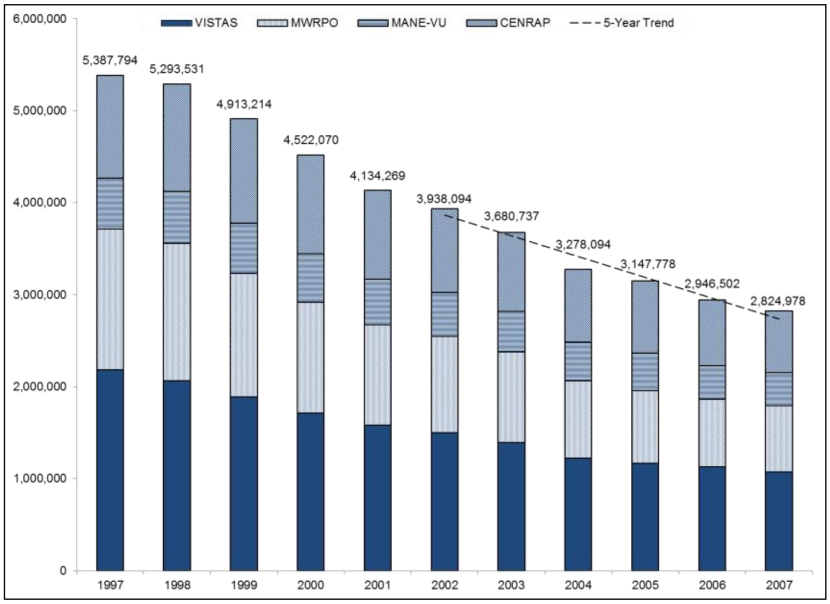
Contributions to Regional Haze in the Northeast and Mid-Atlantic United States:
Preliminary Update Through 2007

Mid-Atlantic/Northeast Visibility Union (MANE-VU) Updated Contribution Assessment

Prepared by Northeast States for Coordinated Air Use Management (NESCAUM)
for the Mid-Atlantic/Northeast Visibility Union (MANE-VU)



March 2012

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PRELIMINARY UPDATE THROUGH 2007

MID-ATLANTIC/NORTHEAST VISIBILITY UNION (MANE-VU) UPDATED CONTRIBUTION ASSESSMENT

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1. INTRODUCTION

NESCAUM performed preliminary analyses to assess the contribution from states and regions on the visibility impairment on Class I areas in the MANE-VU region. NESCAUM designed the analyses to serve as updates to those performed for the report, *Contribution to Regional Haze in the Northeast and Mid-Atlantic United States* (NESCAUM, 2006). In that report, NESCAUM used a suite of analysis tools to assess the absolute and relative contribution of states for the 2002 baseline year.

This report updates the earlier NESCAUM 2002 baseline analysis by providing an initial assessment of the contributions from states in 2007. We mainly use the methodologies of the previous assessment in this work, but note instances where our current methodologies differ. Section 2 presents the results of the updated analyses, and Section 3 compares results of the different methodologies used in this study with each other. Section 4 presents conclusions from these analyses.

2. SUPPORTING ANALYSES

The following subsections present the analyses that NESCAUM performed for this preliminary updated contribution assessment.

2.1. Haze-associated pollutant emissions

This section explores the origin and quantity of haze-forming pollutants emitted in the eastern United States. The pollutants that affect fine particle formation, and thus contribute to regional haze, are sulfur oxides (SO_x), nitrogen oxides (NO_x), volatile organic compounds (VOCs), ammonia (NH_3), and directly emitted particles with an aerodynamic diameter less than or equal to 10 and 2.5 μm (i.e., primary PM_{10} and $PM_{2.5}$). The data analyzed in this section for SO_x and NO_x emissions are from the Continuous Emissions Monitoring System (CEMS) database, available from the U.S. Environmental Protection Agency (USEPA) Clean Air Markets Division (CAMD), which provides hourly pollutant emissions data at regulated emissions sources (electric generating units, or EGUs, of 25 MW or more) (USEPA, 2011a). Also, we examined USEPA's National Emissions Inventory (NEI) to determine the contribution from different source types in each region.

Approximately 41 percent of the 4,951 units that reported emissions to CAMD in the period from 1997 through 2007 had inconsistent reporting, in that the units reported emissions for a different number of months from year to year.[1] Most of the units with differences in reporting (65 percent) had only one year during the 1997 to 2007 span with a reporting difference. We do not attempt to adjust emissions for these differences in reporting. To get a sense of the possible impacts if the reporting differences reflect unreported emissions (as opposed to actual shutdowns), we replaced emissions in years for which units appeared to have incomplete annual reporting with the maximum reported annual emissions for that unit between 1997 and 2007. This replacement increased the total NO_x emissions by less than 1.5 percent and SO_x emissions by less than 0.9 percent. Therefore, it appears that the reporting differences, even

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[1] This inconsistency encompasses all units in the CAMD database, not just units in the studied regions.

if actual omissions, have no discernible effect on the overall emission trends for purposes of these analyses.

Sulfur dioxide (SO_2)

Figure 2-1 shows the combined sulfur dioxide (SO_2) emissions per the CEMS database in four regional planning organizations (USEPA, 2011a): Central Regional Air Planning Association (CENRAP), MANE-VU, Midwest Regional Planning Organization (MWRPO), and Visibility Improvement State and Tribal Association of the Southeast (VISTAS). Overall emissions in the regions decreased from 1997 through 2002, increased slightly or remained steady between 2002 and 2005, and then continued to decrease from 2005 through 2007. Collectively, EGU SO_2 emissions dropped by ~13 percent in the combined regions between 2005 and 2007. The greatest relative decreases (~15 percent) occurred in the VISTAS and MWRPO regions; smaller reductions (8 to 10 percent) occurred in the CENRAP and MANE-VU regions. Regional trends during this period are presented more clearly in Figure 2-2. Figure 2-3 presents these emissions grouped by region on a state-by-state basis.

Figure 2-4 shows the percent contribution from different source categories to overall annual 2008 SO_2 emissions in states from the four regional planning organizations (USEPA, 2011b). The chart shows that point sources dominate SO_2 emissions, which primarily consist of stationary combustion sources for generating electricity, industrial energy, and heat. Smaller stationary combustion sources, identified as “nonpoint” sources (primarily commercial and residential heating), are another important source category in the MANE-VU states. On-road and non-road mobile sources make only a relatively small contribution to overall SO_2 emissions in all four regions.

Point sources are responsible for the overwhelming majority of SO_2 emissions in the regions included in this analysis. In the CENRAP, MANE-VU, MWRPO, and VISTAS states in 2008, point sources account for an average of 92 percent of all SO_2 emissions, or about 8.8 million tons of the 9.5 million tons in the inventory for the included states. Among the regions, point sources in the MANE-VU region have the lowest relative emissions contribution levels, about 82 percent, and nonpoint sources in MANE-VU have higher contributions (~17%) than in other regions (~7 percent average). Mobile sources are responsible for a relatively negligible portion of SO_2 emissions in all studied regions.

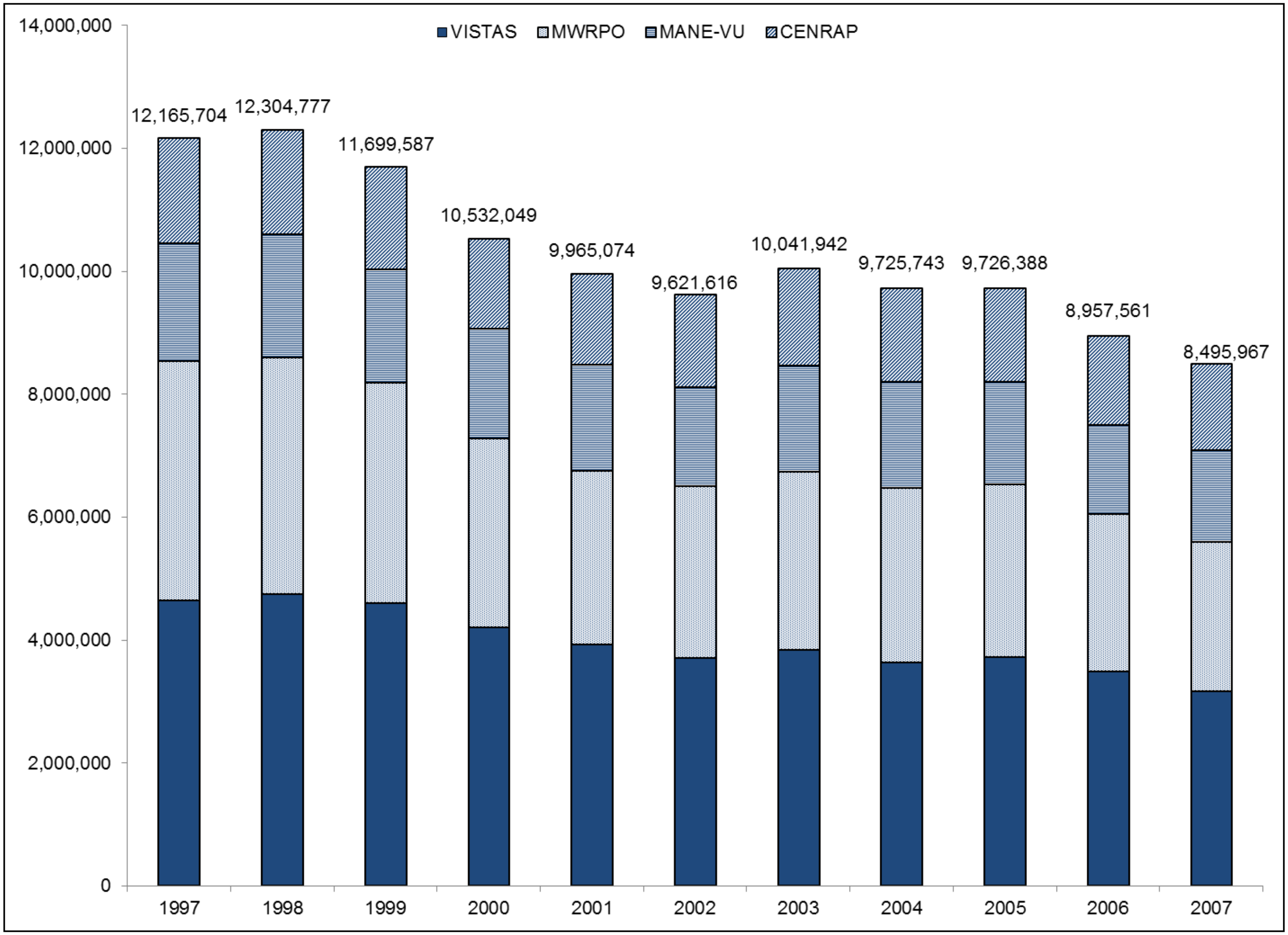
Oxides of nitrogen (NO_x)

Figure 2-5 shows emissions trends for NO_x in the CENRAP, MANE-VU, MWRPO, and VISTAS states per the CEMS database. Overall emissions in the regions decreased steadily between 1997 and 2007 (see the trend line in Figure 2-5). The decreases were approximately uniformly distributed to each of the four regions, declining approximately 30 percent over the five years. Figure 2-6 presents these emissions grouped by region on a state-by-state basis.

Figure 2-7 shows the percent contribution from different source categories to overall, annual 2008 NO_x emissions in the CENRAP, MANE-VU, MWRPO, and VISTAS states (USEPA, 2011b). The chart shows that mobile sources have overtaken stationary sources as the largest source sector of NO_x emissions in most states. Exceptions to this are the largest NO_x emitting states, where large stationary sources contribute significantly to overall NO_x emissions, notably in the CENRAP and MWRPO states, but also some states in MANE-VU and VISTAS, such as Alabama, Kentucky, Pennsylvania, and West Virginia.

