Appendix 9a - Baseline Visibility Conditions, Pollutant Contributions, Needed Visibility Improvement and Glide Paths for the Uniform Rate of Progress

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For the 20% worst visibility days in the northern Class 1 areas, the pollutants that contribute to visibility impairment are sulfates, which represent 35-55% impairment, nitrates are 25-30% of the pollutant contribution and organic carbon contributes 12-22% to visibility impairment . These results are shown below in Figure 1.

Figure 1. 20% Best Days 20% Worst Days

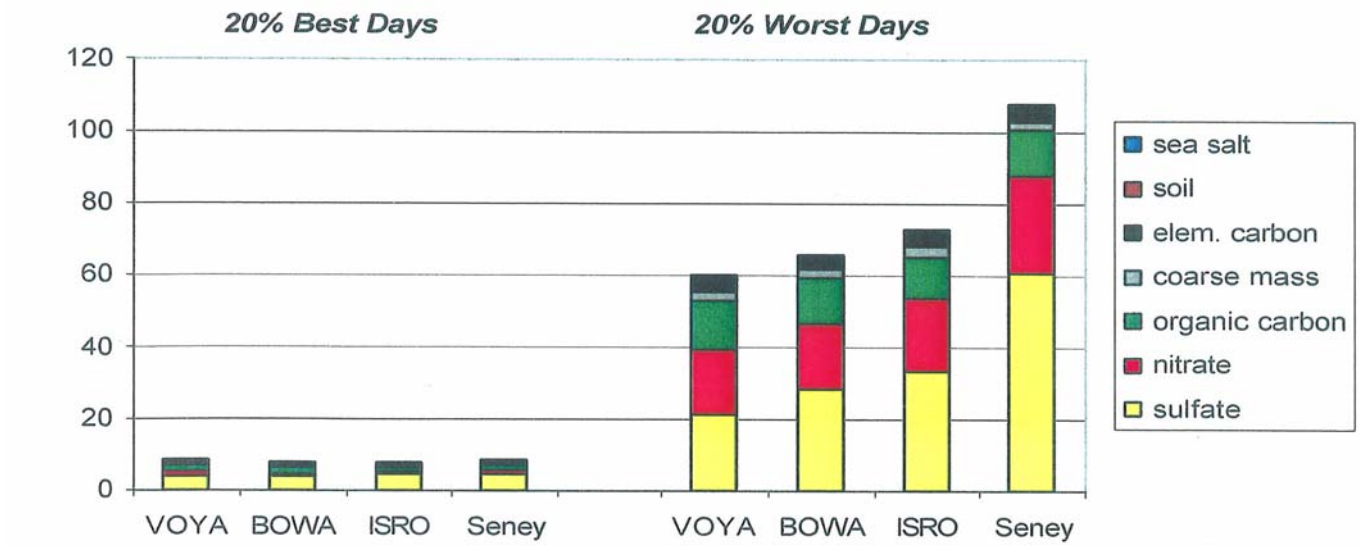
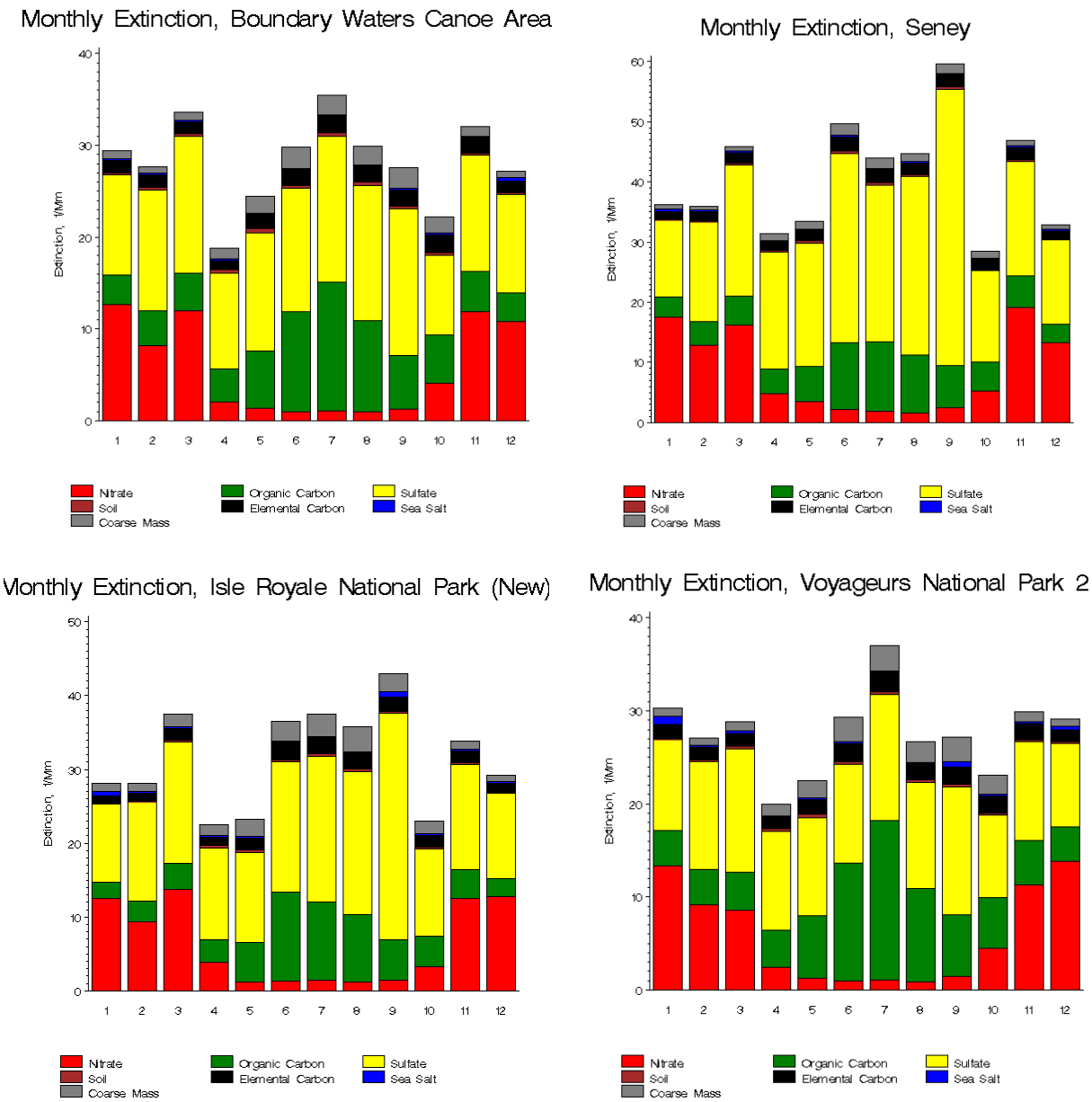


