Selection of States for MANE-VU Regional Haze Consultation (2018)

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Introduction

Under the Regional Haze Rule[1], States with Class I areas are to consult with states contributing to visibility degradation regarding reasonable measures that can be pursued to improve visibility. The purpose of this paper is to review the process used to determine the selection of states for MANE-VU Class I Area state consultation. Consultation does not mean that selected states have not addressed their visibility impairing emissions, but rather technical analysis suggests that their location, historical emissions and prevailing weather patterns create enough possibility for visibility impact on MANE-VU's Class I areas that they should be included in the discussion of "reasonable" measures to include in the Regional Haze SIP's.

In order to determine which states should be consulted an analysis must be conducted to define what states, sources, or sectors reasonably contribute to visibility impairment. EPA's draft guidance document calls for a process for determining which sources or source sectors should be considered.[2] It begins with analyzing monitored emissions data on the 20% most impaired days to determine what pollution is leading to anthropogenic visibility impacts. This is followed by screening for sources or source sectors that are leading to a majority of that impact. The results of this analysis will lead to what source or sectors need a four-factor analysis and which states should be consulted with.

Firstly, MANE-VU concluded, after developing a conceptual model, that the sulfates from SO_2 emissions were still the primary driver behind visibility impairment in the region, though nitrates from NO_X emission sources do play a more significant role than they had in the first planning period.[3] Because of this, MANE-VU chose an approach for contribution assessments that focused on sulfates and included nitrates when they could be included in a technically sound fashion.

Secondly, MANE-VU examined annual inventories of emissions to find sectors that should be considered for further analysis.[4] EGUs emitting SO_2 and NO_X and industrial point sources emitting SO_2 were found to be point source sectors of high emissions that warranted further scrutiny. Mobile sources were also found to be important an important sector in terms of NO_X emissions.

After this initial work, MANE-VU initiated a process of screening states and sectors for contribution using two tools, Q/d and CALPUFF. Support for these tools for screening purposes follows in the next section. Results of this contribution analysis was then compared to air mass trajectories for 20% most impaired days at the MANE-VU Class I Areas.

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[1] US EPA, "Protection of Visibility: Amendments to Requirements for State Plans."

[2] US EPA, "Draft Guidance on Progress Tracking Metrics, Long-Term Strategies, Reasonable Progress Goals and Other Requirements for Regional Haze State Implementation Plans for the Second Implementation Period."

[3] Downs et al., *The Nature of the Fine Particle and Regional Haze Air Quality Problems in the MANE-VU Region: A Conceptual Description*.

[4] Mid-Atlantic Northeast Visibility Union, "Contribution Assessment Preliminary Inventory Analysis."

MANE-VU limited this work to only these two screening analyses to determine which upwind states should be consulted with because of reduced resources within the MANE-VU States. These techniques are conservative, and, more importantly, visibility impacts are not one of the four factors for determining if a future air pollution control is "reasonable" for a state to undertake. The four factors are:

1. Costs of compliance;
2. Time necessary for compliance;
3. Energy and non-air quality environmental impacts; and
4. Remaining useful life of affected sources (40 CFR 51.308(d)(1)(i))

If visibility impacts were specifically determined, this information would not be useful in determining if a control is "reasonable" and would not advance the Clean Air Act mandate of the eventual elimination of all manmade visibility impacts on Class I areas. As a result, the screening work only goes as far as to develop weighted concentration data for use in determining which states have a high likelihood of affecting visibility in MANE-VU's Class I areas.

Support for Use of Q/d and CALPUFF for Screening

Q/d is largely accepted as a screening tool and continues to be as was the conclusion of a July 2015 report by an interagency air quality modeling work group.[5] This conclusion was supported by EPA due to Q/d being a highly conservative screening tool as found in a report by NACAA when assuming 100% conversion of SO_2 gas to the particulate form (NH_3SO_4) that affects visibility[6] EPA has also found that Q/d is well suited for determining the relative impacts for comparison purposes.[7] This means that Q/d lends itself well to determining which states, sectors, or sources have a larger relative impact and warrant further scrutiny.

The FLMs, through the FLAG process, suggest that using the Q/d test is an appropriate initial test when evaluating emissions from new sources "greater than 50 km from a Class I area to determine whether or not any further visibility analysis is necessary".[8] Since many of the sources being examined are well over 50 km from any of the MANE-VU Class I areas, the use of Q/d would appear to be supported.

A review of contribution analyses conducted by MANE-VU, including the previous two NESCAUM Q/d studies (CALPUFF analyses and REMSAD analysis) found similar results regardless of the method.[9] This is demonstrated in the correlation matrix in Table 1 where the ideal result would be that all of the tools produced the exact same results resulting in a correlation coefficient of 100%.

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[5] US EPA, *Interagency Work Group on Air Quality Modeling Phase 3 Summary Report: Near-Field Single Source Secondary Impacts*.

[6] National Association of Clean Air Agencies, *PM2.5 Modeling Implementation for Projects Subject to National Ambient Air Quality Demonstration Requirements Pursuant to New Source Review*.

[7] Baker and Foley, "A Nonlinear Regression Model Estimating Single Source Concentrations of Primary and Secondarily Formed PM2.5."

[8] US Forest Service, *Federal Land Managers' Air Quality Related Values Workgroup (FLAG) Phase I Report--Revised*.

[9] NESCAUM, *Contributions to Regional Haze in the Northeast and Mid-Atlantic United States*.

Table 1: Correlation coefficients obtained from comparing sulfate concentration results from four techniques10

	Q/D	REMSAD	CALPUFF (NWS)	CALPUFF (MM5)
Q/D	100%	93.01%	92.83%	91.86%
REMSAD		100%	95.12%	94.16%
CALPUFF (NWS)			100%	97.82%
CALPUFF (MM5)				100%

In the FLAG report, the FLM's stated that "CALPUFF is still the preferred first-level air quality model for calculating pollutant concentrations," with the first-level analysis being able to determine a relative change in light extinction.[11] In particular, the FLAG report recommends running 3 years of meteorology as was done as part of this work. As demonstrated in Table 1 CALPUFF produces similar results to REMSAD and Q/d as well. Additionally, some inaccuracies caused by CALPUFF's conservative results should be reduced by considering CALPUFF and Q/d on equal footing.

Although these methods are intended as screening tools, the previous analyses provide a precedent for using them to assess which states should be consulted with as part of the Regional Haze process.

Modeling Analysis

MANE-VU conducted two contribution analyses including a state modified Q/d analysis[12] and a CALPUFF dispersion modeling analysis.[13] Each is summarized in detail in separate reports. An overview as to how the information was incorporated in this analysis is in Table 2.