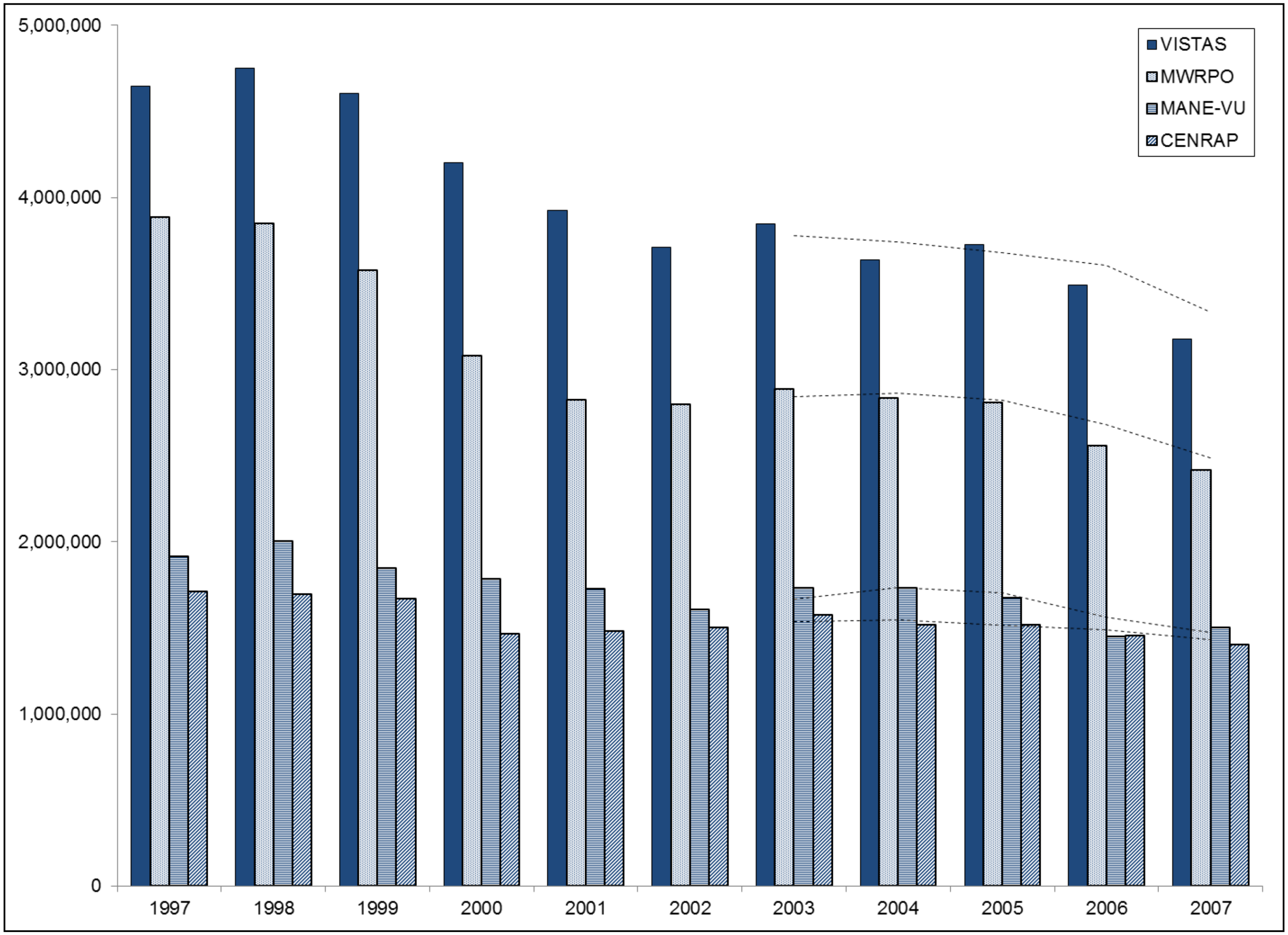
Power plants and mobile sources generally dominate state and regional NO_x emissions inventories. In the CENRAP, MANE-VU, MWRPO, and VISTAS regions in 2008, point sources account for 34 percent of all NO_x emissions, amounting to over four million tons. Point sources have the highest relative emissions compared to other source types in the MWRPO and VISTAS regions, where they account for 40 and 38 percent, respectively. On-road sources in the more urbanized mid-Atlantic and northeast states dominate to a far greater extent, as shown in Figure 2-7. In these states, on-road mobile sources—a category that mainly includes highway vehicles—represent the most significant NO_x source category. Nonpoint emissions make up another 20 percent of the inventory, and are highest (~29 percent) in the CENRAP region. Emissions from non-road (i.e., off-highway) mobile sources, primarily diesel engines, are the least significant source category in the regions, making up only ~12 percent of the inventory.

Figure 2-1. 1997-2007 power plant sulfur dioxide emissions by regional planning organization, stacked


VISTAS
MWRPO
MANE-VU
CENRAP
14,000,000
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
0
12,165,704
12,304,777
11,699,587
10,532,049
9,965,074
9,621,616
10,041,942
9,725,743
9,726,388
8,957,561
8,495,967
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007

Source: USEPA (2011a)

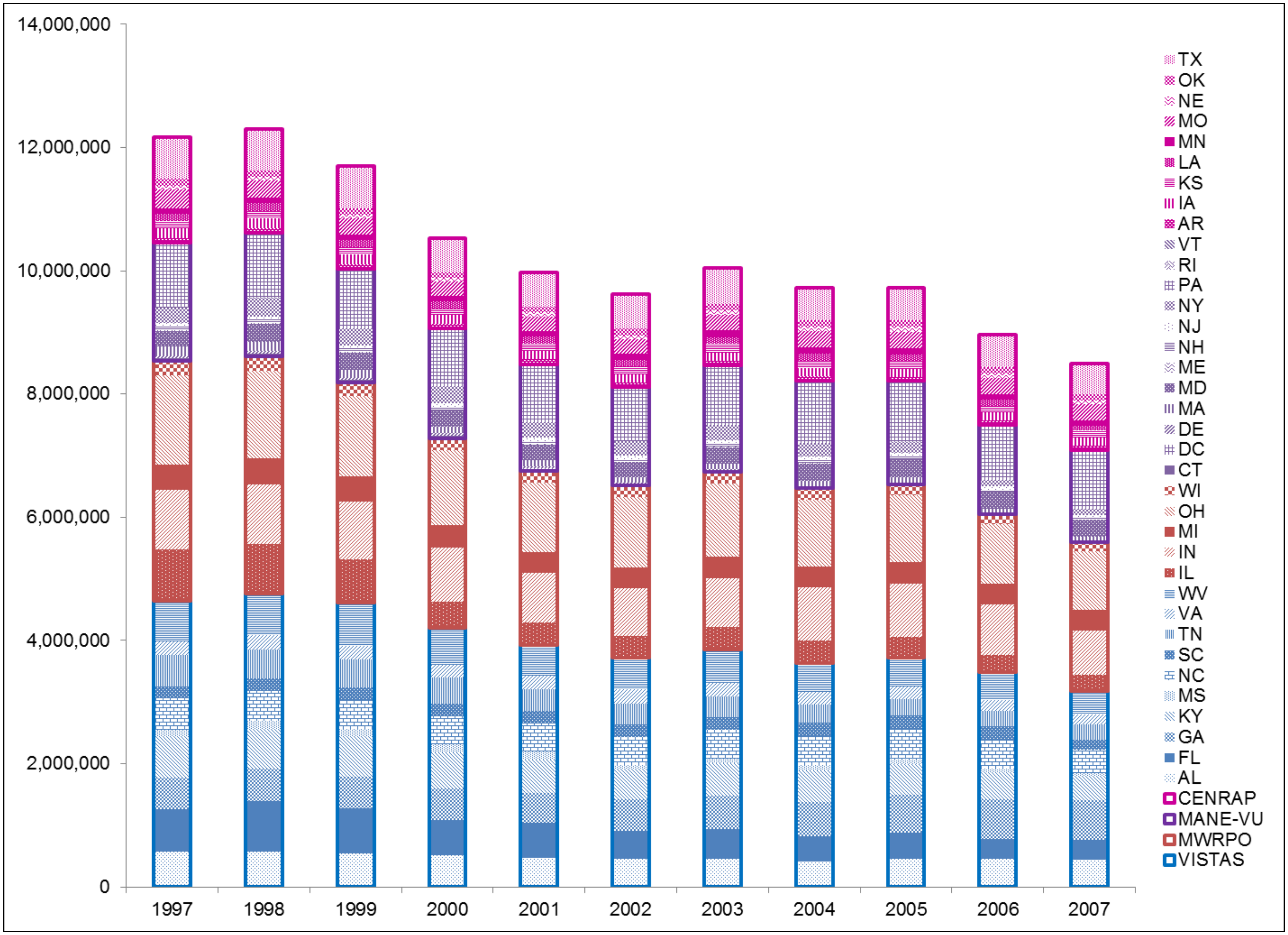
Figure 2-2. 1997-2007 power plant sulfur dioxide emissions and trends by regional planning organization, clustered


5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
0
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
VISTAS
MWRPO
MANE-VU
CENRAP

The bar chart presents aggregate emissions of SO_2 for each regional planning organization. Trend lines are 2-period moving annual averages using data from 2002 through 2007.

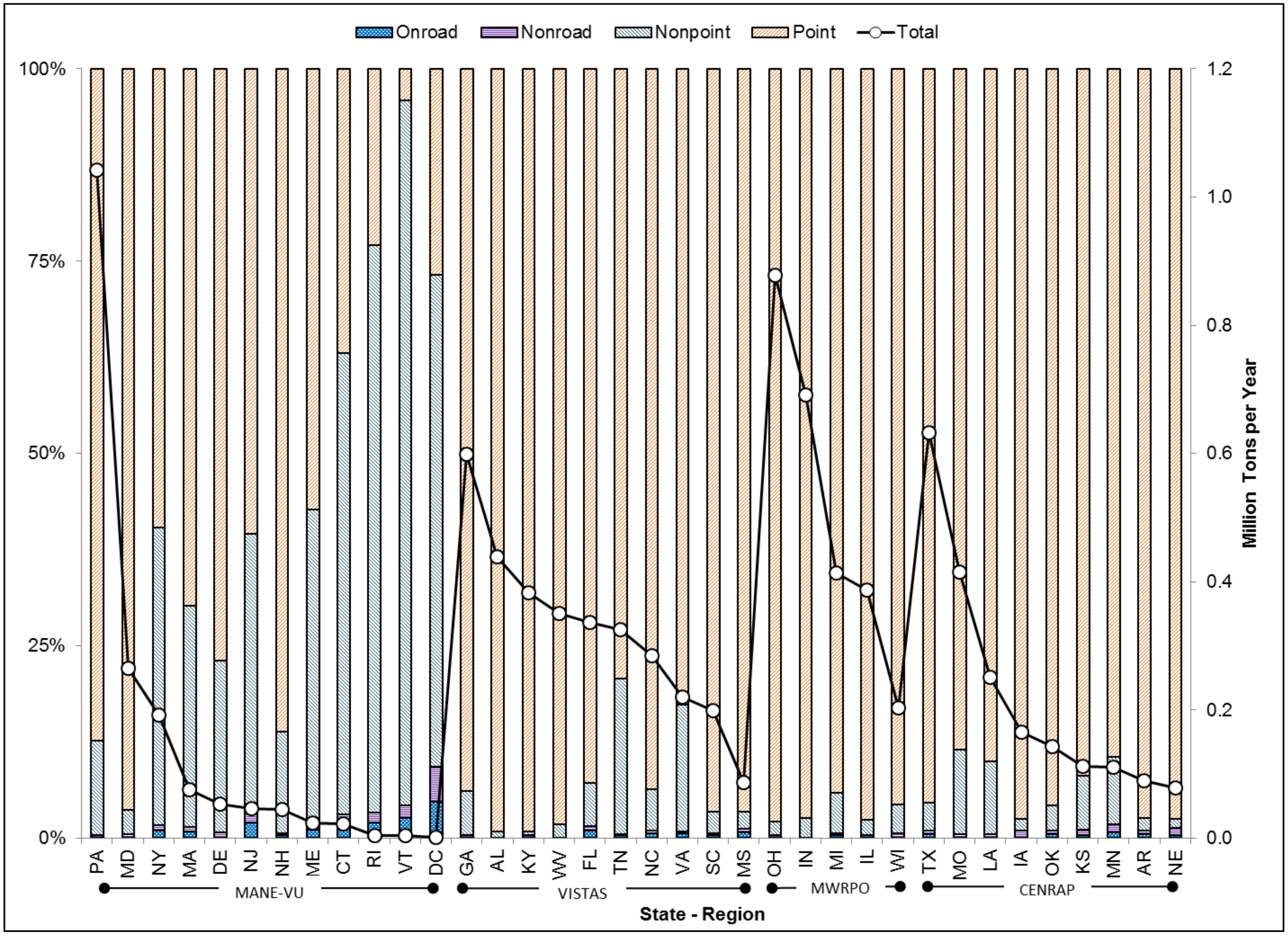
Source: USEPA (2011a)

Figure 2-3. 1997-2007 power plant sulfur dioxide emissions by regional planning organization and state, stacked



Source: USEPA (2011a)

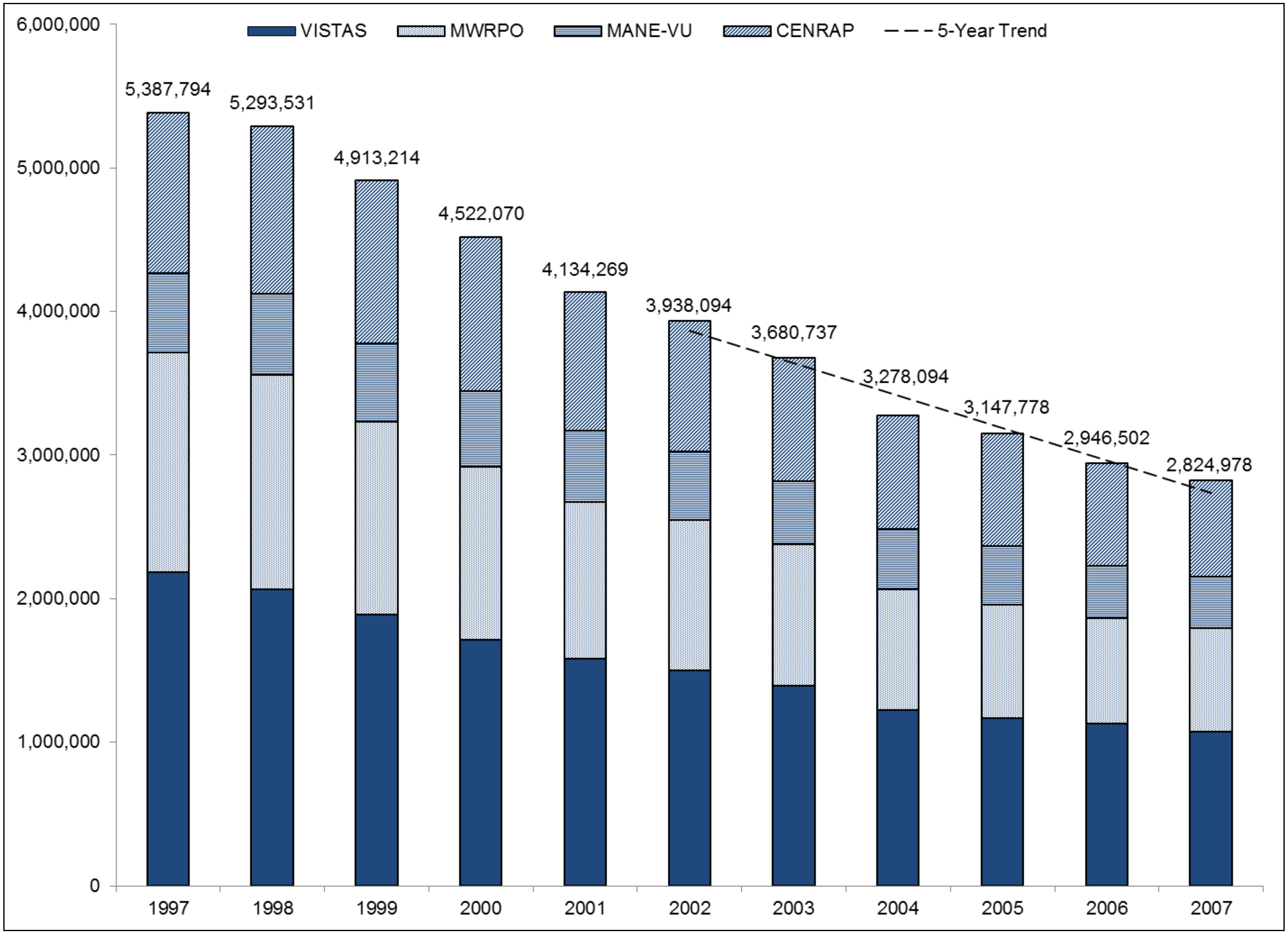
Figure 2-4. 2008 sulfur dioxide emissions by source sector and state


Onroad
Nonroad
Nonpoint
Point
Total
100%
75%
50%
25%
0%
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Million Tons per Year
PA
MD
NY
MA
DE
NJ
NH
ME
CT
RI
VT
DC
GA
AL
KY
WV
FL
TN
NC
VA
SC
MS
OH
IN
MI
IL
WI
TX
MO
LA
IA
OK
KS
MN
AR
NE
MANE-VU
VISTAS
MWRPO
CENRAP
State - Region

The bar chart presents relative contributions of SO_2 emissions by source type in percent for each state, and the circles connected by a line represents the annual SO_2 emissions in millions of tons for each state. States are grouped by regional planning organization and sorted from highest to lowest SO_2 emissions.