Figure 1. Chemical composition of light extinction for 20% best visibility days (left) and 20% worst visibility days (right) in terms of Mm^{-1}

Monthly average light extinction values for the northern Class 1 areas are shown below in Figure 2. Sulfates represent the highest contributing pollutant to light extinction with nitrates and organic carbon providing seasonal contributions. Nitrates have higher contributions during the late fall, winter and early spring while organic carbon has higher contributions to light extinction during the summer. Elemental carbon, and coarse mass are fairly consistent throughout the year at all northern Class 1 areas.

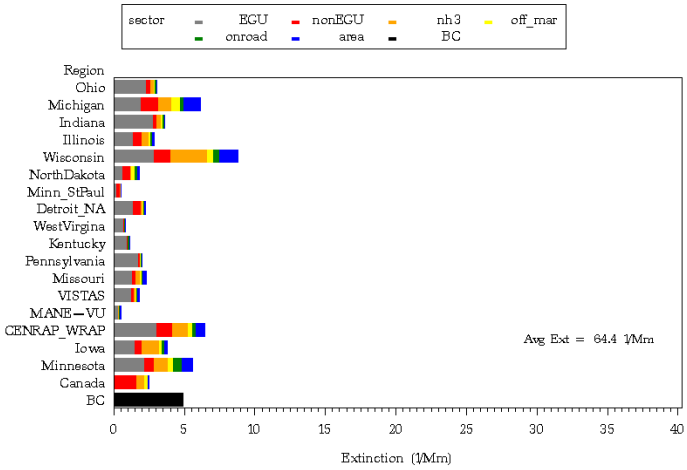
Figure 2. Monthly Average Light Extinction Values for Northern Class 1 Areas