Table 2: Data Sources Used and Created

Data Sources Used:					
CALPUFF	2015	EGU	NO_X & SO_2	95th daily %tile	Used for relative impact and to provide NO_3/SO_4 chemistry ratio estimates for Q/d
	2011	EGU	NO_X & SO_2	95th daily %tile	Used to insert into 2015 for EGUs only modeled using 2011 emissions
	2011	ICI	NO_X & SO_2	typical day	Used for impact and to provide NO_3/SO_4 chemistry ratio estimates for Q/d
Q/d	2011	EGU	SO_4	annual	Used to validate Q/d State-wide data for SO_4
	2011	State-wide	SO_4	annual	Used to estimate 2015 statewide Q/d SO_4
Data Sources Created:					
Q/d	2015	State-wide	SO_4	annual	Used for relative impact
	2015	State-wide	NO_3	annual	Used for relative impact

The CALPUFF analyses considered 500 EGU and 121 ICI units throughout the eastern United States. For EGUs, the ninety-fifth percentile of daily NO_X and SO_2 emissions for 2011 and 2015 were modeled with three different years of meteorology (2002, 2011, and 2015) and the maximum value from three years of meteorology was used to assess contribution. The 2015 results were used directly in determining relative impact. However some EGUs were only modeled using 2011 emissions, and in these cases the 2011 emissions were scaled at the unit level to represent 2015 emissions at those particular EGUs and then were used to determine impact. Although several EGUs were modeled in Texas in the CALPUFF

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[10] Ibid.

[11] US Forest Service, *Federal Land Managers' Air Quality Related Values Workgroup (FLAG) Phase I Report--Revised*.

[12] Mid-Atlantic Northeast Visibility Union, *MANE-VU Updated Q/d*C Contribution Assessment*.

[13] Mid-Atlantic Northeast Visibility Union, *2016 MANE-VU Source Contribution Modeling Report*.

analysis, their locations were adjusted in that analysis to bring them within the modeling domain, which means that those results could not be used for relative contribution and thus the CALPUFF results from Texas were excluded from the analysis.

For ICI units, typical day NO_X and SO_2 emissions for 2011 were modeled with three different years of meteorology (2002, 2011, and 2015) and the maximum value from three years of meteorology was used to assess contribution. ICI units could not be scaled to 2015 since 2015 emissions were not available for those sources. The ICI results were used directly to determine relative impact.

No point sources were modeled with CALPUFF for the District of Columbia, Florida, Louisiana, Mississippi, Rhode Island, and Vermont due to either a lack of major point sources or that their geography was just beyond the modeling domain. As mentioned before with Texas, CALPUFF modeling was excluded in the contribution analysis.

The CALPUFF 2015 EGU and 2011 ICI relative contribution results for NO_3 and SO_4 were summed by state and are provided in Table 3.

Table 3: Summary of state level impacts from 2015 SO_4 and NO_3 from large point sources modeled using CALPUFF

Contrib.	*CALPUFF SO_4 ($\mu g/m^3$)*					*CALPUFF NO_3 ($\mu g/m^3$)*				
State	**Acadia**	**Brigantine**	**Great Gulf**	**Lye Brook**	**Moosehorn**	**Acadia**	**Brigantine**	**Great Gulf**	**Lye Brook**	**Moosehorn**
AL	0.437	0.634	0.226	0.284	0.310	0.060	0.189	0.059	0.079	0.053
AR	0.144	0.113	0.117	0.156	0.136	0.066	0.061	0.059	0.073	0.062
CT	0.144	0.109	0.068	0.140	0.127	0.072	0.151	0.103	0.127	0.112
DE	0.054	0.055	0.042	0.052	0.060	0.004	0.007	0.003	0.003	0.006
GA	0.323	0.521	0.352	0.272	0.203	0.089	0.109	0.092	0.073	0.060
IA	0.144	0.123	0.175	0.133	0.136	0.085	0.078	0.100	0.084	0.081
IL	0.194	0.315	0.329	0.217	0.243	0.068	0.080	0.097	0.069	0.059
IN	1.468	1.711	1.668	1.772	1.368	0.373	0.655	0.546	0.728	0.338
KS	0.039	0.047	0.040	0.060	0.041	0.001	0.001	0.001	0.002	0.001
KY	0.662	1.221	0.682	0.954	0.734	0.194	0.572	0.277	0.352	0.209
MA	0.687	0.347	0.246	0.269	0.425	0.302	0.191	0.232	0.115	0.223
MD	0.399	0.969	0.290	0.404	0.410	0.149	0.460	0.106	0.159	0.117
ME	0.458	0.268	0.349	0.304	0.521	0.262	0.066	0.303	0.246	0.156
MI	1.026	1.550	0.895	0.784	0.882	0.301	0.568	0.378	0.307	0.308
MN	0.044	0.073	0.061	0.058	0.032	0.051	0.069	0.071	0.066	0.047
MO	0.238	0.488	0.482	0.427	0.316	0.091	0.106	0.109	0.144	0.088
NE	0.040	0.054	0.086	0.049	0.038	0.012	0.018	0.030	0.016	0.011
NC	0.750	0.681	0.371	0.504	0.426	0.158	0.673	0.197	0.313	0.150
NH	0.319	0.145	0.266	0.150	0.406	0.410	0.284	0.750	0.193	0.265
NJ	0.063	0.108	0.042	0.051	0.058	0.035	0.155	0.046	0.067	0.029
NY	0.553	0.596	0.452	0.875	0.401	0.285	0.389	0.479	0.544	0.175
OH	2.388	2.810	1.997	3.218	1.970	0.513	1.102	0.827	0.940	0.565
OK	0.122	0.322	0.322	0.408	0.180	0.011	0.029	0.008	0.035	0.010
PA	2.449	4.991	4.077	4.669	2.215	0.767	3.215	0.940	1.685	0.919
SC	0.095	0.118	0.059	0.049	0.087	0.033	0.063	0.019	0.040	0.030
TN	0.292	0.491	0.150	0.210	0.220	0.049	0.184	0.057	0.076	0.052
VA	0.563	1.558	0.406	0.714	0.495	0.075	0.229	0.103	0.134	0.057
WI	0.050	0.080	0.128	0.116	0.059	0.051	0.072	0.122	0.088	0.043
WV	0.561	1.170	0.651	1.070	0.467	0.359	1.188	0.621	0.644	0.470
Total (excl. est. states)	**14.705**	**21.668**	**15.026**	**18.372**	**12.970**	**4.927**	**10.963**	**6.737**	**7.401**	**4.698**

The Q/d analysis considered several approaches to determining impact. Some of these used specific point source locations and some used state centroids. Some looked at both NO_X and SO_2 emissions and some only SO_2 emissions. Some looked at 2011 emissions and some looked at 2018. The Q/d study used dispersion factors developed during a similar analysis conducted by MANE-VU for the 2008 regional haze SIP process. The specific Q/d analyses taken forward in this study are the state-wide 2011 SO_2 emissions emanating from the state centroid. The state-wide results were chosen as the focus since they included emissions from mobile and area sources. This analysis was cross-checked with the analysis of point source specific 2011 SO_2 emissions emanating from the location of the point source for quality assurance purposes. The 2011 state-wide SO_2 emissions were then scaled to 2015 levels for use in the impact analysis. This was done by taking the ratio of 2015 SO_2 emissions to 2011 SO_2 emissions for the state and applying that to the 2011 Q/d contribution result. The resulting 2015 SO_4 Q/d results are presented in Table 4.