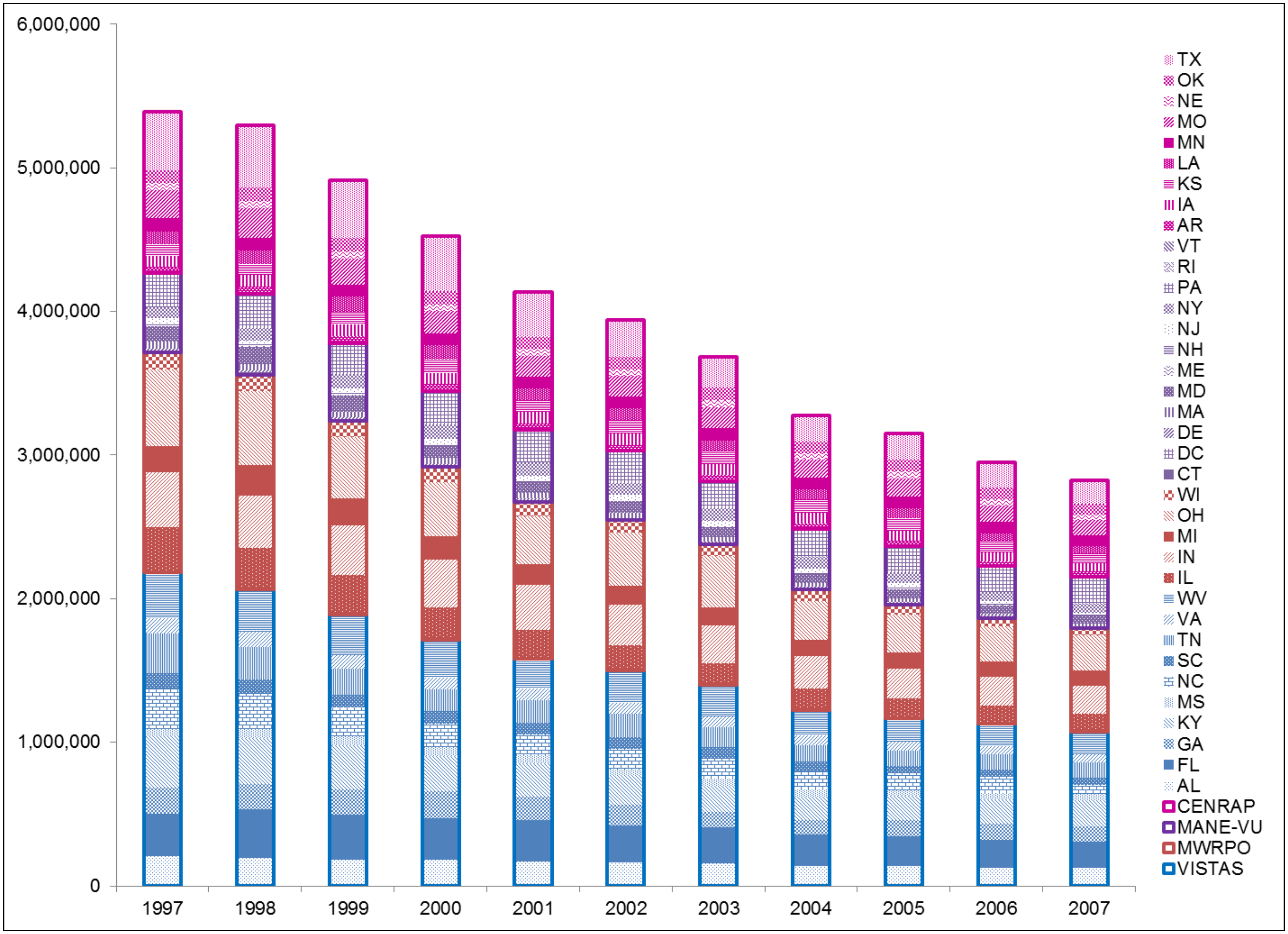
Source: USEPA (2011b)

Figure 2-5. 1997-2007 power plant oxides of nitrogen emissions and trends by regional planning organization, stacked



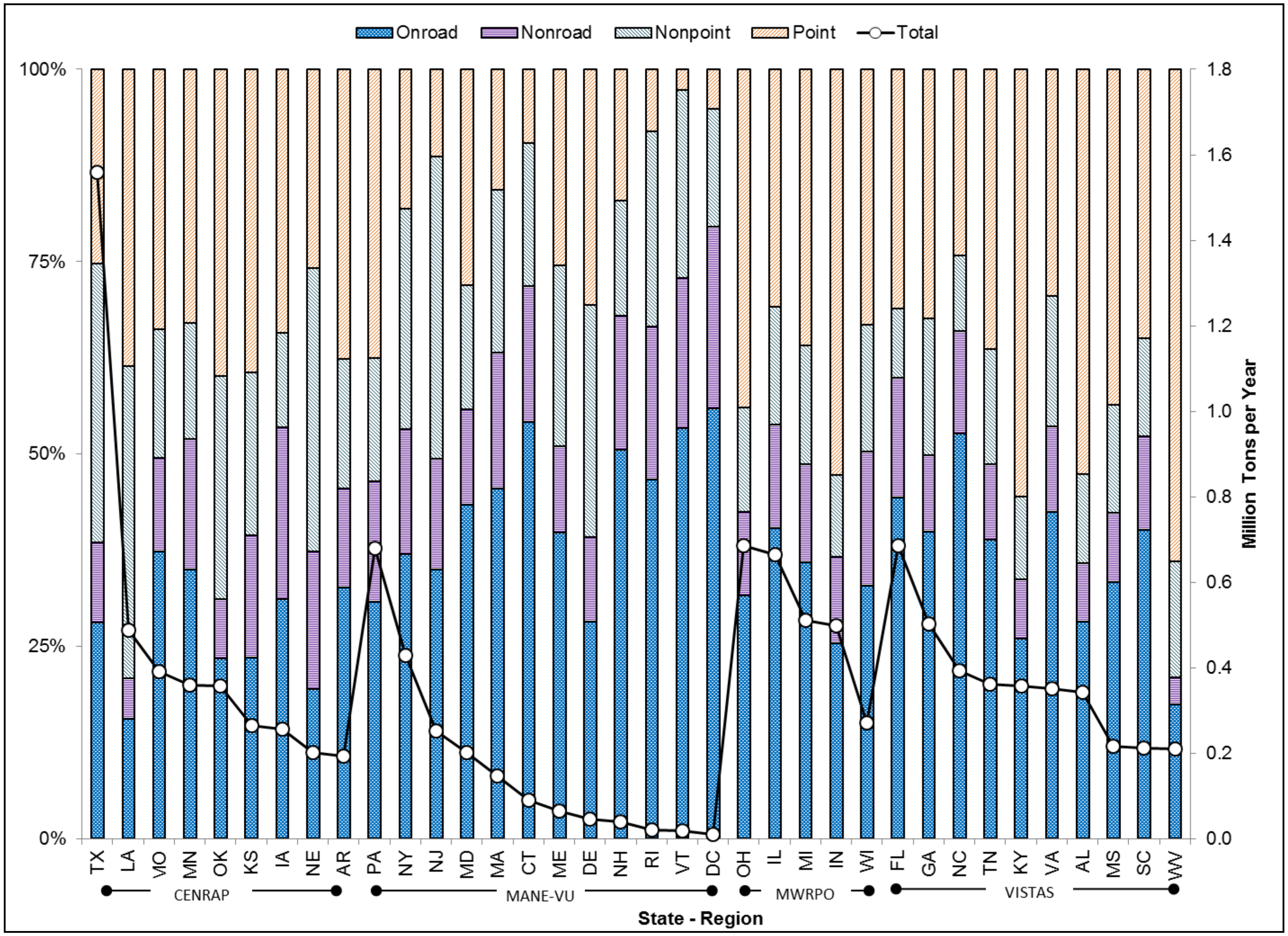
Source: USEPA (2011a)

Figure 2-6. 1997-2007 power plant oxides of nitrogen emissions by regional planning organization and state, stacked



Source: USEPA (2011a)

Figure 2-7. 2008 oxides of nitrogen emissions by source sector and state


Onroad
Nonroad
Nonpoint
Point
Total
100%
75%
50%
25%
0%
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Million Tons per Year
TX
LA
MO
MN
OK
KS
IA
NE
AR
PA
NY
NJ
MD
MA
CT
ME
DE
NH
RI
VT
DC
OH
IL
MI
IN
WI
FL
GA
NC
TN
KY
VA
AL
MS
SC
WV
CENRAP
MANE-VU
MWRPO
VISTAS
State - Region

The bar chart presents relative contributions of NO_x emissions by source type in percent for each state, and the circles connected by a line represents the annual NO_x emissions in millions of tons for each state. States are grouped by regional planning organization and sorted from highest to lowest NO_x emissions.
Source: USEPA (2011b)

2.2. Sulfur Dioxide Emissions Divided by Distance

This section provides methods and results for the emissions over distance (*Q/d*) approach. This approach is described in the original analysis (NESCAUM, 2006), but a brief summary of methods is presented here, with emphasis on deviations from the previous analysis.

The geographic domain of the sources included in the *Q/d* study consisted of states in four regional planning organizations: CENRAP, MANE-VU, MWRPO, and VISTAS. Emissions data were obtained from the USEPA's 2008 National Emissions Inventory (NEI), and consisted of point sources, nonpoint sources (or area sources), non-road sources, and on-road sources. Because regional 2007 emissions inventories were not yet available for the MANE-VU or other U.S. regions, NESCAUM used data from the 2008 NEI as a reasonable approximation. We also included data from the eastern Canadian provinces: New Brunswick, Newfoundland and Labrador, Nova Scotia, Ontario, Prince Edward Island, and Quebec. NESCAUM obtained Canadian emissions from Environment Canada's National Pollutant Release Inventory (NPRI): 2007 for point sources; and 2009 for area, non-road mobile, and on-road mobile sources, since those sources were only available at a province level for 2009.

The previous analysis only included emissions from 52 point sources from Canada, whereas this analysis includes nearly 400 such sources, which accounts for the large discrepancy in emissions from Canada between this and the previous analysis. Because of the incompleteness of the SO_2 inventory for Canada in the previous analysis, results for CALPUFF are likely underestimated (NESCAUM, 2006).

Results were calculated for seven receptors: Acadia National Park, Brigantine Wilderness Area in the Forsythe National Wildlife Refuge, Dolly Sods Wilderness Area, Great Gulf Wilderness Area, Lye Brook Wilderness Area, Moosehorn Wilderness Area, and Shenandoah National Park.

The empirical formula that relates emission source strength and estimated impact is expressed through the following equation:

$$I = C_i \left(Q / d \right)$$

In this equation, the strength of an emission source, *Q*, is linearly related to the impact, *I*, that it will have on a receptor located a distance, *d*, away. As in the previous analysis, distances were computed using the Haversine function, using an earth radius of 6371 km.[2] The effect of meteorological prevailing winds can be factored into this approach by establishing the constant, C_i, as a function of the "wind direction sectors" relative to the receptor site. By establishing a different constant for each wind direction sector, based on prior modeling results—in this case, CALPUFF results—we are in effect "scaling" *Q/d* results by CALPUFF-calculated source impacts. The absolute impacts produced are then dependent on the CALPUFF results. The relative contributions, however, of each source within a wind direction sector is established completely independent of the CALPUFF calculation, yielding a quasi-independent method of apportionment to add to our weight-of-evidence approach.

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[2] The Haversine function is an algorithm to calculate the distance between two points along the surface of a perfect sphere. It is discussed in greater detail in the previous report (NESCAUM, 2006).

The same values for C_i as were used in the previous analysis were used in this analysis. Therefore, this analysis essentially uses 2002 meteorology and conditions to process the 2007 estimated emissions. By using wind vector factors derived from 2002 meteorology, we have a common set of conditions to compare potential changes in relative contributions among upwind states between 2002 and 2007 looking at changes in emissions alone. The C_i constants are presented in Appendix A.

As with the previous analysis, to calculate the impact that each state had on a given receptor, we summed the area and mobile source SO_2 emissions across the entire state, and calculated the distance to the receptor site for those emission sources based on that state's geographic center, adjusted for population density. Population centers were not available for Canadian provinces, so we used the coordinates of the highest population city or region for each province instead.[3] U.S. state population centers for 2010 were obtained from the U.S. Census Bureau (2011). In this way, we treated the area source emissions as a single point source located at the population-weighted center of each state. We then added these impacts to those from individually-calculated point sources.