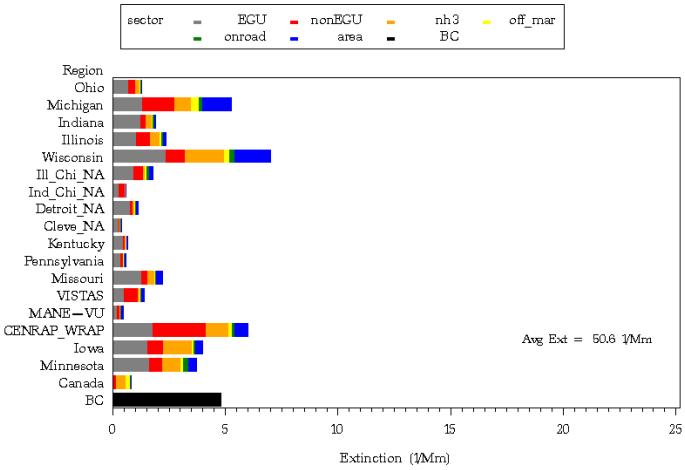
LADCO conducted photochemical modeling for baseline and future year light extinction. This source apportionment modeling analyzed regional, source and pollutant impacts on visibility at Isle Royale in Michigan (as shown below in Figure 3); Mammoth Cave National Park in Kentucky (Figure 4); Shenandoah National Park in Virginia (Figure 5); and Lye Brook Wilderness in Vermont (Figure 6). Indiana's contributions to visibility impairment in the northern Class 1 areas of Isle Royale, Seney and Boundary Waters, comprises mainly of sulfates from EGU emissions.

Figure 3. Isle Royale, Michigan

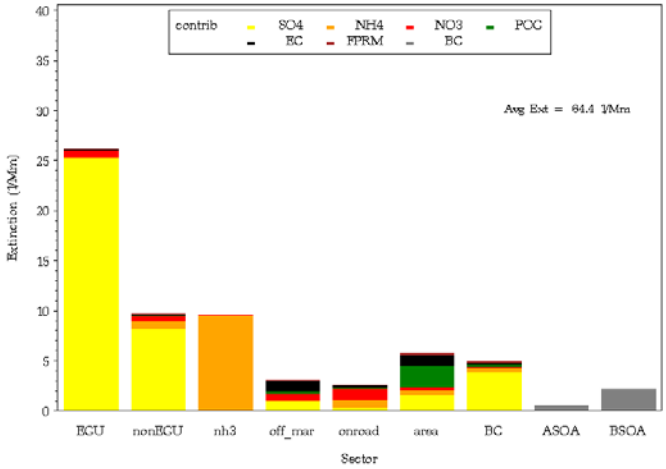
2005 (LADCO Round 5)



2018 (LADCO Round 5)



2005 (LADCO Round 5)



2018 (LADCO Round 5)