Table 4: Summary of state level impacts from 2011 and processed 2015 SO_4 state-wide emissions using Q/d

Contrib.	*SO_2 (annual tons)*		*2011 State Level Impacts*					*2015 State Level Impacts*				
State	2011	2015	Acadia	Brigantine	Great Gulf	Lye Brook	Moosehorn	Acadia	Brigantine	Great Gulf	Lye Brook	Moosehorn
AL	278,364	182,712	0.022	0.034	0.015	0.025	0.021	0.014	0.022	0.010	0.016	0.014
AR	93,232	76,057	0.006	0.009	0.007	0.007	0.006	0.005	0.007	0.005	0.006	0.005
CT	15,339	11,955	0.006	0.005	0.001	0.005	0.004	0.005	0.004	0.001	0.004	0.003
DC	1,829	236	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DE	13,891	2,700	0.003	0.026	0.002	0.002	0.002	0.001	0.005	0.000	0.000	0.000
FL	172,796	121,963	0.013	0.010	0.002	0.005	0.003	0.009	0.007	0.001	0.004	0.002
GA	234,683	67,691	0.025	0.035	0.014	0.017	0.018	0.007	0.010	0.004	0.005	0.005
IA	130,830	67,527	0.013	0.011	0.011	0.012	0.010	0.007	0.006	0.006	0.006	0.005
IL	287,830	149,995	0.035	0.031	0.030	0.033	0.037	0.018	0.016	0.016	0.017	0.019
IN	425,202	218,945	0.057	0.054	0.048	0.054	0.058	0.029	0.028	0.025	0.028	0.030
KS	60,379	25,469	0.005	0.004	0.004	0.004	0.005	0.002	0.002	0.002	0.002	0.002
KY	272,958	151,644	0.028	0.051	0.020	0.034	0.026	0.015	0.028	0.011	0.019	0.014
LA	236,912	148,015	0.015	0.021	0.010	0.016	0.014	0.009	0.013	0.006	0.010	0.009
MA	51,372	15,584	0.029	0.011	0.005	0.007	0.017	0.009	0.003	0.002	0.002	0.005
MD	71,945	44,540	0.015	0.063	0.010	0.014	0.011	0.010	0.039	0.006	0.008	0.007
ME	15,557	11,849	0.027	0.002	0.003	0.001	0.011	0.021	0.002	0.002	0.001	0.009
MI	273,632	162,175	0.044	0.027	0.039	0.044	0.030	0.026	0.016	0.023	0.026	0.018
MN	70,880	38,240	0.006	0.004	0.001	0.006	0.001	0.003	0.002	0.001	0.003	0.001
MO	261,903	152,685	0.026	0.022	0.021	0.023	0.027	0.015	0.013	0.012	0.013	0.016
MS	63,940	43,427	0.005	0.007	0.003	0.005	0.004	0.003	0.004	0.002	0.003	0.003
NC	118,723	52,997	0.017	0.030	0.010	0.012	0.012	0.008	0.014	0.004	0.005	0.005
NE	76,213	68,418	0.007	0.005	0.005	0.006	0.005	0.006	0.005	0.005	0.005	0.004
NH	31,261	6,918	0.017	0.006	0.006	0.005	0.013	0.004	0.001	0.001	0.001	0.003
NJ	18,008	8,895	0.005	0.015	0.001	0.003	0.003	0.003	0.007	0.000	0.002	0.002
NY	115,001	64,517	0.030	0.045	0.027	0.054	0.026	0.017	0.025	0.015	0.030	0.015
OH	680,421	249,640	0.111	0.123	0.098	0.116	0.080	0.041	0.045	0.036	0.043	0.029
OK	133,249	94,614	0.011	0.012	0.008	0.009	0.011	0.007	0.008	0.006	0.006	0.008
PA	398,659	252,340	0.076	0.144	0.062	0.132	0.016	0.048	0.091	0.039	0.084	0.010
RI	4,696	3,710	0.002	0.001	0.000	0.001	0.000	0.002	0.001	0.000	0.000	0.000
SC	103,244	34,465	0.013	0.020	0.007	0.009	0.009	0.004	0.007	0.002	0.003	0.003
TN	160,323	98,949	0.014	0.023	0.010	0.017	0.013	0.009	0.014	0.006	0.010	0.008
TX	559,803	383,717	0.031	0.040	0.021	0.032	0.029	0.021	0.027	0.014	0.022	0.020
VA	107,821	58,336	0.020	0.050	0.012	0.016	0.014	0.011	0.027	0.006	0.008	0.007
VT	3,450	1,478	0.002	0.001	0.004	0.001	0.002	0.001	0.000	0.002	0.000	0.001
WI	147,401	73,814	0.018	0.010	0.015	0.017	0.013	0.009	0.005	0.008	0.008	0.007
WV	122,785	76,580	0.016	0.040	0.012	0.022	0.015	0.010	0.025	0.008	0.014	0.009
Total	***5,544,346***	***3,072,403***	***0.737***	***0.942***	***0.518***	***0.727***	***0.540***	***0.390***	***0.501***	***0.274***	***0.395***	***0.283***

Nitrate impacts were not originally estimated using Q/d. At the time of the Q/d analysis, the recommendation of MANE-VU was to only estimate sulfates, however it has since been realized that an approximation of mobile and area source NO_X emissions was necessary to demonstrate the impact of those sectors on visbility impairment. In order to develop this estimate, the ratio of NO_3/SO_4 was calculated based on 2015 CALPUFF statewide averages and applied to the estimated 2015 SO_4 Q/d results. This ratio was chosen to approximate the differing chemsitry between NO_3 and SO_4 formation which is captured in the CALPUFF results and was accounted for on a ton-by-ton basis of each pollutant. Several states did not have CALPUFF NO_3/SO_4 ratio results so a surrogate was chosen as shown in Table 5. The full set of state level Q/d NO_3 calculations is in Table 6.

Table 5: Surrogate States for NO_3/SO_4 CALPUFF Ratio Calculations

STATE W/O CALPUFF RESULTS	DC	FL	LA	MS	RI	TX	VT
SURROGATE	MD	GA	AR	AL	CT	AR	NH

Table 6: Summary of state level impacts from processed 2015 NO_3 state-wide emissions using Q/d

Contrib. State	*NO_X (Annual Tons)*	*Acadia*	*Brigantine*	*Great Gulf*	*Lye Brook*	*Moosehorn*
AL	304,148	0.015	0.023	0.010	0.017	0.015
AR	193,075	0.014	0.019	0.014	0.015	0.013
CT	55,306	0.019	0.016	0.003	0.015	0.012
DC	7,263	0.002	0.006	0.001	0.002	0.001
DE	25,239	0.002	0.015	0.001	0.001	0.001
FL	497,837	0.026	0.021	0.004	0.011	0.006
GA	335,264	0.026	0.036	0.015	0.017	0.019
IA	186,490	0.019	0.016	0.016	0.017	0.014
IL	414,852	0.052	0.046	0.044	0.049	0.054
IN	344,858	0.036	0.035	0.031	0.035	0.037
KS	261,025	0.030	0.024	0.024	0.026	0.032
KY	256,751	0.020	0.037	0.014	0.024	0.019
LA	375,883	0.024	0.034	0.016	0.026	0.023
MA	111,784	0.060	0.023	0.011	0.014	0.035
MD	126,608	0.033	0.135	0.021	0.030	0.023
ME	49,090	0.256	0.019	0.029	0.011	0.108
MI	350,062	0.058	0.036	0.052	0.059	0.040
MN	239,171	0.019	0.012	0.003	0.021	0.004
MO	303,948	0.032	0.027	0.026	0.028	0.033
MS	144,231	0.006	0.009	0.004	0.007	0.006
NC	260,575	0.009	0.017	0.005	0.007	0.007
NE	175,037	0.013	0.010	0.011	0.011	0.009
NH	32,346	0.030	0.010	0.010	0.009	0.022
NJ	147,801	0.028	0.077	0.004	0.017	0.018
NY	306,614	0.124	0.183	0.112	0.219	0.107
OH	394,956	0.048	0.054	0.043	0.051	0.035
OK	328,105	0.027	0.030	0.021	0.022	0.028
PA	459,406	0.073	0.138	0.060	0.127	0.016
RI	23,814	0.009	0.005	0.002	0.002	0.002
SC	162,401	0.008	0.013	0.005	0.006	0.006
TN	245,434	0.012	0.020	0.009	0.014	0.011
TX	1,097,981	0.055	0.071	0.037	0.058	0.053
VA	259,624	0.025	0.065	0.015	0.020	0.018
VT	13,943	0.013	0.004	0.027	0.005	0.012
WI	211,154	0.046	0.025	0.039	0.042	0.033
WV	210,048	0.025	0.062	0.019	0.035	0.023
Total	***8,490,922***	***1.226***	***1.287***	***0.701***	***0.993***	***0.837***