States that contribute to any MANE-VU receptor above 0.10 $\mu g/m^3$ are: Georgia, Indiana, Kentucky, Maryland, North Carolina, Ohio, Pennsylvania, Virginia, and West Virginia. Canada in the aggregate also contributes above this level. Table 2-1 shows the relative contribution of eastern states and Canadian provinces on several receptor sites in the region. Figure 2-8 and Figure 2-9 show the corresponding *Q/d* rankings across a set of Northeast and Mid-Atlantic Class I areas in or near the MANE-VU region.

Acadia, Great Gulf, Lye Brook, and Moosehorn had the greatest impacts from states in MANE-VU and MWRPO, followed by VISTAS. Canada had a large impact at Acadia. The Brigantine, Dolly Sods, and Shenandoah Class I areas were most affected by MANE-VU and VISTAS sources, followed by MWRPO. Canadian sources had a much smaller impact at these Class I areas. Certain states had high impacts at multiple Class I areas. Pennsylvania had the highest total emissions, and the highest impacts of any U.S. state at all seven studied Class I areas. Ohio and Indiana had the second and third highest impacts of any U.S. state at Acadia, Great Gulf, and Moosehorn, as well as having high impacts at other areas.

Table 2-2 presents the differences by state of projected impacts between the current analysis and the previous analysis. For most states, the direction of the change in emissions correlates well with the direction of the change in impacts. There are a few states whose impacts increased despite lower emissions (Louisiana and Iowa, notably). Conversely, there are two states (Maryland and Pennsylvania) whose impacts decreased despite higher emissions. Changes in the geographic locations of emissions within these states may account for these discrepancies. The largest decreases in impacts, according to this analysis, were attributable to Illinois, Indiana, Kentucky, Massachusetts, New Jersey, New York, North Carolina, Ohio, Virginia, West Virginia, and Canada. Taken in aggregate, Table 2-2 shows an overall decrease in impacts in 2007/2008 relative to 2002 at receptor sites due to large emission reductions in contributing sources.

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[3] For area and mobile sources, NESCAUM used the geographic coordinates of Moncton for New Brunswick, St. John's for Newfoundland and Labrador, Halifax for Nova Scotia, Toronto for Ontario, Charlottetown for Prince Edward Island, and Montreal for Quebec.

Table 2-1. 2008 SO_2 CALPUFF-scaled emissions over distance impacts ($\mu g/m^3$) at Northeast and Mid-Atlantic Class I areas

State	Acadia[1]	Brigantine[1]	Dolly Sods[1]	Great Gulf[1]	Lye Brook[1]	Moosehorn[1]	Shenandoah[1]	Emissions[2,3] (short tons)
Pennsylvania	**0.18**	**0.40**	**0.50**	**0.15**	**0.29**	**0.16**	**0.42**	1,042,759
Ohio	**0.13**	**0.19**	**0.43**	**0.12**	**0.16**	**0.11**	**0.32**	878,456
Indiana	0.08	**0.11**	**0.15**	0.07	0.08	0.08	**0.12**	690,816
Texas	0.04	0.05	0.05	0.03	0.04	0.03	0.05	632,990
Georgia	0.06	0.09	**0.10**	0.04	0.06	0.04	**0.10**	598,846
Alabama	0.03	0.05	0.06	0.02	0.04	0.02	0.06	438,922
Missouri	0.04	0.05	0.05	0.03	0.04	0.04	0.05	415,203
Michigan	0.07	0.06	0.09	0.06	0.07	0.07	0.08	413,878
Ontario	0.07	0.05	0.06	0.05	0.09	0.07	0.05	387,400
Illinois	0.04	0.05	0.06	0.04	0.04	0.04	0.05	386,897
Kentucky	0.04	0.07	**0.10**	0.03	0.05	0.04	0.09	382,954
West Virginia	0.05	**0.10**	**0.32**	0.04	0.07	0.04	**0.20**	350,204
Florida	0.03	0.04	0.03	0.01	0.02	0.01	0.04	336,758
Tennessee	0.03	0.05	0.07	0.02	0.04	0.03	0.06	325,546
North Carolina	0.04	0.07	0.06	0.02	0.03	0.03	**0.10**	284,952
Maryland	0.05	**0.20**	**0.12**	0.03	0.05	0.03	**0.15**	265,074
Louisiana	0.02	0.02	0.02	0.01	0.02	0.01	0.02	251,465
Virginia	0.03	0.09	0.07	0.02	0.03	0.02	**0.11**	220,444
Wisconsin	0.02	0.02	0.03	0.02	0.02	0.02	0.02	202,605
South Carolina	0.02	0.04	0.03	0.01	0.02	0.02	0.04	198,689
New York	0.05	0.06	0.03	0.05	0.09	0.04	0.04	192,149
Iowa	0.02	0.01	0.02	0.01	0.01	0.02	0.02	165,047
Quebec	0.05	0.02	0.01	0.01	0.01	0.03	0.02	160,354
Oklahoma	0.01	0.01	0.01	0.01	0.01	0.01	0.01	143,112
Nova Scotia	0.04	0.01	0.01	<0.01	<0.01	0.01	0.01	127,507
Kansas	0.01	0.01	0.01	0.01	0.01	0.01	0.01	112,265
Minnesota	0.01	0.01	0.01	0.01	0.01	0.01	0.01	110,968
Arkansas	0.01	0.01	0.01	0.01	0.01	0.01	0.01	89,609
Mississippi	0.01	0.01	0.01	<0.01	0.01	<0.01	0.01	87,131
Nebraska	0.01	0.01	0.01	0.01	0.01	0.01	0.01	79,023
Massachusetts	0.04	0.02	0.01	0.01	0.01	0.02	0.01	76,339

State	**Acadia[1]**	**Brigantine[1]**	**Dolly Sods[1]**	**Great Gulf[1]**	**Lye Brook[1]**	**Moosehorn[1]**	**Shenandoah[1]**	**Emissions[2,3] (short tons)**
New Brunswick	0.03	0.01	<0.01	<0.01	<0.01	0.01	<0.01	61,990
Delaware	0.01	0.08	0.01	0.01	0.01	0.01	0.02	53,460
New Jersey	0.01	0.07	0.01	0.01	0.01	0.01	0.01	46,377
New Hampshire	0.03	0.01	<0.01	0.01	0.01	0.02	0.01	45,185
Newfoundland	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	38,161
Maine	0.04	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	23,718
Connecticut	0.01	0.01	<0.01	<0.01	0.01	<0.01	<0.01	22,209
Rhode Island	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	4,452
Vermont	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	4,078
District of Columbia	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	1,281
Prince Edward Island	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	1,179

Notes:

1. Values equal to or above 0.10 μg/m^3 are presented in bold.
2. This analysis uses 2002 CALPUFF results to scale 2008 NEI emissions, 2007 NPRI point source emissions, and 2009 NPRI area and mobile source emissions.
3. States and provinces are sorted from highest to lowest total emissions.

Table 2-2. Change in 2007-estimated CALPUFF-scaled emissions over distance impacts ($\mu g/m^3$) at Northeast and Mid-Atlantic Class I areas from previous analysis

State	**Acadia**	**Brigantine**	**Dolly Sods**	**Great Gulf**	**Lye Brook**	**Moosehorn**	**Shenandoah**	**Change in Emissions[1] (short tons)**
Pennsylvania	-0.01	+0.02	-	+0.04	-0.01	-	-0.01	-47,803
Ohio	-0.06	-0.08	-0.17	-0.05	-0.07	-0.04	-0.14	-395,299
Indiana	-0.03	-0.03	-0.06	-0.03	-0.03	-0.03	-0.05	-223,223
Texas	-0.01	-0.01	-0.01	-	-0.01	-	-0.02	-216,841
Georgia	-0.02	-0.03	-0.03	-0.01	-0.01	-0.02	-0.04	-6,194
Alabama	-0.01	-0.02	-0.02	-0.01	-0.01	-0.02	-0.02	-109,132
Missouri	-	-	-	-	-	-	-	+53,292
Michigan	-0.01	-	-0.01	-0.01	-0.01	-0.01	-0.01	-18,288
Illinois	-0.03	-0.03	-0.04	-0.02	-0.03	-0.03	-0.05	-255,367
Kentucky	-0.02	-0.04	-0.05	-0.02	-0.02	-0.02	-0.05	-138,629
West Virginia	-0.03	-0.06	-0.29	-0.02	-0.02	-0.02	-0.13	-222,932
Florida	-0.02	-0.02	-0.01	-0.01	-0.01	-0.03	-0.03	-200,569
Tennessee	-0.01	-0.02	-0.03	-0.01	-0.01	-0.01	-0.03	-98,159
North Carolina	-0.03	-0.07	-0.29	-0.02	-0.03	-0.02	-0.16	-225,500
Maryland	-0.01	-0.04	-0.04	+0.03	-0.01	-0.02	-0.05	-27,896
Louisiana	+0.01	+0.01	+0.01	+0.01	+0.01	-	+0.01	-94,705
Virginia	-0.02	-0.05	-0.03	-0.01	-0.01	-0.02	-0.06	-89,265
Wisconsin	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.02	-60,435
South Carolina	-0.01	-0.02	-0.01	-0.01	-	-0.01	-0.02	-64,178
New York	-0.06	-0.09	-0.04	-0.01	-0.06	-0.06	-0.09	-149,344
Iowa	+0.01	+0.01	+0.01	-	-	+0.01	-	-65,629
Oklahoma	-	-	-	-	-	-	-	+3,785
Kansas	-	-	-	-	-	-	-	-23,839
Minnesota	-	-	-	-	-	-	-0.01	-13,183
Arkansas	-	-	-	-	-	-	-	-50,487
Mississippi	-	-	-	-	-	-	-0.01	-39,325
Nebraska	-	-	-	-	-	-	-	+32,949
Massachusetts	-0.05	-0.01	-0.01	-0.07	-0.01	-0.03	-0.04	-47,415
Delaware	-0.01	-0.02	-0.01	-	-0.01	-0.01	-0.02	-30,089
New Jersey	-0.01	-0.07	-0.01	-0.04	-0.01	-0.01	-0.06	-18,060
New Hampshire	-0.01	-	-	-	+0.01	-	-	-8,587
Maine	-0.01	-	-	-0.01	-	-0.02	-	-15,705
Connecticut	-	-	-	-0.01	-	-	-0.01	-18,884
Rhode Island	-	-	-	-	-	-	-	+1,921
Vermont	-	-	-	-0.01	-	-	-	+2,503
District of Columbia	-	-	-	-	-	-	-	-434
Canada[2]	-0.13	-0.11	N/A	N/A	-0.18	N/A	-0.17	+730,743

Notes:

1. States and provinces are sorted from highest to lowest total emissions.
2. Results for Canada in the previous analysis were aggregated to the country level, and were not available for comparison for all Class I areas.

Figure 2-8. Ranked state percent sulfate contributions to Northeast Class I receptors based on 2008 emissions divided by distance (Q/d) results

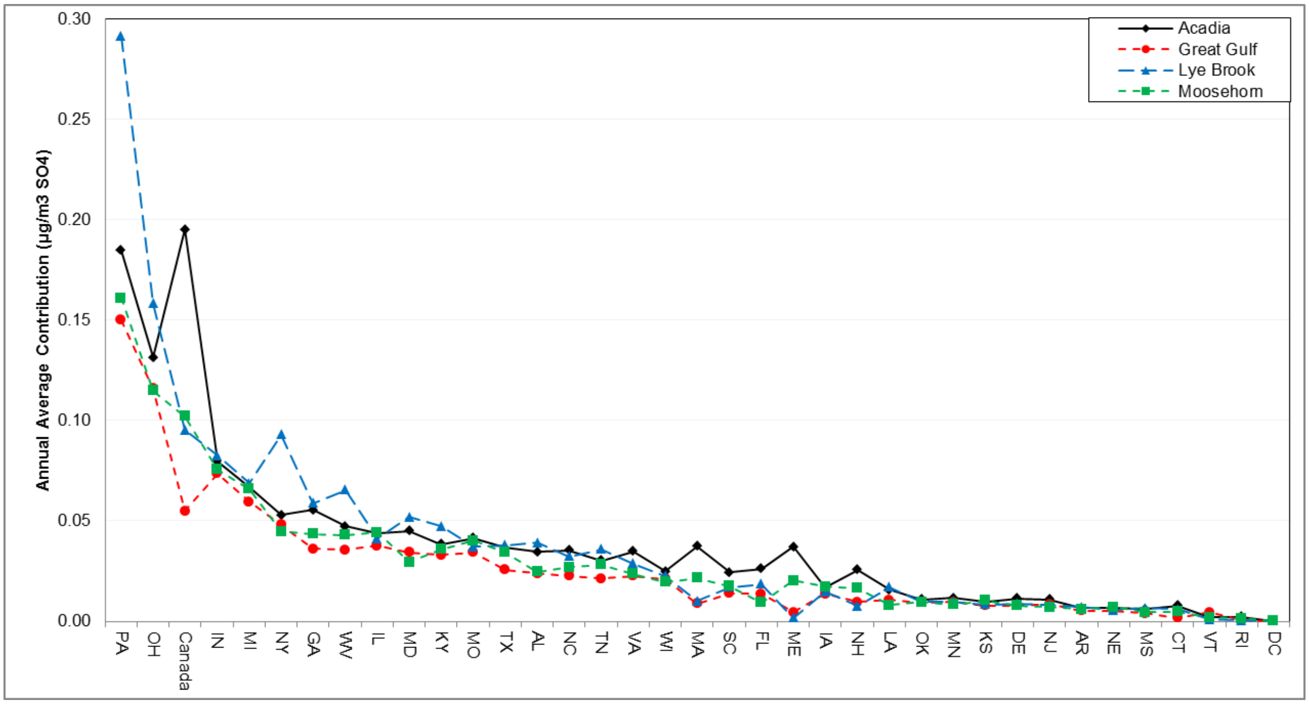
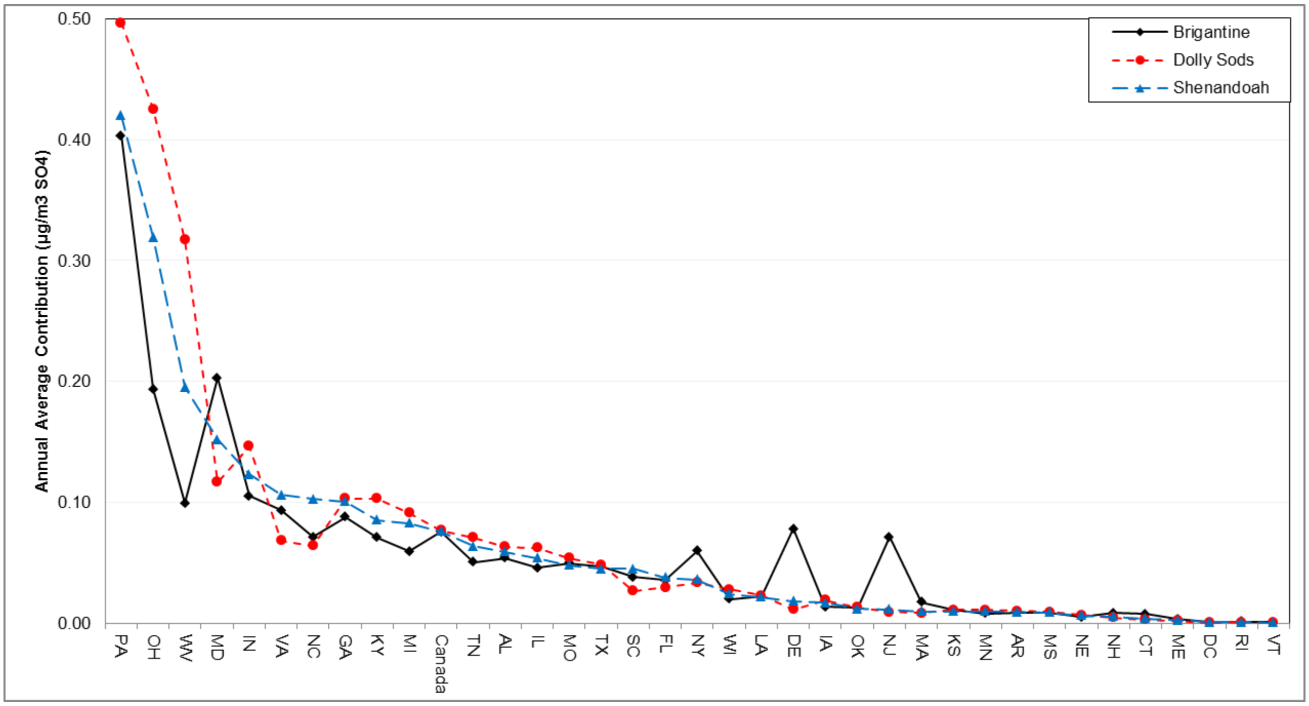