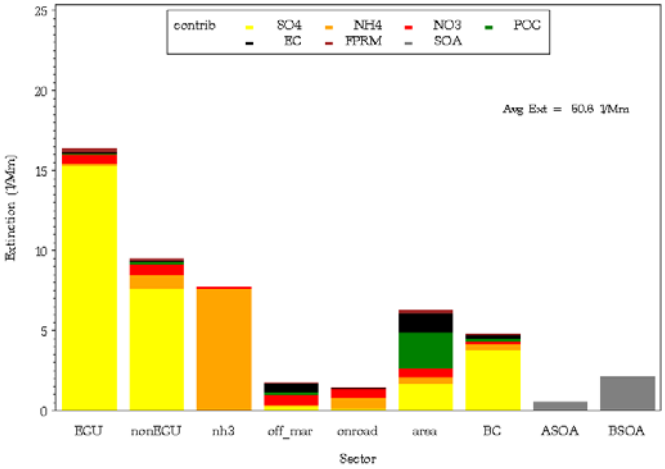
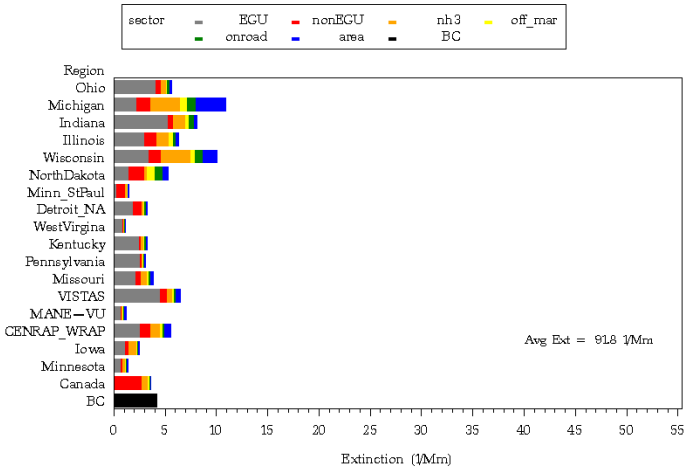
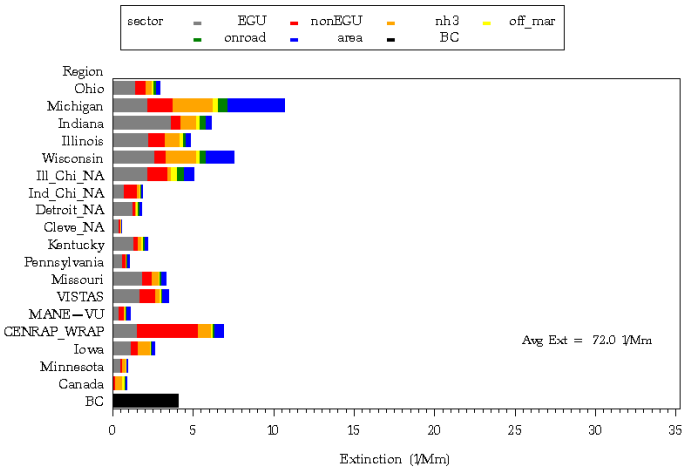


Figure 4. Seney, Michigan

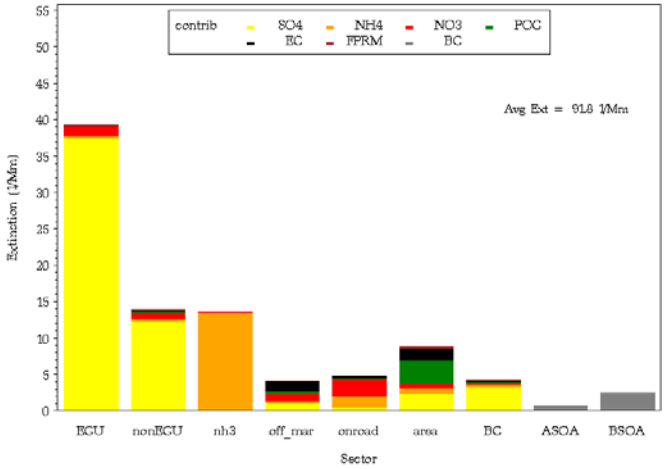
2005 (LADCO Round 5)



2018 (LADCO Round 5)



2005 (LADCO Round 5)



2018 (LADCO Round 5)