Both techniques (Q/d and CALPUFF) provided estimates for potential visibility impacting masses. Rather than relying solely on one technique for identifying contributing states, both techniques were included by means of an average of each relative contribution calculation for NO_3 and SO_4. Since nitrates and sulfates have similar visibility impairment for similar ambient air concentrations, they weighted equally in the impact calculations and Q/D and CALPUFF results were also equally weighed when both were available. 2015 CALPUFF results were not available for the District of Columbia, Florida, Louisiana, Mississippi, Rhode Island, Texas, and Vermont so only Q/d results were considered for those states.

Table 7 provides average relative percent contributions for each analyzed state to five MANE-VU Class I Areas. The scores for the 36 states total 100 (or 100%). States listed towards the top of the table (in orange shading) are each estimated to contribute 3 percent or greater of the 36 state total contributions. States in the pink shade contribute 2 to 3 percent and states listed in green contribute less than 2 percent in this ranking. In addition, the table provides the maximum percentage that a state contributes any Class I area in MANE-VU and the average mass estimated by the four methods. The column furthest to the right provides a relative mass factor of NO_3 and SO_4 combined which was used as a filter to ensure the major NO_3 and SO_4 mass contributing states are identified and also to determine if a state contributing a relatively low amount of mass was identified as a contributing state at one or more of the MANE-VU Class I Areas. Figure 1 through Figure 5 provide maps of these results for five MANE-VU Class I Areas.

Table 7: Percent Mass-Weighted Sulfate and Nitrate Contribution for top 36 Eastern States to all MANE-VU Class I areas consolidated (maximum to any Class I area), individual MANE-VU Class I areas, and average contributed mass (mass factor)

Rank	Maximum		Acadia		Brigantine		Great Gulf		Lye Brook		Moosehorn		Mass Factor	
1	**PA**	20.0	**PA**	12.4	**PA**	19.9	**PA**	15.6	**PA**	20.0	**PA**	10.5	**PA**	2.11
2	**OH**	11.3	**OH**	10.1	**OH**	8.8	**OH**	10.9	**OH**	11.3	**OH**	10.2	**OH**	1.06
3	**NY**	10.0	**ME**	8.3	**MD**	6.5	**IN**	8.0	**NY**	10.0	**IN**	8.0	**IN**	0.64
4	**ME**	8.3	**IN**	6.9	**WV**	6.4	**NY**	7.6	**IN**	7.4	**TX**	6.3	**WV**	0.61
5	**IN**	8.0	**MI**	6.0	**NY**	6.1	**MI**	6.6	**TX**	5.4	**MI**	6.0	**MI**	0.54
6	**MI**	6.6	**NY**	5.8	**IN**	5.4	**TX**	4.9	**WV**	5.3	**NY**	5.9	**VA**	0.47
7	**MD**	6.5	**TX**	4.7	**TX**	5.1	**WV**	4.7	**MI**	5.1	**ME**	5.6	**KY**	0.47
8	**WV**	6.4	**MA**	4.4	**VA**	4.8	**IL**	3.7	**KY**	4.2	**WV**	4.8	**TX**	0.44
9	**TX**	6.3	**WV**	3.9	**KY**	4.7	**NH**	3.7	**IL**	2.7	**KY**	4.2	**NY**	0.42
10	**VA**	4.8	**NH**	3.4	**MI**	4.5	**KY**	3.6	**MO**	2.5	**IL**	3.9	**MD**	0.40
11	**KY**	4.7	**KY**	3.4	**NC**	2.7	**MO**	3.1	**LA**	2.4	**MA**	3.4	**NC**	0.34
12	**MA**	4.4	**IL**	2.8	**AL**	2.6	**ME**	2.9	**VA**	2.4	**MO**	3.3	**MA**	0.27
13	**IL**	3.9	**NC**	2.7	**LA**	2.5	**WI**	2.6	**NC**	2.3	**NH**	3.1	**NH**	0.26
14	**NH**	3.7	**MD**	2.7	**NJ**	2.2	**LA**	2.2	**MD**	2.3	**LA)**	2.8	**ME**	0.25
15	**MO**	3.3	**VA**	2.5	**IL**	2.1	**VA**	2.1	**AL**	2.03	**MD**	2.6	**AL**	0.22
16	**LA**	2.8	**MO**	2.4	**TN**	2.01	**NC**	2.1	**WI**	1.9	**AL**	2.5	**LA**	0.21
17	**NC**	2.7	**AL**	2.2	**GA**	1.97	**MD**	2.1	**OK**	1.6	**VA**	2.4	**TN**	0.18
18	**AL**	2.6	**FL**	2.1	**MO**	1.9	**VT**	2.1	**ME**	1.6	**NC**	2.2	**GA**	0.17
19	**WI**	2.6	**LA**	2.1	**FL**	1.5	**AL**	1.8	**TN**	1.5	**OK**	1.8	**MO**	0.16
20	**NJ**	2.2	**GA**	1.9	**MA**	1.4	**OK**	1.8	**GA**	1.3	**WI**	1.8	**FL**	0.13
21	**FL**	2.1	**WI**	1.8	**OK**	1.4	**MA**	1.8	**IA**	1.2	**TN**	1.7	**IL**	0.12
22	**VT**	2.1	**TN**	1.5	**NH**	1.1	**GA**	1.8	**MA**	1.2	**GA**	1.7	**OK**	0.12
23	**TN**	2.01	**IA**	1.5	**NE**	1.0	**IA**	1.7	**CT**	1.2	**IA**	1.5	**VT**	0.09
24	**GA**	1.97	**CT**	1.3	**AR**	1.0	**AR**	1.3	**AR**	1.2	**CT**	1.4	**NJ**	0.09
25	**OK**	1.8	**OK**	1.2	**CT**	1.0	**TN**	1.3	**NH**	1.1	**AR**	1.4	**IA**	0.07
26	**IA**	1.7	**AR**	1.2	**WI**	0.9	**KS**	1.0	**MN**	1.0	**KS**	1.2	**WI**	0.07
27	**CT**	1.4	**NJ**	1.0	**ME**	0.9	**NE**	0.8	**FL**	1.0	**NJ**	0.9	**CT**	0.07
28	**AR**	1.4	**MN**	0.9	**IA**	0.9	**CT**	0.7	**KS**	0.8	**MS**	0.8	**MS**	0.07
29	**KS**	1.2	**KS**	0.8	**SC**	0.8	**MS**	0.7	**NJ**	0.8	**NE**	0.8	**AR**	0.06
30	**NE**	1.0	**NE**	0.8	**MS**	0.8	**SC**	0.5	**MS**	0.7	**VT**	0.8	**SC**	0.05
31	**MN**	1.0	**SC**	0.8	**DE**	0.6	**MN**	0.5	**NE**	0.6	**SC**	0.8	**MN**	0.04
32	**MS**	0.8	**MS**	0.6	**KS**	0.6	**FL**	0.5	**SC**	0.5	**FL**	0.7	**NE**	0.03
33	**SC**	0.8	**VT**	0.6	**MN**	0.6	**NJ**	0.4	**VT**	0.3	**MN**	0.5	**RI**	0.02
34	**DE**	0.6	**RI**	0.5	**RI**	0.3	**RI**	0.2	**RI**	0.2	**DE**	0.2	**KS**	0.02
35	**RI**	0.5	**DE**	0.2	**DC**	0.2	**DE**	0.2	**DE**	0.1	**RI**	0.1	**DE**	0.02
36	**DC**	0.2	**DC**	0.1	**VT**	0.2	**DC**	0.1	**DC**	0.1	**DC**	0.1	**DC**	0.016