Figure 2-9. Ranked state percent sulfate contributions to Mid-Atlantic Class I receptors based on 2008 emissions divided by distance (Q/d) results



2.3. Emissions Times Upwind Probability

The "emissions times upwind probability" (E×UP) method of assessing contribution to pollution involves multiplying the back-trajectory-calculated residence time probability for a grid cell with the total emissions—over the same time period—from that grid cell. The product is an emissions-weighted probability field that can be integrated within state boundaries to calculate relative probabilities of each state contributing to pollution transport.

The back trajectories used in this study were calculated by the HYSPLIT system (Draxler, 1999). Five years of back trajectories, calculated eight times per day, results in 14,608 back trajectories per receptor. The back trajectories are 72-hours in length and have calculated endpoints, or locations, at hourly intervals that specify the air mass path. The HYSPLIT system terminates when the backward trajectory encounters missing meteorological data (i.e., wind speed and direction) or the top of the domain (set at 10,000 m). The endpoints are therefore slightly biased toward more nearby locations. We used meteorological data from the Eta Data Assimilation System (EDAS) archive for December 2004 through December 2009 (NCDC, 2011), i.e., the five year period centered around 2007. The endpoints from all trajectories are mapped into a matrix of residence times spent in individual grid cells over the five year period (from 2005 to 2009). The resulting sum expresses the likelihood that air spent time in a particular quarter degree longitude by quarter degree latitude grid cell over a domain between

25° and 57° latitude and -110° to -50° longitude. This domain includes parts of Canada and Mexico, states in the CENRAP, MANE-VU, MWRPO, and VISTAS regions, and some states in the Western Regional Air Partnership (WRAP) region. These residence times are then multiplied by the emissions in that grid for 2007.[4] The resulting product matrix contains the SO_2 emission-weighted residence times that are then summed within the boundaries of each state to define a "contribution" for each state. This provides a relative ranking of contribution by state that can be used to compare with other methods of attribution.

By using 2007 meteorology in this approach, we learn more about the actual state contributions in 2007. Comparing results from analyses using 2002 versus 2007 meteorological data is a complicating factor, and we take this inconsistency into account when we attempt such comparisons in Section 3 (i.e., results of the E×UP analysis, which relies on 2007 meteorology, against results of the Q/d analysis, which relies on 2002 meteorology).

The area of analysis included all states and provinces wholly or partially within the domain. Mexico and ocean emission sources were not included. NESCAUM developed Python 2.7 scripts to allocate point sources to grid cells using the nearest neighbor search algorithm in the Fast Library for Approximate Nearest Neighbors (FLANN, version 1.6.11) (Muja, 2011). We allocated area sources by state and apportioned them to grid cells according to their land area.

Results were calculated for seven receptors: Acadia National Park, Brigantine Wilderness Area in the Forsythe National Wildlife Refuge, Dolly Sods Wilderness Area, Great Gulf Wilderness Area, Lye Brook Wilderness Area, Moosehorn Wilderness Area, and Shenandoah National Park. Table 2-3 presents the relative contribution of each state using the percent E×UP approach for seven receptor locations. These results are also presented in Figure 2-10 and Figure 2-11.

According to this analysis, Acadia, Great Gulf, Lye Brook, and Moosehorn have the greatest impacts from Canada, followed by states in MANE-VU and MWRPO, while those sites had low relative contributions from VISTAS states. MANE-VU, MWRPO, and VISTAS states had the greatest relative impacts at the Brigantine Class I area, with Canada having low relative contributions. The Dolly Sods and Shenandoah Class I areas had the greatest contributions from VISTAS states, followed by MANE-VU and MWRPO states and very low contributions from Canada. CENRAP and WRAP states contributed negligibly to all studied Class I areas. Certain states had high impacts at multiple Class I areas. Pennsylvania had the highest total emissions and impacts of any state at all seven studied Class I areas. New York and Ohio had the next highest impacts for states at all the studied Class I areas.

Table 2-4 presents the differences by state of relative contributions between the current analysis and the previous analysis for the four Class I areas for which results were presented: Acadia, Brigantine, Lye Brook, and Shenandoah. Relative contributions from MWRPO and

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[4] Sulfur dioxide emissions for the United States are from the 2008 National Emissions Inventory (NEI), and include point, nonpoint, on-road, and non-road sources. Canadian point sources are from the 2007 National Pollution Release Inventory (NPRI), while Canadian nonpoint, on-road, and non-road sources are from the 2009 NPRI. Only point sources were mapped by latitude and longitude to specific grid cells. Emissions density of nonpoint, on-road, and non-road sources was treated as constant across each state. For states and provinces that were partially outside of the domain, area source emissions were scaled by the geographic area inside the domain.

VISTAS states generally decreased from the previous to the current analysis, and MANE-VU states generally increased slightly from the previous to the current analysis. Canada had large increases in relative contribution, most likely because of increases in the emissions inventory. Illinois, North Carolina, and West Virginia had the largest decreases in relative contribution, and Canada and Pennsylvania had the largest increases. Because the data presented in Table 2-4 represent relative changes, and because different meteorological data were used to generate results, it is unsurprising that emissions may have decreased (or increased) absolutely while relative impacts increased (or decreased) at receptor sites.

Table 2-3. 2008 emissions times upwind probability results at MANE-VU Class I areas

State	**Acadia[1]**	**Brigantine[1]**	**Dolly Sods[1]**	**Great Gulf[1]**	**Lye Brook[1]**	**Moosehorn[1]**	**Shenandoah[1]**	**Emissions[2,3] (short tons)**
Canada	**0.38**	**0.12**	**0.05**	**0.36**	**0.28**	**0.46**	**0.07**	2,429,161
Pennsylvania	**0.13**	**0.26**	**0.17**	**0.15**	**0.19**	**0.11**	**0.19**	1,042,759
Ohio	0.06	0.10	**0.20**	0.09	0.09	0.05	**0.16**	878,456
Indiana	0.02	0.03	0.04	0.03	0.03	0.02	0.04	690,816
Georgia	0.01	0.02	0.03	0.01	0.01	0.01	0.03	598,846
Alabama	<0.01	0.01	0.02	<0.01	0.01	<0.01	0.02	438,922
Missouri	0.01	0.01	0.01	0.01	0.01	0.01	0.01	415,203
Michigan	0.03	0.02	0.02	0.04	0.03	0.03	0.02	413,878
Illinois	0.01	0.02	0.02	0.02	0.02	0.01	0.02	386,897
Kentucky	0.02	0.03	0.08	0.03	0.03	0.02	0.07	382,954
West Virginia	0.03	0.04	**0.20**	0.03	0.03	0.02	**0.13**	350,204
Tennessee	0.01	0.01	0.03	0.01	0.01	<0.01	0.02	325,546
North Carolina	0.01	0.01	0.01	<0.01	<0.01	<0.01	0.01	284,952
Maryland	0.03	0.08	0.02	0.02	0.03	0.03	0.06	265,074
Virginia	0.03	0.05	0.03	0.01	0.01	0.02	0.06	220,444
Wisconsin	0.01	0.01	0.01	0.01	0.01	0.01	0.01	202,605
South Carolina	<0.01	0.02	0.01	<0.01	<0.01	<0.01	0.02	198,689
New York	0.05	0.04	0.01	0.07	**0.11**	0.04	0.01	192,149
Massachusetts	0.04	0.01	<0.01	0.02	0.02	0.04	<0.01	76,339
Delaware	0.01	0.03	<0.01	0.01	0.01	0.01	0.01	53,460
New Jersey	0.01	0.05	<0.01	0.01	0.01	0.01	<0.01	46,377
New Hampshire	0.03	<0.01	<0.01	0.04	0.01	0.02	<0.01	45,185
Maine	0.03	<0.01	<0.01	0.01	<0.01	0.04	<0.01	23,718
Connecticut	0.01	<0.01	<0.01	0.01	0.01	0.01	<0.01	22,209

Notes:

1. Values equal to or above 0.10 are presented in bold.
2. This analysis uses 2002 CALPUFF results to scale 2008 NEI emissions, 2007 NPRI point source emissions, and 2009 NPRI area and mobile source emissions. Emissions from the entire state or country are presented, rather than just those inside the domain grid. Values reflect emissions within the state prior to grid allocation.
3. States and provinces are sorted from highest to lowest total emissions.
4. Several states included in the study had relative contributions of less than 1 percent at all MANE-VU Class I areas. These are excluded from this table: Arizona, Arkansas, Colorado, District of Columbia, Florida, Iowa, Kansas, Louisiana, Minnesota, Mississippi, Montana, Nebraska, New Mexico, North Dakota, Oklahoma, Rhode Island, South Dakota, Texas, Utah, Vermont, and Wyoming.

Table 2-4. Change in relative contribution from states at MANE-VU Class I areas from previous analysis for the 2008 emissions times upwind probability approach

State	**Acadia**[1]	**Brigantine**[1]	**Lye Brook**[1]	**Shenandoah**[1]	**Emissions change (2008-2002, tpy)**
Canada	0.15	0.04	0.08	0.02	2,383,313
Pennsylvania	0.04	0.13	0.06	0.12	-47,803
Ohio	-0.03	-	-0.02	0.04	-395,299
Indiana	-0.03	-0.02	-0.02	-0.02	-223,223
Georgia	-0.01	-0.02	-0.01	-0.02	-6,194
Alabama	-0.01	-0.01	-	-	-109,132
Michigan	-0.01	-	-0.01	-	-18,288
Illinois	-0.05	-0.02	-0.03	-0.02	-255,367
Kentucky	-0.02	-0.03	-0.02	-0.02	-138,629
West Virginia	-0.03	-0.05	-0.04	-0.06	-222,932
Tennessee	-0.01	-0.01	-	-0.02	-98,159
North Carolina	-0.01	-0.04	-0.01	-0.06	-225,500
Maryland	0.01	0.04	0.01	0.03	-27,896
Virginia	-	-0.01	-0.01	-	-89,265
Wisconsin	-0.01	-	-0.01	-	-60,435
South Carolina	-0.01	-	-0.01	-	-64,178
New York	-0.02	-	-	-0.01	-149,344
Iowa	-0.01	-	-	-	-65,629
Minnesota	-0.01	-	-0.01	-	-13,183
Massachusetts	0.02	0.01	0.01	-	-47,415
Delaware	0.01	0.01	-	0.01	-30,089
New Jersey	-0.01	-0.02	-0.01	-0.01	-18,060
New Hampshire	0.01	-	-	-	-8,587
Maine	0.01	-	-	-	-15,705
Vermont	-	-	0.01	-	2,503

Notes:

1. States and provinces are sorted from highest to lowest total emissions. Changes in relative contributions within ±0.01 are considered *de minimis*, and are presented as dashes. Changes in relative contributions for the following states were within ±0.01 for all studied Class 1 areas: Arkansas, Connecticut, District of Columbia, Florida, Kansas, Louisiana, Mississippi, Missouri, Oklahoma, Rhode Island, and Texas.