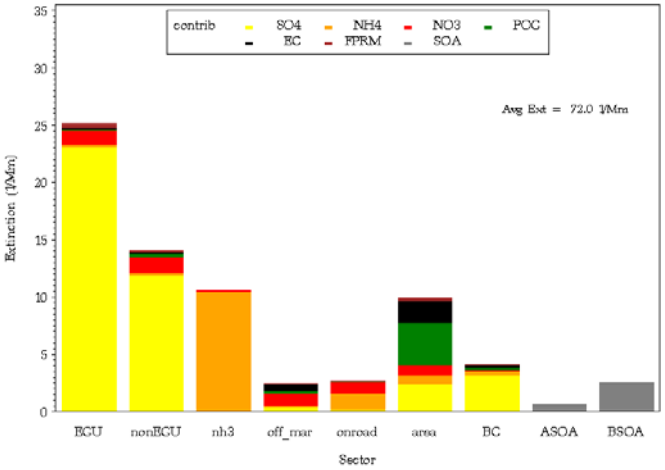
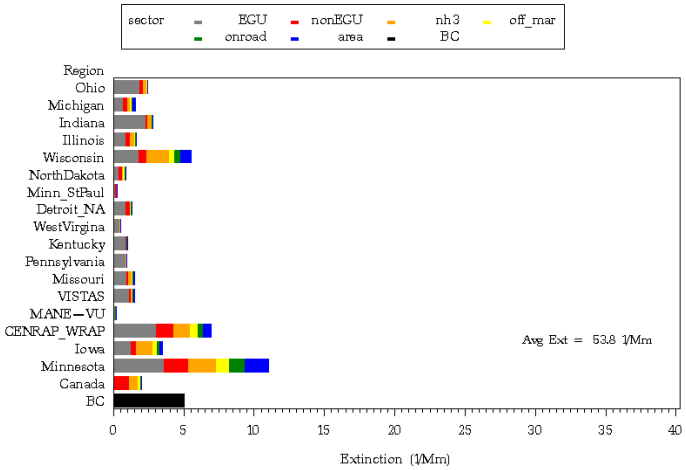
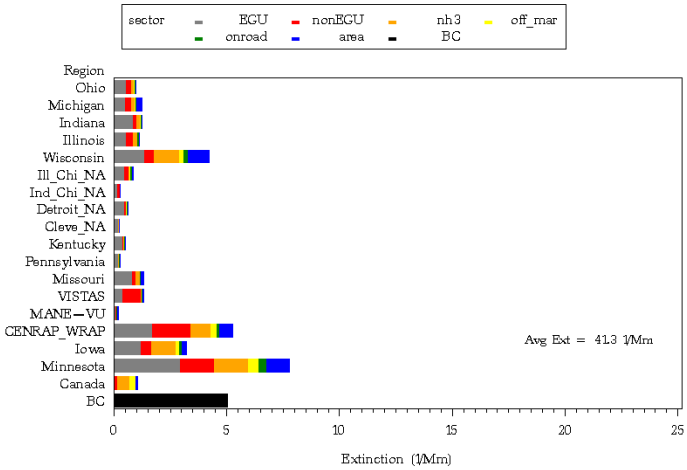


Figure 5. Boundary Waters, Minnesota

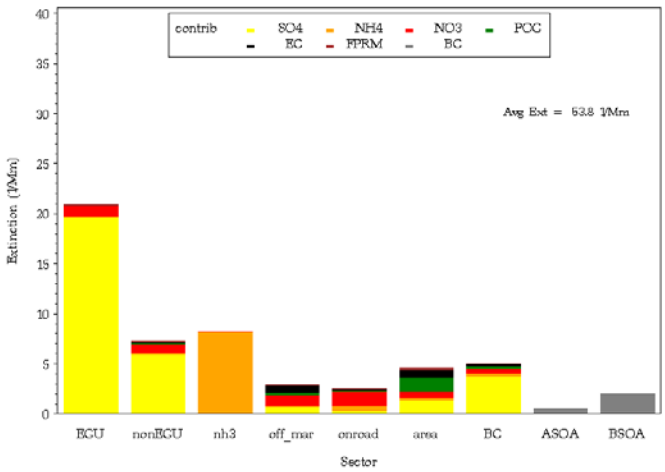
2005 (LADCO Round 5)



2018 (LADCO Round 5)



2005 (LADCO Round 5)



2018 (LADCO Round 5)