Figure 1: States Contributing to 2011 Visibility Impairment at Acadia Based on Mass Weighting Analysis

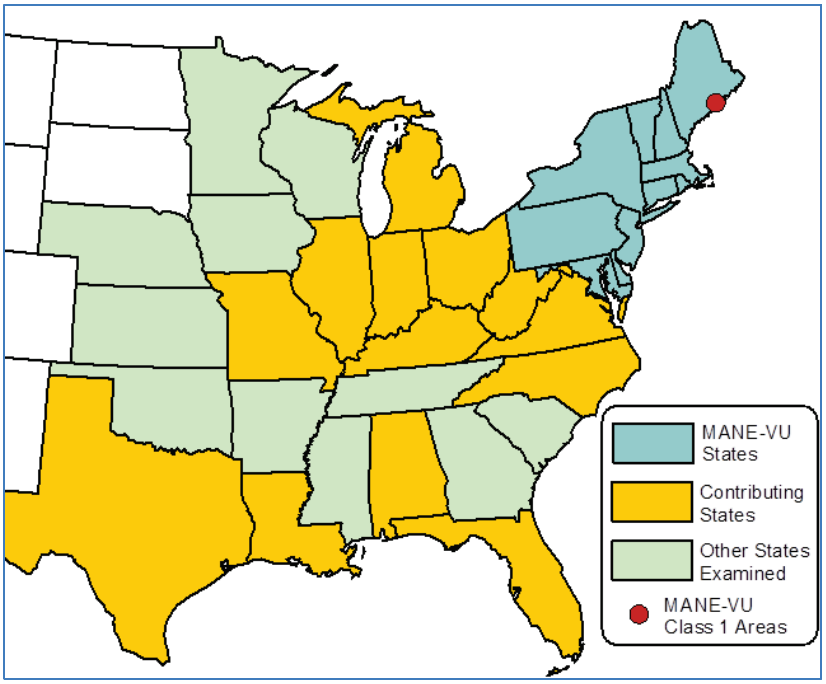


Figure 2: States Contributing to 2011 Visibility Impairment at Brigantine Based on Mass Weighting Analysis

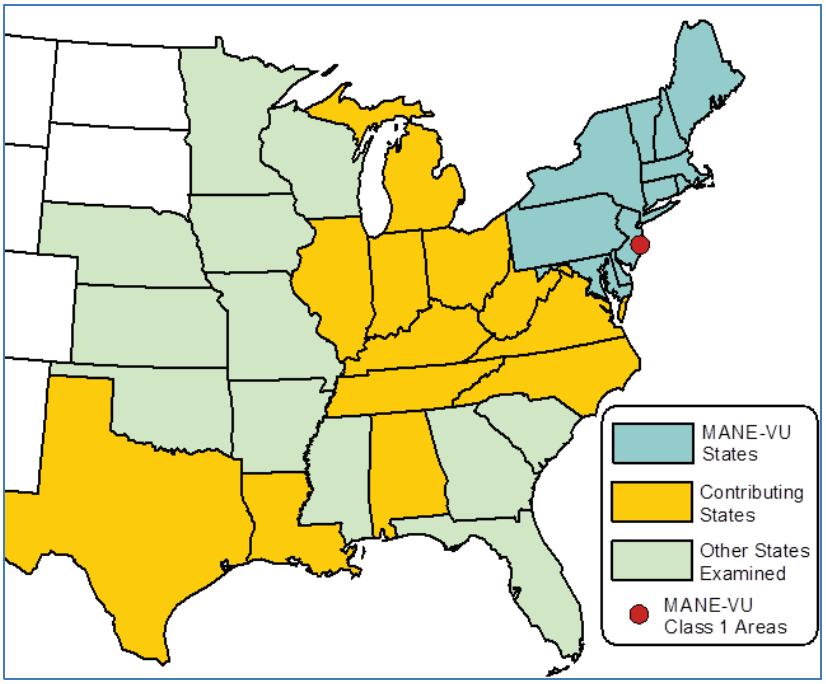


Figure 3: States Contributing to 2011 Visibility Impairment at Great Gulf Based on Mass Weighting Analysis

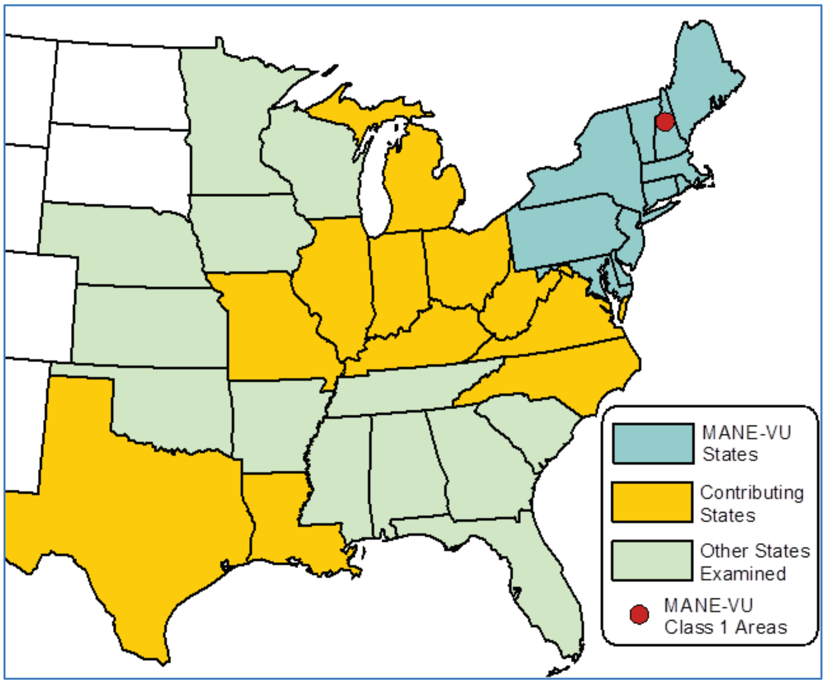


Figure 4: States Contributing to 2011 Visibility Impairment at Lye Brook Based on Mass Weighting Analysis