Figure 2-10. Ranked state percent sulfate contributions to the Acadia, Great Gulf, Lye Brook, and Moosehorn Class I areas based on percent upwind probability (%UP) results

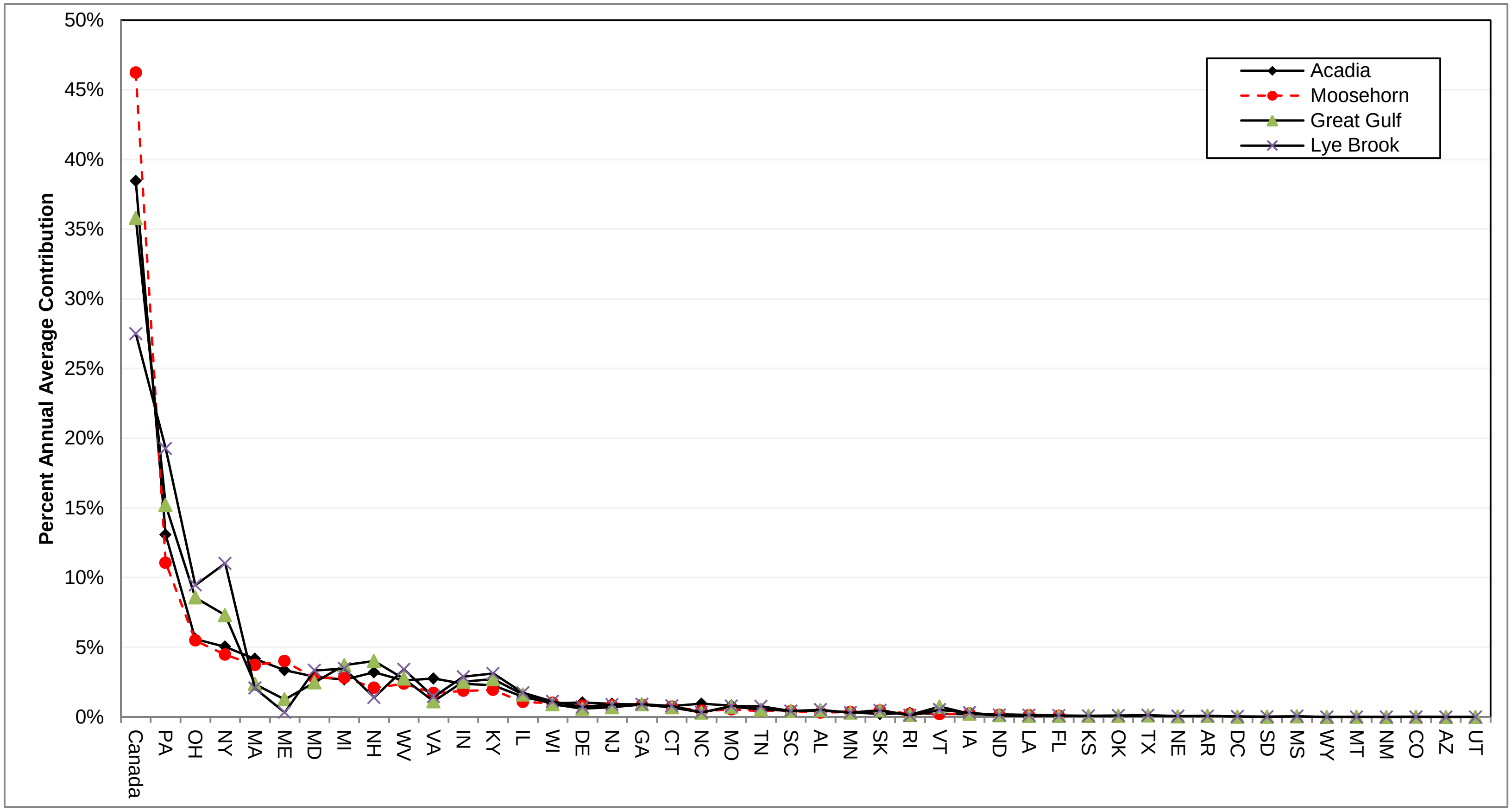
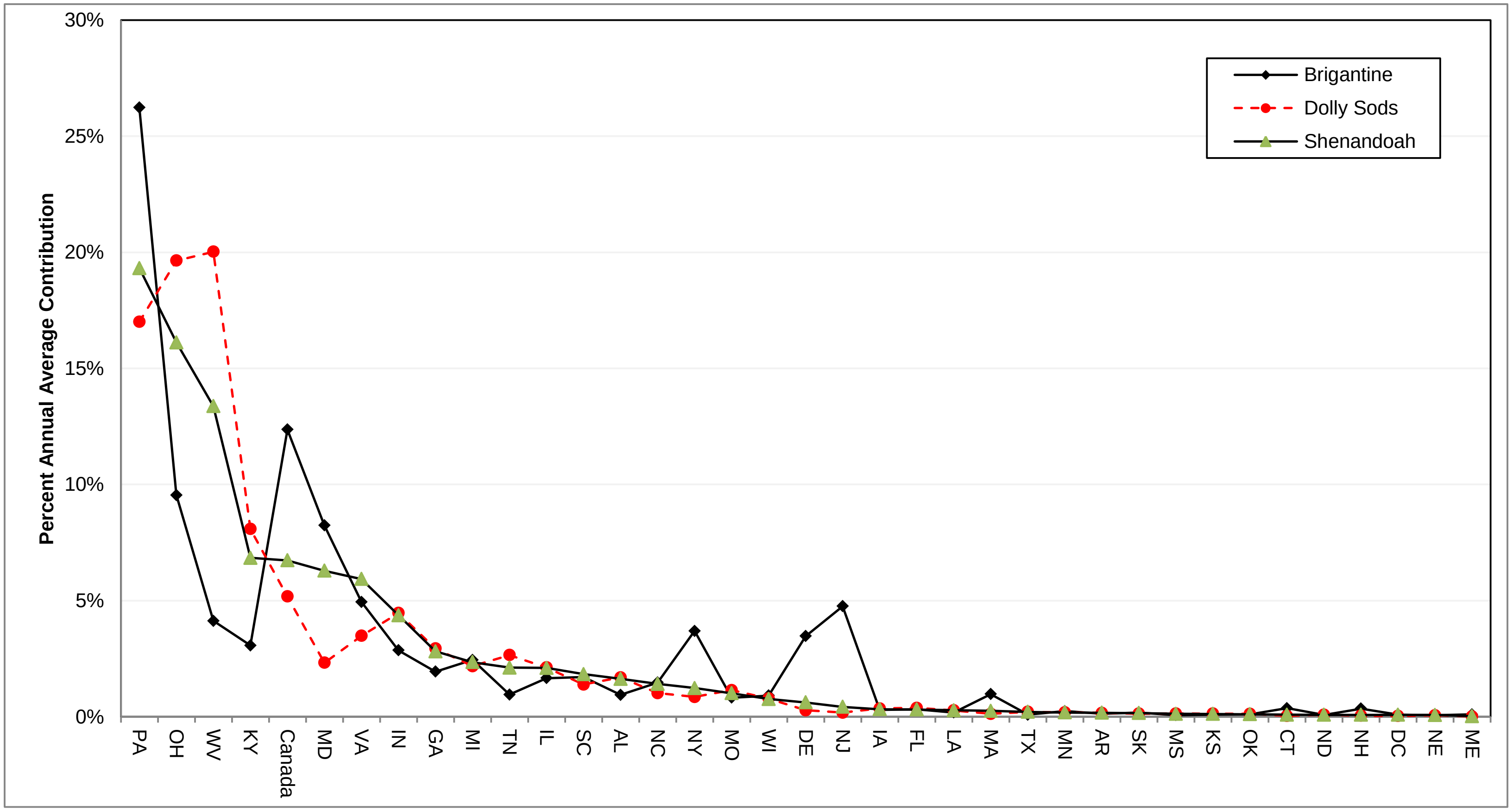


Figure 2-11. Ranked state percent sulfate contributions to the Brigantine, Dolly Sods, and Shenandoah Class I areas based on percent upwind probability (%UP) results



3. COMPARISON OF RESULTS

This section presents a comparison of the results of the different contribution analyses on a site-by-site basis. Because the analyses are fundamentally different (different modeling systems, different meteorological data) and have different strengths and weaknesses, we do not expect the results to be completely consistent. Rather, the consistency between the results indicates the level of confidence that we can have in drawing conclusions about the state contributions.

We also expect differences in results from use of different meteorological data in each analysis. The E×UP approach used meteorological data from the five year period around 2007, while the *Q/d* approach relied on "wind vector constants" that were derived from modeled 2002 CALPUFF trajectories.

We present summary relative contribution results for both analyses in table form in Table 3-1 and Table 3-2, and in graphical form in Figure 3-1 through Figure 3-7 for each of the seven studied MANE-VU Class I areas. States are presented from highest to lowest average contribution level for each site. We also present the state rankings produced by the two approaches for Acadia in Table 3-3.

The relative rankings for state contributions to MANE-VU receptor sites differ according to each analysis. At the most northern Class I areas in the MANE-VU region, the E×UP approach ranks MANE-VU states higher than under the *Q/d* approach. It also ranks Canada higher for all MANE-VU Class I areas except Acadia, at which Canada is the top contributor according to both methods. The *Q/d* approach generally ranks states in the MWRPO, VISTAS, and, particularly, CENRAP regions higher than does the E×UP approach at the more northern MANE-VU Class I areas. Rankings by region at the Dolly Sods and Shenandoah Class I areas did not differ greatly between methods. At Brigantine, the E×UP method largely ranked MANE-VU sites as higher relative contributors, whereas the *Q/d* method generally ranked states in the VISTAS and CENRAP regions higher.

The most striking difference between the state contribution levels using the E×UP and *Q*/*d* methods occurs is for Canada. The contribution levels from Canada according to the *Q*/*d* method are lower for each Class I area than according to the E×UP method.

- At Acadia, the *Q*/*d* approach predicts higher relative contribution from states with higher emission levels, particularly states in the MWRPO and VISTAS regions. The relative contribution level from Canada according to the E×UP method is 38 percent, compared to 14 percent according to the *Q/d* method. The difference in relative contribution between the two methods is similar at Moosehorn.
- At Brigantine, the *Q/d* approach has attributes lower relative contributions from Pennsylvania and high relative levels from southern states in the VISTAS and CENRAP regions.
- At Dolly Sods, the E×UP approach shows higher relative contribution levels from Ohio, West Virginia, and Kentucky, in addition to Canada. The *Q/d* approach shows higher relative contribution levels from Southern VISTAS and CENRAP states, and from Maryland.

- At Great Gulf and Lye Brook, the E×UP approach indicates higher relative contribution levels from Canada and most MANE-VU states (excepting Pennsylvania), while the *Q/d* approach attributes higher relative contributions from MWRPO and VISTAS states.
- At Shenandoah, the E×UP method attributes higher levels of relative contribution compared to the *Q/d* method for the highest contributing states, especially West Virginia, Kentucky, and Indiana, and lower relative contribution levels for the lower contributing states, especially those in the South.

The state ranks, if not the precise relative contribution levels, are generally consistent between the two methods. There are several notable differences in relative contribution levels between the two approaches at Acadia, as shown in Table 3-3. The *Q/d* approach attributes notably higher relative contribution levels to Georgia, Indiana, Missouri, and Texas than does the E×UP approach. Conversely, the *Q/d* approach ranks Delaware, New Hampshire, New Jersey, Maine, Massachusetts, and Virginia notably lower than does the E×UP approach.

Table 3-1. Relative fractional contribution from 2008 emissions by state and region from the *Q/d* approach

RPO	State	Acadia	Brigantine	Dolly Sods	Great Gulf	Lye Brook	Moosehorn	Shenandoah
Canada		**0.14**	**0.04**	**0.03**	**0.07**	**0.07**	**0.11**	**0.03**
Canada	New Brunswick	0.02	<0.01	<0.01	<0.01	<0.01	0.01	<0.01
	Newfoundland and Labrador	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	Nova Scotia	0.03	<0.01	<0.01	<0.01	<0.01	0.01	<0.01
	Ontario	0.05	0.02	0.02	0.05	0.06	0.06	0.02
	Prince Edward Island	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	Quebec	0.04	0.01	0.01	0.01	0.01	0.03	0.01
CENRAP		**0.11**	**0.08**	**0.08**	**0.12**	**0.10**	**0.12**	**0.08**
CENRAP	Arkansas	<0.01	<0.01	<0.01	0.01	<0.01	0.01	<0.01
	Iowa	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	Kansas	0.01	0.01	<0.01	0.01	0.01	0.01	<0.01
	Louisiana	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	Minnesota	0.01	<0.01	<0.01	0.01	0.01	0.01	<0.01
	Missouri	0.03	0.02	0.02	0.03	0.03	0.03	0.02
	Nebraska	<0.01	<0.01	<0.01	0.01	<0.01	0.01	<0.01
	Oklahoma	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	Texas	0.03	0.02	0.02	0.03	0.03	0.03	0.02
MANE-VU		**0.29**	**0.40**	**0.27**	**0.28**	**0.33**	**0.27**	**0.28**
MANE-VU	Connecticut	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	Delaware	0.01	0.04	<0.01	0.01	0.01	0.01	0.01
	District of Columbia	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	Maine	0.03	<0.01	<0.01	<0.01	<0.01	0.02	<0.01
	Maryland	0.03	0.09	0.05	0.03	0.04	0.03	0.07
	Massachusetts	0.03	0.01	<0.01	0.01	0.01	0.02	<0.01

