0.0519	0.0546	1.0001
30 miles	0.0850	0.1307	0.0966	0.0790	0.0834	0.0785	0.0533	0.0563	0.0484	0.0525	0.0336	0.0282	0.0272	0.0340	0.0536	0.0596	0.9999
20-30 ave.	0.0860	0.1332	0.0958	0.0792	0.0836	0.0814	0.0537	0.0535	0.0482	0.0524	0.0330	0.0310	0.0270	0.0326	0.0528	0.0571	
30 miles	0.0850	0.1307	0.0966	0.0790	0.0834	0.0785	0.0533	0.0563	0.0484	0.0525	0.0336	0.0282	0.0272	0.0340	0.0536	0.0596	0.9999
40 miles	0.0893	0.1287	0.096	0.0815	0.0838	0.0731	0.0548	0.0598	0.0467	0.0529	0.0353	0.024	0.0259	0.0377	0.0511	0.0592	0.9998
30-40 ave.	0.0872	0.1297	0.0963	0.0803	0.0836	0.0758	0.0541	0.0581	0.0476	0.0527	0.0345	0.0261	0.0266	0.0359	0.0524	0.0594	
40 miles	0.0893	0.1287	0.096	0.0815	0.0838	0.0731	0.0548	0.0598	0.0467	0.0529	0.0353	0.024	0.0259	0.0377	0.0511	0.0592	0.9998
50 miles	0.0921	0.1279	0.0991	0.0822	0.0846	0.0707	0.0573	0.0582	0.0481	0.053	0.0338	0.0255	0.0233	0.0372	0.0519	0.0548	0.9997
40-50 ave.	0.0907	0.1283	0.09755	0.08185	0.0842	0.0719	0.05605	0.059	0.0474	0.05295	0.03455	0.02475	0.0246	0.03745	0.0515	0.0570	

Table 6. CALMET -Based Exposure Index (Based on 100-m elevation data)

Index	Direction	Total Population by Sector	CALMET average of 1-, 2-, 3-, 4-, 5-, 6-, 7-, 8-, 9-, and 10-mile trajectory rose	0 to 10 mile Population Exposure Index	CALMET average of 10-mile and 20-mile trajectory rose	10 miles to 20 mile Population Exposure Index	CALMET average of 20-mile and 30-mile trajectory rose	20 miles to 30 mile Population Exposure Index	CALMET average of 30-mile and 40-mile trajectory rose	30 miles to 40 miles Population Exposure Index	CALMET average of 40-mile and 50-mile trajectory rose	40 miles to 50 miles Population Exposure Index
1	N	80,474	0.0922	0	0.0905	0	0.0860	0	0.0872	0	0.0907	7,299
2	NNE	3	0.1404	0	0.1381	0	0.1332	0	0.1297	0	0.1283	0
3	NE	3	0.0943	0	0.0947	0	0.0958	0	0.0963	0	0.0976	0
4	ENE	33,124	0.0752	0	0.0776	0	0.0792	2,623	0.0803	0	0.0819	0
5	E	56,311	0.0845	0	0.0840	0	0.0836	2,769	0.0836	1,938	0.0842	0
6	ESE	142,445	0.0909	2	0.0870	0	0.0814	4,042	0.0758	7,030	0.0719	0
7	SE	149,996	0.0561	53	0.0549	545	0.0537	6,225	0.0541	1,253	0.0561	0
8	SSE	165,647	0.0505	671	0.0502	3,488	0.0535	4,430	0.0581	0	0.0590	0
9	S	383,324	0.0484	1,147	0.0479	4,760	0.0482	6,379	0.0476	4,012	0.0474	2,057
10	SSW	142,037	0.0527	1,249	0.0513	2,553	0.0524	1,240	0.0527	1,222	0.0530	1,149
11	SW	836,194	0.0373	884	0.0346	2,460	0.0330	9,139	0.0345	12,040	0.0346	3,958
12	WSW	904,685	0.0315	747	0.0324	2,300	0.0310	8,585	0.0261	9,122	0.0248	4,530
13	W	1,046,851	0.0291	690	0.0282	2,001	0.0270	7,475	0.0266	10,310	0.0246	7,045
14	WNW	899,663	0.0311	513	0.0315	2,239	0.0326	3,857	0.0359	10,879	0.0375	14,611
15	NW	2,212,205	0.0458	516	0.0494	3,508	0.0528	10,290	0.0524	80,054	0.0515	20,886
16	NNW	437,682	0.0398	223	0.0482	1,713	0.0571	2,475	0.0594	1,859	0.0570	18,348
		7,490,644										
Total Exposure Index		321,396	1.0000	6,698	1.0002	25,567	1.0000	69,530	0.9999	139,719	0.9998	79,883
MACCS2 EI (Table 2)		282,429		6,263		22,516		66,220		120,502		66,927
(CALMET EI)/(MACCS2 EI) Ratio for Interval				1.0693		1.1355		1.0500		1.1595		1.1936
(CALMET EI)/(MACCS2 EI)		1.1380		13.80%								

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