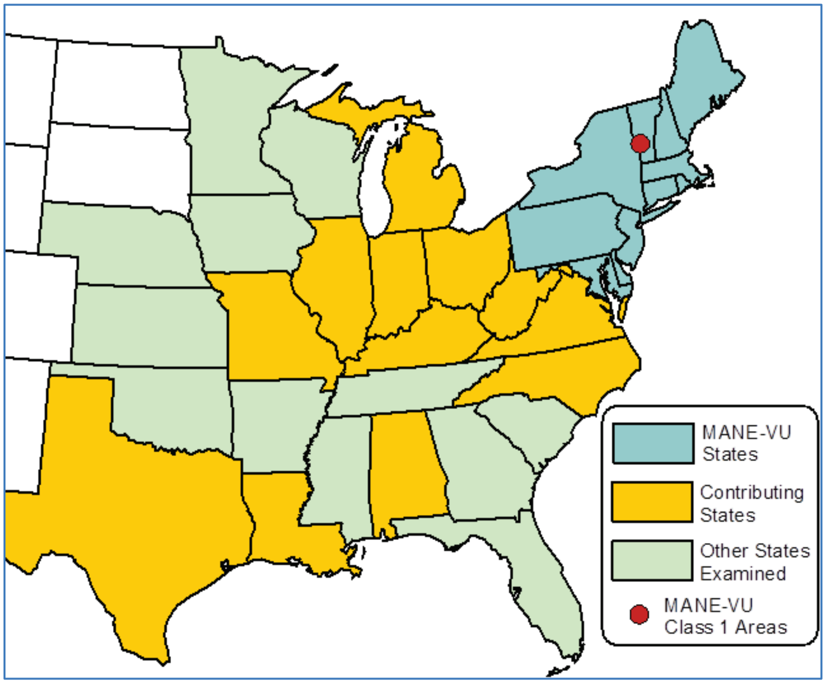


Figure 5: States Contributing to 2011 Visibility Impairment at Moosehorn Based on Mass Weighting Analysis

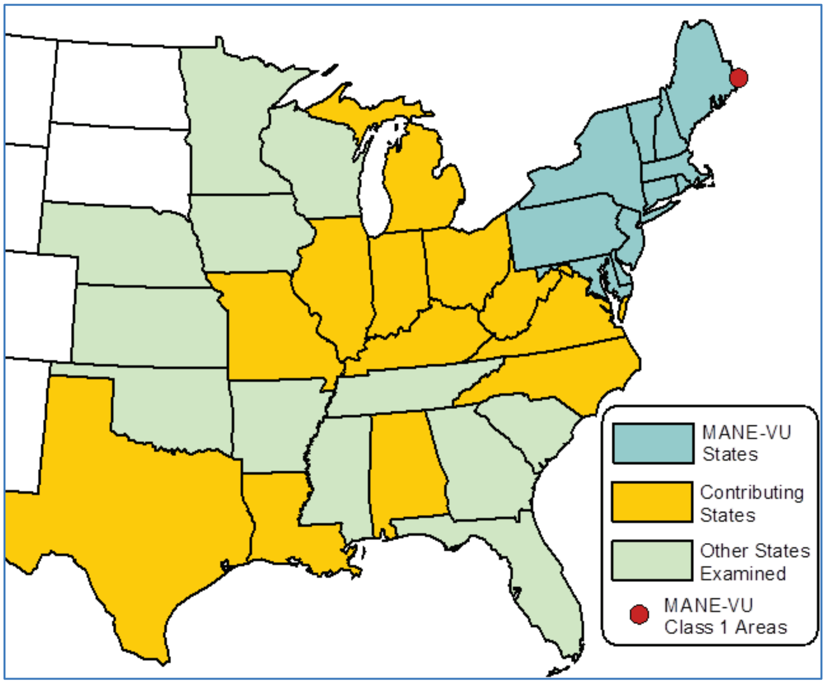
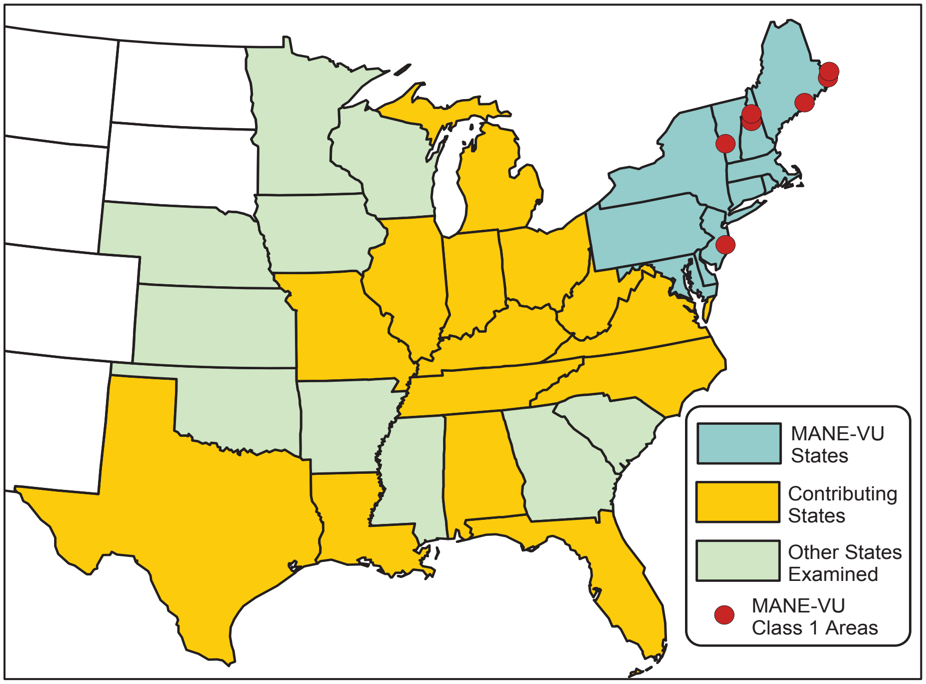


Figure 6 provides a consolidated map for the five MANE-VU Class I Areas (Acadia, Brigantine, Great Gulf, Lye Brook, and Moosehorn). If a state was estimated to contribute two percent or more at any of the five Class I Areas it was considered to be a contributing state. In addition, states were removed from consideration if their mass factor was below 1% (0.01 µg/m^3).

Figure 6: States Contributing to 2011 Visibility Impairment at MANE-VU Class I Areas Based on Mass Weighting Analysis



Trajectory Analysis

A trajectory analysis was also conducted by MANE-VU to better understand the source areas of the country where wind patterns transported emissions during the 20% most impaired visibility days in a MANE-VU Class I area. The analysis considered the 20% most impaired visibility days during 2002, 2011 and 2015 at each of the MANE-VU Class I Areas, excepting Lye Brook in 2015 where 20% most impaired days were not available so the 20% worst visibility days were used. Details of this analysis are contained in a separate report.[14] Having this analysis provides a qualitative opportunity to cross check the reasonability for including states highlighted in Figure 6 in the MANE-VU 2018 SIP consultation process.