RPO	State	Acadia	Brigantine	Dolly Sods	Great Gulf	Lye Brook	Moosehorn	Shenandoah
	New Hampshire	0.02	<0.01	<0.01	0.01	0.01	0.01	<0.01
	New Jersey	0.01	0.03	<0.01	0.01	0.01	0.01	<0.01
	New York	0.04	0.03	0.01	0.05	0.06	0.04	0.02
	Pennsylvania	0.13	0.19	0.19	0.15	0.20	0.14	0.18
	Rhode Island	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	Vermont	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
MWRPO		**0.24**	**0.20**	**0.29**	**0.31**	**0.26**	**0.27**	**0.26**
MWRPO	Illinois	0.03	0.02	0.02	0.04	0.03	0.04	0.02
	Indiana	0.05	0.05	0.06	0.07	0.06	0.06	0.05
	Michigan	0.05	0.03	0.04	0.06	0.05	0.06	0.04
	Ohio	0.09	0.09	0.17	0.12	0.11	0.10	0.14
	Wisconsin	0.02	0.01	0.01	0.02	0.02	0.02	0.01
VISTAS		**0.23**	**0.28**	**0.33**	**0.23**	**0.24**	**0.22**	**0.35**
VISTAS	Alabama	0.02	0.03	0.02	0.02	0.03	0.02	0.03
	Florida	0.02	0.02	0.01	0.01	0.01	0.01	0.02
	Georgia	0.04	0.04	0.04	0.04	0.04	0.04	0.04
	Kentucky	0.03	0.03	0.04	0.03	0.03	0.03	0.04
	Mississippi	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	North Carolina	0.02	0.03	0.02	0.02	0.02	0.02	0.04
	South Carolina	0.02	0.02	0.01	0.01	0.01	0.01	0.02
	Tennessee	0.02	0.02	0.03	0.02	0.02	0.02	0.03
	Virginia	0.02	0.04	0.03	0.02	0.02	0.02	0.05
	West Virginia	0.03	0.05	0.12	0.04	0.05	0.04	0.08

Table 3-2. Relative fractional contribution from 2008 emissions by state and region from the E×UP approach

RPO	State	Acadia	Brigantine	Dolly Sods	Great Gulf	Lye Brook	Moosehorn	Shenandoah
Canada		**0.38**	**0.12**	**0.05**	**0.36**	**0.28**	**0.46**	**0.07**
CENRAP		**0.02**	**0.02**	**0.03**	**0.02**	**0.02**	**0.02**	**0.02**
CENRAP	Arkansas	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	Iowa	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	Kansas	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	Louisiana	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	Minnesota	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	Missouri	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	Nebraska	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	Oklahoma	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	Texas	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
MANE-VU		**0.35**	**0.48**	**0.21**	**0.36**	**0.40**	**0.31**	**0.28**
MANE-VU	Connecticut	0.01	<0.01	<0.01	0.01	0.01	0.01	<0.01
	Delaware	0.01	0.03	<0.01	0.01	0.01	0.01	0.01
	District of Columbia	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	Maine	0.03	<0.01	<0.01	0.01	<0.01	0.04	<0.01
	Maryland	0.03	0.08	0.02	0.02	0.03	0.03	0.06
	Massachusetts	0.04	0.01	<0.01	0.02	0.02	0.04	<0.01
	New Hampshire	0.03	<0.01	<0.01	0.04	0.01	0.02	<0.01
	New Jersey	0.01	0.05	<0.01	0.01	0.01	0.01	<0.01
	New York	0.05	0.04	0.01	0.07	0.11	0.04	0.01
	Pennsylvania	0.13	0.26	0.17	0.15	0.19	0.11	0.19
	Rhode Island	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	Vermont	<0.01	<0.01	<0.01	0.01	0.01	<0.01	<0.01
MWRPO		**0.13**	**0.17**	**0.29**	**0.17**	**0.19**	**0.12**	**0.26**

RPO	State	Acadia	Brigantine	Dolly Sods	Great Gulf	Lye Brook	Moosehorn	Shenandoah
MWRPO	Illinois	0.01	0.02	0.02	0.02	0.02	0.01	0.02
	Indiana	0.02	0.03	0.04	0.03	0.03	0.02	0.04
	Michigan	0.03	0.02	0.02	0.04	0.03	0.03	0.02
	Ohio	0.06	0.10	0.20	0.09	0.09	0.05	0.16
	Wisconsin	0.01	0.01	0.01	0.01	0.01	0.01	0.01
VISTAS		**0.11**	**0.20**	**0.42**	**0.09**	**0.11**	**0.09**	**0.36**
VISTAS	Alabama	<0.01	0.01	0.02	<0.01	0.01	<0.01	0.02
	Florida	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	Georgia	0.01	0.02	0.03	0.01	0.01	0.01	0.03
	Kentucky	0.02	0.03	0.08	0.03	0.03	0.02	0.07
	Mississippi	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	North Carolina	0.01	0.01	0.01	<0.01	<0.01	<0.01	0.01
	South Carolina	<0.01	0.02	0.01	<0.01	<0.01	<0.01	0.02
	Tennessee	0.01	0.01	0.03	0.01	0.01	<0.01	0.02
	Virginia	0.03	0.05	0.03	0.01	0.01	0.02	0.06
	West Virginia	0.03	0.04	0.20	0.03	0.03	0.02	0.13
WRAP		**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**

Table 3-3. Ranked contributing states to Acadia sulfate

Average	*Q/d*	E×UP
Canada	Canada	Canada
PA	PA	PA
OH	OH	OH
NY	IN	NY
IN	MI	MA
MI	GA	ME
MA	NY	NH
MD	WV	MD
ME	MD	VA
WV	IL	MI
VA	MO	WV
NH	KY	IN
KY	MA	KY
GA	ME	IL
IL	TX	DE
MO	NC	WI
NC	VA	NC
AL	AL	NJ
WI	TN	GA
TN	FL	MO
TX	NH	CT
SC	WI	TN
FL	SC	AL
DE	IA	SC
NJ	LA	MN
IA	MN	RI
CT	DE	VT
LA	NJ	IA
MN	OK	LA
OK	KS	FL
KS	CT	KS
NE	NE	OK
AR	AR	TX
RI	MS	NE
MS	VT	AR
VT	RI	DC
DC	DC	MS

States are ordered in this table from highest to lowest contribution. Color schemes indicate highest (red) to lowest (navy) relative contribution, and are grouped such that there are five states in each group. These colors present a visual guide when comparing each method’s resulting contribution ranking.

Figure 3-1. Comparison of state rankings from different attribution analyses results for the Acadia Class I area

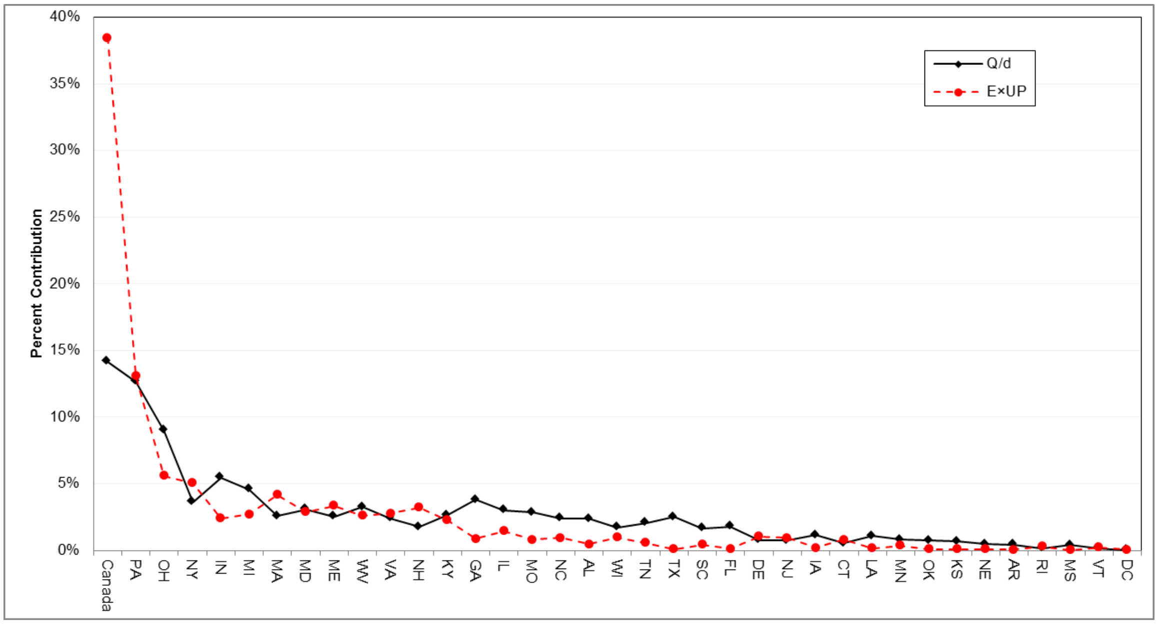


Figure 3-2. Comparison of state rankings from different attribution analyses results for the Brigantine Class I area

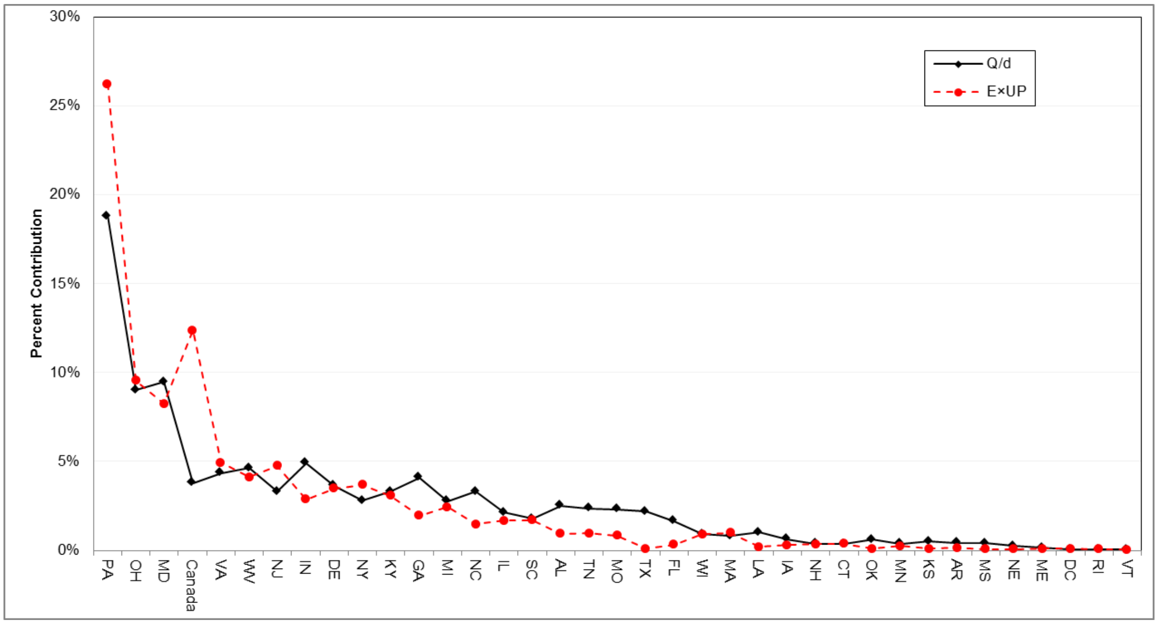


Figure 3-3. Comparison of state rankings from different attribution analyses results for the Dolly Sods Class I area

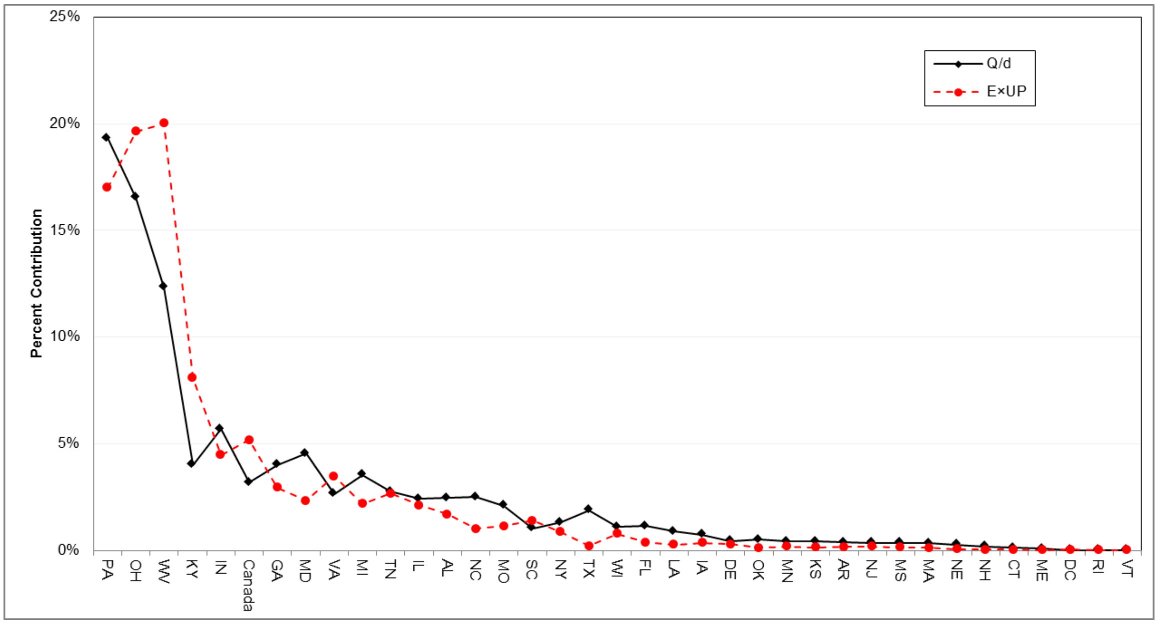


Figure 3-4. Comparison of state rankings from different attribution analyses results for the Great Gulf Class I area