The 500m trajectories were modeled by NOAA's HYSPLIT model, which was consistent with analyses conducted in the previous planning period.[15] 72-hour back trajectories were created 4 times per day at 3AM & PM and 9AM & PM. 2002 trajectories used EDAS 89 km MET and 2011 and 2015 used 40 km. Grid cells are 25 x 25 miles. Examples of the back trajectories for Acadia and Brigantine are Figure 7 and Figure 8. In order to determine how potential contributing states align with 72-hour back trajectories on 20% most impaired visibility days, percentages of trajectories per state were calculated.

Figure 7: Trajectory analyses of Acadia National Park most impaired days during 2015

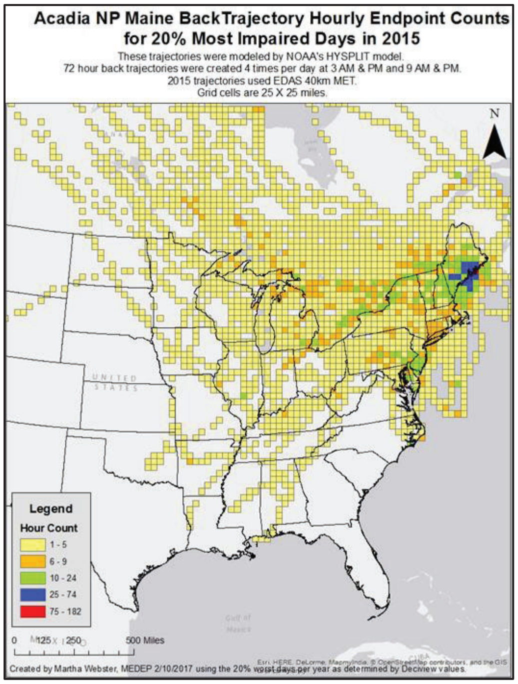
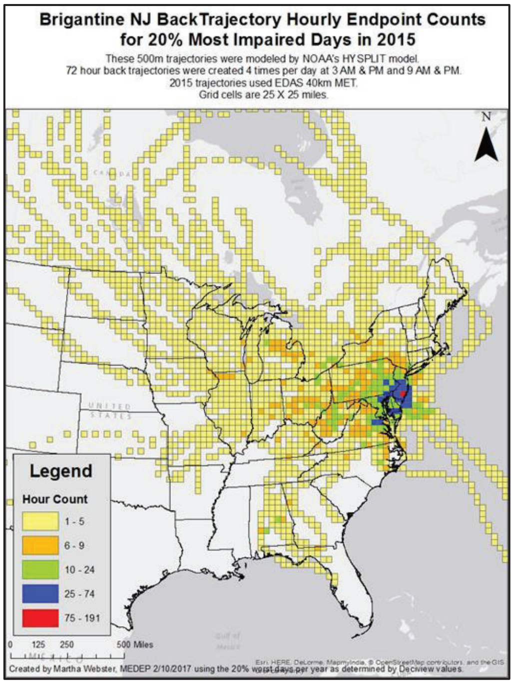


Figure 8: Trajectory analyses of Brigantine National Wildlife Refuge most impaired days during 2015



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[14] Mid-Atlantic Northeast Visibility Union, *Regional Haze Metrics Trends and HYSPLIT Trajectory Analyses*.

[15] NESCAUM, *Contributions to Regional Haze in the Northeast and Mid-Atlantic United States*.

In general, the trajectories support the results from the consolidated identification of contributing states. There is strong support for consultation with states located to the west and immediate south of the MANE-VU area. States of Indiana, Illinois, Kentucky, Maryland, Michigan, Missouri, New York, Ohio, Pennsylvania, Virginia and West Virginia were strongly tied to trajectories on 20% most impaired visibility days at each of the five MANE-VU Class I Areas assessed. Trajectory analyses further suggest that Wisconsin and Iowa are frequently upwind on many 20% most impaired visibility days. Modeling suggests that Wisconsin had enough emissions to qualify as a 2% regional haze contributor in 2011, but Iowa did not produce enough emissions to reach the 2% contribution threshold.

20% most impaired visibility day trajectories to the MANE-VU Class I Areas passed over the southern states less frequently than they did with states to the west and immediate south of the OTR. However in virtually all cases, at least one trajectory passed over other states that were identified by modeling as being 2 and 3 percent contributing states. This enables enough total emission contribution to cause a 20% most impaired visibility day.

It appears that the 20% most impaired visibility days at MANE-VU Class I areas are dominated by the clustering of large contributing states which offer a larger total mass of emissions than states along other trajectories. This includes most of the states identified by modeling as contributing states to MANE-VU Class I area visibility impairment. Beyond these states, modeling identified Alabama, Florida, Louisiana and Texas as 2% contributing states, which suggests they have the potential with their actual emissions to cause notable visibility impairment. In each case, trajectory analyses identified weaker connections on 20% most impaired visibility days in the MANE-VU region. These states are relatively isolated from other states identified by modeling as being larger visibility impacting states, and thus lack a cumulative impact and frequency that a clustering of higher emitting states have in order to create 20% most impaired visibility days. When a 20% most impaired visibility day trajectory does pass over Alabama, Florida, Louisiana or Texas, it also passes over at least one of the other 2% contribution states, which likely adds enough additional pollutant mass to create a 20% most impaired visibility day.

Modeling and trajectory analyses appear to support Alabama, North Carolina and Tennessee as being 2% contribution states. Each has sufficient emissions to cause some degree of visibility impact in the MANE-VU area and the trajectories suggest a connection on 20% most impaired visibility days, even if they are not as frequent as other states.

In summary, trajectory analysis supports the list of states identified in Table 7 by the consolidated modeling effort for the purpose of initiating the regional haze consultation process.

Table 8: Percentage of Trajectories per State on 20% most impaired visibility days