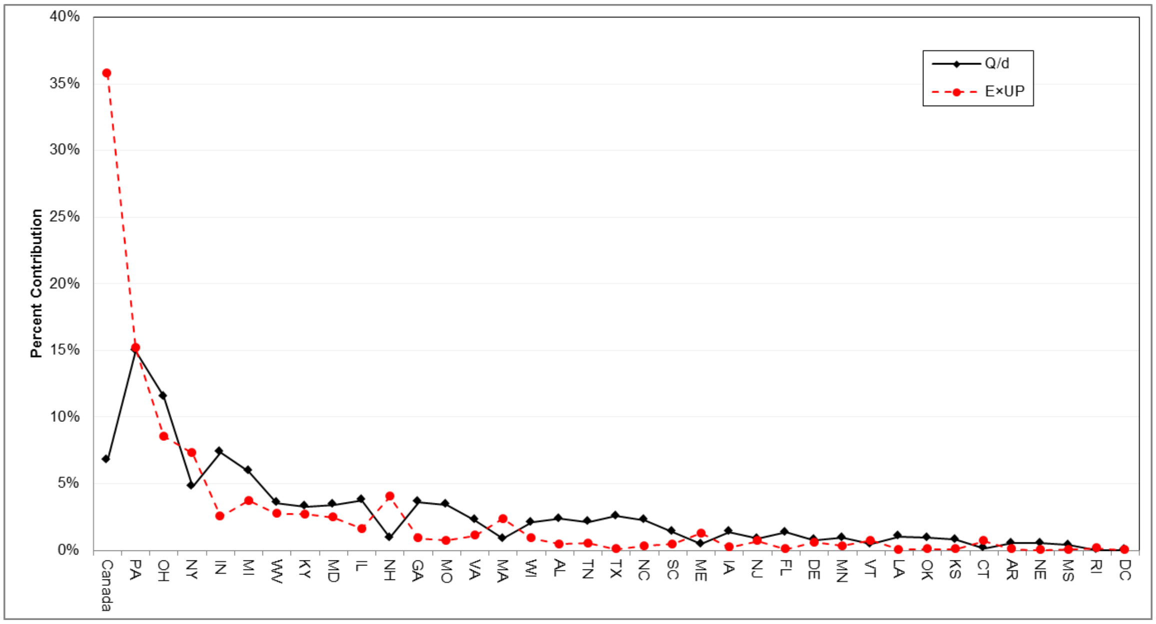


Figure 3-5. Comparison of state rankings from different attribution analyses results for the Lye Brook Class I area

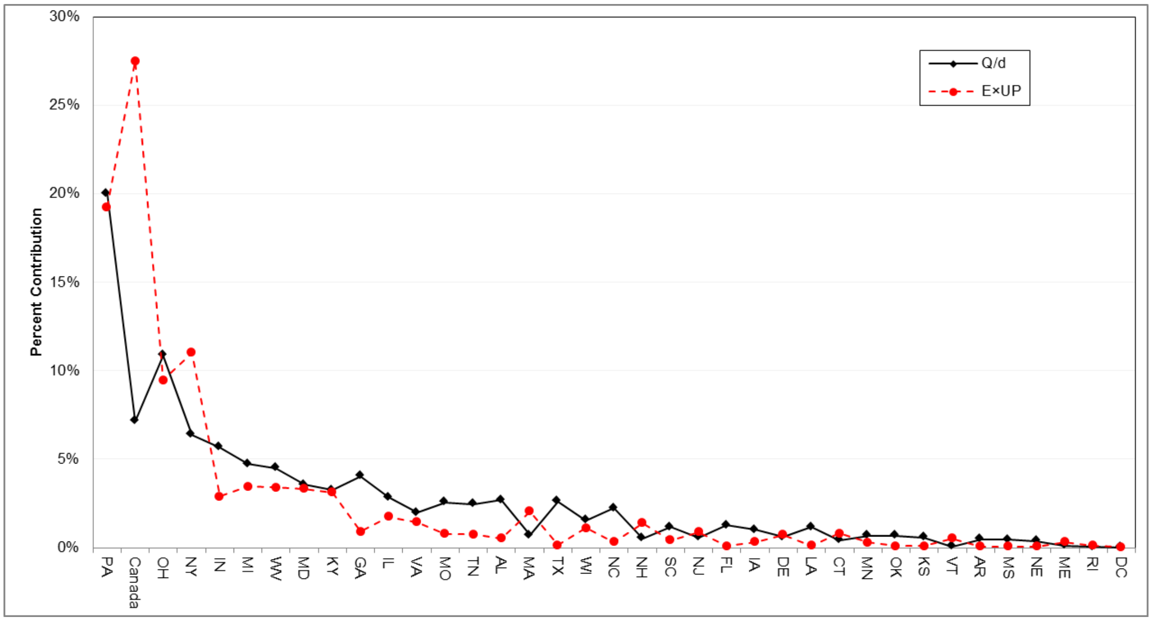


Figure 3-6. Comparison of state rankings from different attribution analyses results for the Moosehorn Class I area

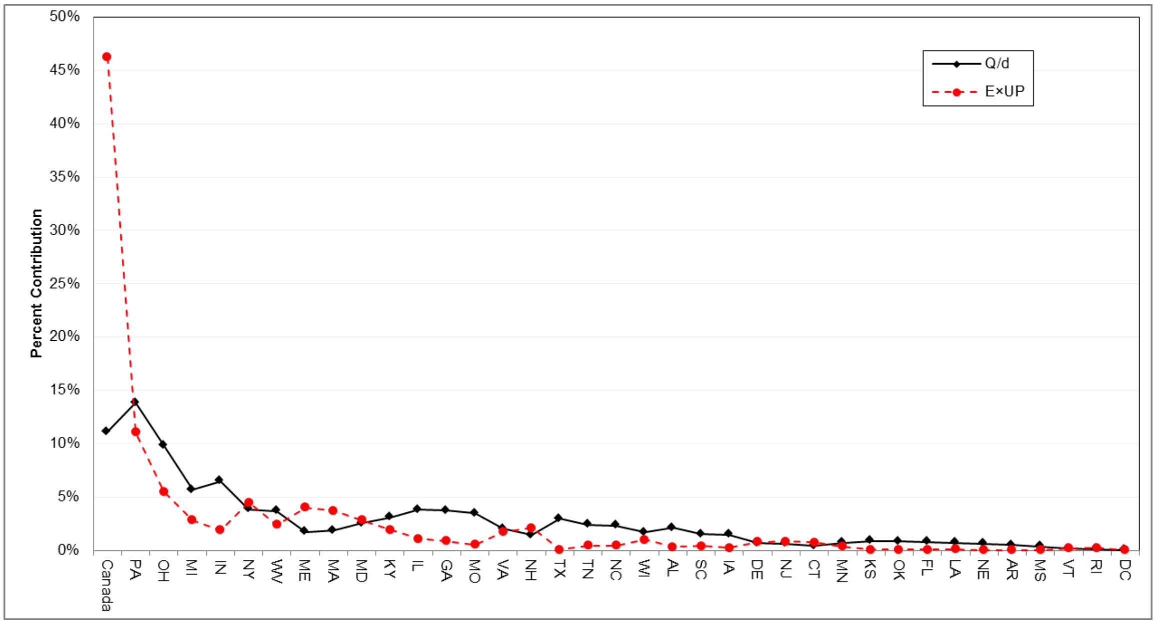
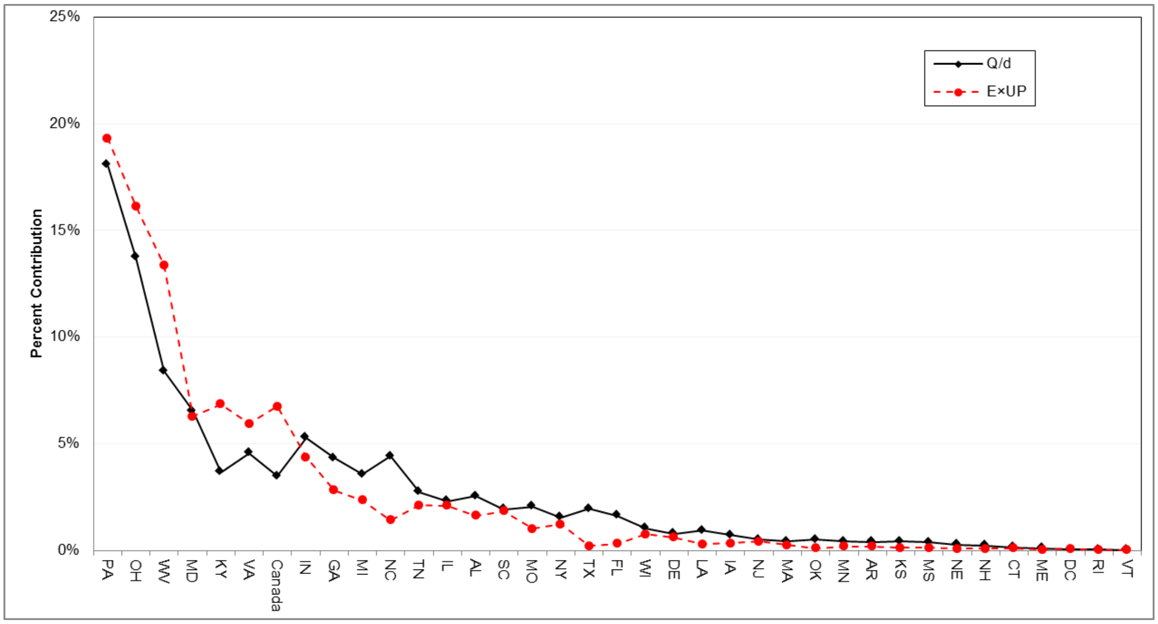


Figure 3-7. Comparison of state rankings from different attribution analyses results for the Shenandoah Class I area



4. CONCLUSIONS

The emissions times upwind probability analysis identified Canada as one of the primary contributors to MANE-VU Class I areas. While there is not agreement about the relative level of contribution between the two methods in this report, the E×UP approach was the only one to fully include an updated Canadian emission inventory for 2007. Therefore, the influence of Canadian emissions on MANE-VU Class I areas warrants increased attention based on these results.

The results presented in this report indicate that emissions continue to decline for pollutants relevant to visibility at MANE-VU Class I areas. The primary contributors to visibility impairment at the Class I areas remain largely consistent with those identified in the previous analysis (NESCAUM, 2006). Continued progress in emissions reductions of SO_2 and NO_x in these states is vital to the continued improvement in visibility at the Class I areas.

5. REFERENCES

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Appendix A: Inputs to the emissions over distance approach

Appendix A: Inputs to the emissions over distance approach

This appendix presents inputs used in the emissions over distance approach (*Q/d*).

Table A-1. Geographic coordinates used for "center of state" locations

State	Latitude	Longitude
Alabama	33.008097	-86.756826
Arkansas	35.14258	-92.655243
Connecticut	41.497001	-72.870342
Delaware	39.358946	-75.556835
District of Columbia	38.91027	-77.014468
Florida	27.822726	-81.634654
Georgia	33.376825	-83.882712
Illinois	41.286759	-88.390334
Indiana	40.149246	-86.259514
Iowa	41.946066	-93.036629
Kansas	38.464949	-96.462812
Kentucky	37.824499	-85.248467
Louisiana	30.722814	-91.508833
Maine	44.29995	-69.736482
Maryland	39.140769	-76.797763
Massachusetts	42.272291	-71.36337
Michigan	42.873187	-84.203434
Minnesota	45.203555	-93.571903
Mississippi	32.590954	-89.579514
Missouri	38.423798	-92.198469
Nebraska	41.1743	-97.315578
New Hampshire	43.154858	-71.461974
New Jersey	40.43181	-74.432208
New York	41.501299	-74.620909
North Carolina	35.543075	-79.658232
Ohio	40.455191	-82.773339
Oklahoma	35.598464	-96.836786
Pennsylvania	40.456756	-77.00968
Rhode Island	41.753609	-71.450869
South Carolina	34.025176	-81.011022
Tennessee	35.80809	-86.359136
Texas	30.905244	-97.365594
Vermont	44.094874	-72.816417
Virginia	37.810313	-77.81116
West Virginia	38.795594	-80.731308
Wisconsin	43.721933	-89.018997
New Brunswick	46.0878165	-64.7782313
Newfoundland and Labrador	47.5605413	-52.7128315
Nova Scotia	44.648881	-63.575312

State	Latitude	Longitude
Ontario	43.653226	-79.3831843
Prince Edward Island	46.247847	-63.12021
Quebec	45.5086699	-73.5539925

Table A-2. Geographic coordinates used for Class I area locations

Class I Area	Area Abbreviation	Latitude	Longitude
Acadia National Park	ACAD	44.3771	-68.2612
Moosehorn Wilderness Area	MOOS	45.1259	-67.2661
Great Gulf Wilderness Area	GRGU	44.3082	-71.2177
Brigantine Wilderness Area	BRIG	39.465	-74.4492
Lye Brook Wilderness Area	LYBR	43.1481	-73.1267
Shenandoah National Park	SHEN	38.5228	-78.4347
Dolly Sods Wilderness Area	DOSO	39.1069	-79.4262

Table A-3. Wind direction sector constants

Class I Area Abbreviation	Minimum Angle	Maximum Angle	Constant (C_i)
ACAD	0	171	0.00016071
ACAD	172	197	0.00020593
ACAD	198	216	0.00016071
ACAD	217	226	0.00019667
ACAD	227	360	0.00016071
DOSO	0	140	0.00008446
DOSO	141	254	0.00013503
DOSO	255	355	0.00006458
DOSO	356	360	0.00006458
BRIG	0	33	0.0000882
BRIG	34	156	0.0000882
BRIG	157	179	0.00012905
BRIG	180	189	0.00017808
BRIG	190	237	0.00016108
BRIG	238	360	0.0000882
GRGU	0	170	0.00002371
GRGU	171	203	0.00014956
GRGU	204	236	0.00009968
GRGU	237	289	0.00002371
GRGU	290	360	0.00002371
LYBR	0	143	0.00002303
LYBR	144	225	0.00014575
LYBR	226	240	0.00010289
LYBR	241	299	0.00005815
LYBR	300	360	0.00002303
MOOS	0	173	0.00003842
MOOS	174	184	0.00015274
MOOS	185	196	0.00022409

Class I Area Abbreviation	**Minimum Angle**	**Maximum Angle**	**Constant (C_i)**
MOOS	197	209	0.00015967
MOOS	210	211	0.00003842
MOOS	212	212	0.00016344
MOOS	213	215	0.00012298
MOOS	216	225	0.00015147
MOOS	225	360	0.00003842
SHEN	0	133	0.00009164
SHEN	134	280	0.00012969
SHEN	281	311	0.00006097
SHEN	312	360	0.00006097

Note: Angles are measured in degrees counterclockwise, with east equal to zero degrees.