State	Acadia			Brigantine			Great Gulf			Lye Brook			Moosehorn		
	2002	2011	2015	2002	2011	2015	2002	2011	2015	2002	2011	2015	2002	2011	2015
AL	0.27%	0.45%	0.65%	0.61%	0.00%	1.44%	0.07%	0.00%	0.67%	0.71%	0.42%	0.04%	0.40%	0.31%	0.48%
AR	0.25%	0.25%	0.50%	0.83%	0.52%	0.28%	0.38%	0.52%	0.00%	0.44%	0.00%	0.34%	0.64%	0.17%	0.25%
CT	0.78%	0.61%	0.79%	0.63%	0.24%	0.25%	0.81%	1.78%	0.61%	1.55%	1.60%	2.33%	0.71%	0.57%	0.28%
DC	0.00%	0.00%	0.00%	0.03%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.03%	0.00%	0.00%	0.00%	0.00%
DE	0.16%	0.10%	0.29%	1.10%	1.27%	1.58%	0.06%	0.11%	0.02%	0.38%	0.29%	0.31%	0.20%	0.06%	0.29%
FL	0.37%	0.38%	0.01%	0.47%	0.00%	0.48%	0.00%	0.00%	0.00%	0.24%	0.13%	0.00%	0.25%	0.17%	0.09%
GA	0.28%	0.33%	0.07%	0.36%	0.06%	0.78%	0.33%	0.00%	0.15%	0.29%	0.41%	0.27%	0.58%	0.38%	0.06%
IA	0.59%	0.65%	0.65%	1.40%	1.57%	1.19%	0.58%	0.77%	1.05%	1.57%	0.00%	0.57%	0.52%	0.60%	0.63%
IL	1.14%	1.11%	1.66%	1.93%	3.46%	2.48%	1.72%	1.65%	1.37%	2.94%	0.44%	2.82%	1.31%	0.73%	1.35%
IN	0.82%	1.44%	1.01%	1.78%	3.63%	2.19%	1.23%	1.48%	1.15%	3.79%	0.83%	2.12%	1.07%	1.15%	1.02%
KS	0.58%	0.17%	0.07%	0.47%	0.30%	0.25%	0.13%	0.21%	0.00%	0.26%	0.00%	0.18%	0.22%	0.58%	0.52%
KY	1.01%	0.72%	1.15%	1.60%	1.36%	1.54%	1.63%	1.01%	1.53%	1.54%	1.39%	2.03%	0.89%	0.83%	0.81%
LA	0.00%	0.32%	0.06%	0.17%	0.06%	0.00%	0.01%	0.00%	0.10%	0.02%	0.11%	0.30%	0.09%	0.35%	0.00%
MA	2.27%	1.36%	0.82%	0.27%	0.37%	0.16%	1.30%	2.48%	1.56%	1.25%	2.87%	2.07%	1.69%	1.42%	0.64%
MD	0.70%	0.23%	0.84%	3.10%	2.55%	3.78%	0.32%	0.98%	0.44%	1.34%	1.94%	1.70%	0.35%	0.15%	0.95%
ME	9.23%	9.22%	9.63%	0.27%	0.03%	0.39%	1.89%	2.95%	3.05%	0.17%	0.67%	0.46%	15.72%	12.95%	11.52%
MI	2.06%	2.31%	3.96%	3.43%	5.32%	3.32%	2.24%	2.35%	3.36%	5.28%	2.09%	2.67%	1.37%	1.26%	3.38%
MN	1.17%	0.64%	1.25%	1.67%	1.02%	1.80%	1.10%	0.38%	1.88%	1.72%	0.47%	0.72%	0.35%	0.92%	0.64%
MO	1.51%	0.20%	0.28%	1.75%	0.96%	1.03%	1.14%	0.86%	0.49%	0.95%	0.00%	1.76%	0.55%	0.28%	0.65%
MS	0.38%	0.56%	0.15%	1.05%	0.34%	0.00%	0.14%	0.36%	0.21%	0.59%	0.29%	0.24%	0.45%	0.29%	0.22%
NC	0.73%	0.95%	0.55%	3.11%	1.54%	2.00%	0.77%	0.47%	0.00%	1.21%	1.08%	1.84%	0.38%	1.00%	1.22%
NE	0.00%	0.06%	0.00%	0.52%	0.43%	0.20%	0.46%	0.11%	0.31%	0.21%	0.00%	0.18%	0.03%	0.47%	0.25%
NH	2.57%	3.12%	1.92%	0.11%	0.51%	0.19%	6.97%	8.92%	8.05%	0.17%	0.42%	0.70%	2.22%	2.17%	1.09%
NJ	0.56%	0.91%	1.07%	7.19%	6.47%	8.02%	1.00%	0.73%	0.36%	2.73%	1.37%	1.87%	1.08%	0.42%	0.55%
NY	6.77%	6.82%	5.08%	3.02%	4.29%	3.51%	14.83%	14.09%	11.57%	17.45%	22.11%	19.80%	8.70%	4.20%	4.25%
OH	1.97%	2.04%	1.37%	3.90%	5.42%	4.25%	4.42%	1.97%	2.45%	3.50%	2.51%	2.79%	1.86%	1.53%	1.25%
OK	0.92%	0.26%	0.22%	0.33%	0.19%	0.09%	0.00%	1.19%	0.00%	0.26%	0.00%	0.09%	0.06%	0.36%	0.36%
PA	3.83%	3.58%	4.21%	7.25%	13.58%	9.87%	6.52%	5.38%	3.84%	11.64%	9.65%	7.07%	2.67%	2.65%	2.30%
RI	0.11%	0.14%	0.10%	0.06%	0.04%	0.06%	0.14%	0.03%	0.16%	0.17%	0.13%	0.07%	0.10%	0.07%	0.04%
SC	0.27%	0.26%	0.00%	0.57%	0.00%	0.09%	1.14%	0.00%	0.00%	0.85%	0.31%	0.60%	0.33%	0.19%	0.06%
TN	0.47%	0.25%	0.37%	0.98%	0.46%	0.70%	0.46%	1.03%	0.99%	0.47%	0.91%	0.70%	0.74%	0.32%	0.48%
TX	0.23%	0.74%	0.03%	0.00%	0.07%	0.03%	0.00%	0.05%	0.00%	0.03%	0.00%	0.00%	0.25%	0.20%	0.38%
VA	0.82%	0.68%	0.51%	5.22%	4.05%	5.51%	0.98%	1.11%	1.15%	1.34%	3.57%	2.84%	1.04%	0.25%	1.95%
VT	2.07%	2.08%	1.63%	0.13%	0.30%	0.12%	4.86%	7.60%	5.04%	2.66%	3.93%	3.94%	1.40%	0.90%	1.16%
WI	2.07%	0.61%	1.65%	4.09%	4.98%	2.06%	1.24%	0.83%	1.93%	2.75%	0.62%	0.88%	1.33%	0.60%	1.99%
WV	0.73%	0.36%	0.59%	2.47%	1.95%	3.64%	1.24%	0.62%	1.02%	0.81%	2.61%	1.45%	0.49%	0.32%	0.63%

Summary

MANE-VU considered the results of a weight-of-evidence approach that looked at Q/d calculations, CALPUFF modeling, and HYSPLIT back trajectories in assessing which upwind states contributed to visibility impairment at a level that it would be reasonable to consult with. In conducting this assessment MANE-VU considered emissions from EGUs and ICI units predominately, but also included state-wide emissions to account for the impact of area and mobile sources. Since impairment from winter nitrates have increased percentage wise in several MANE-VU Class I areas, SO_2 and NO_X emissions were both considered. 2015 emissions were either directly considered or estimated so that recent changes in the make-up of the emissions inventory were considered. When these factors were considered, states that contributed 2% or more of the visibility impairment and had an average mass impact of over 1% (0.01 μg/m^3) were considered to be necessary to consult with as part of the Regional Haze SIP process. This lead to the 14 upwind states in 3 upwind RPOs in Table 9 being considered necessary to consult with.

Table 9: States in each upwind RPO that are considered contributing to a MANE-VU Class I area

LADCO	Illinois	Indiana	Ohio	Michigan			
SESARM	Alabama	Florida	Kentucky	N. Carolina	Tennessee	Virginia	W. Virginia
CENSARA	Louisiana	Missouri	Texas				