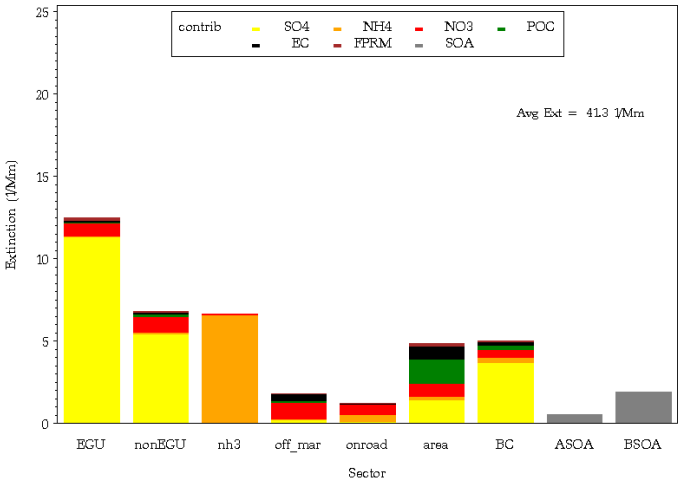
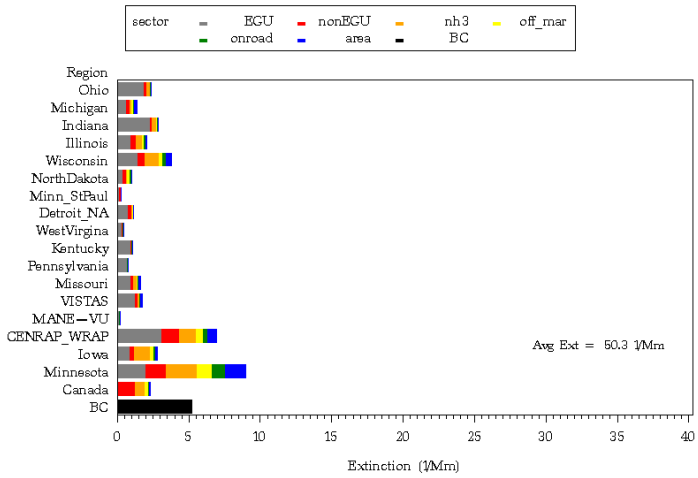
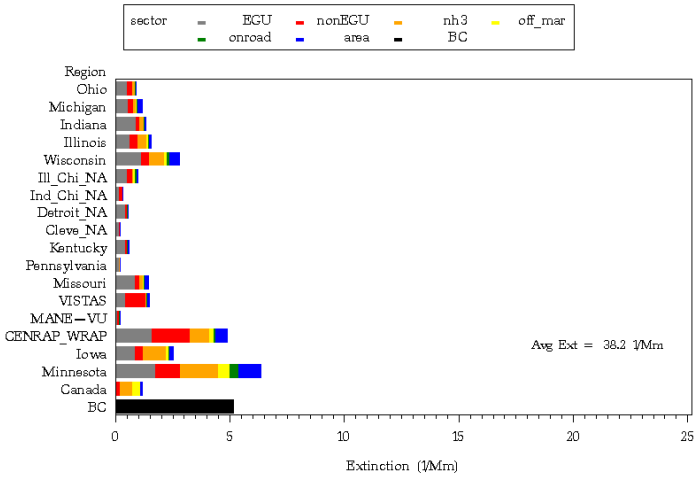


Figure 6. Voyageurs, Minnesota

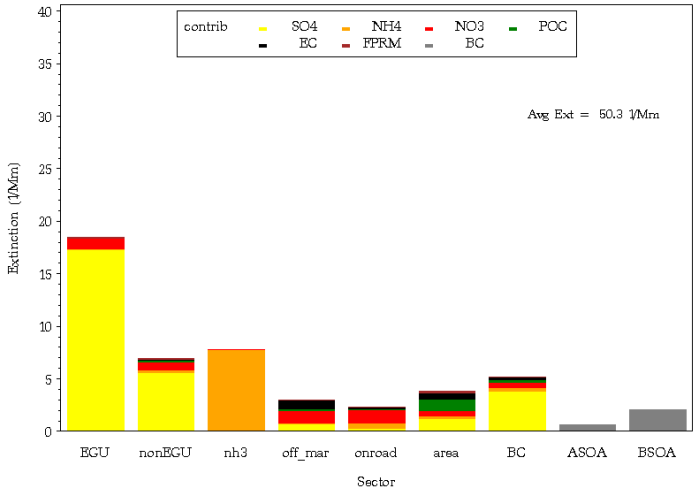
2005 (LADCO Round 5)



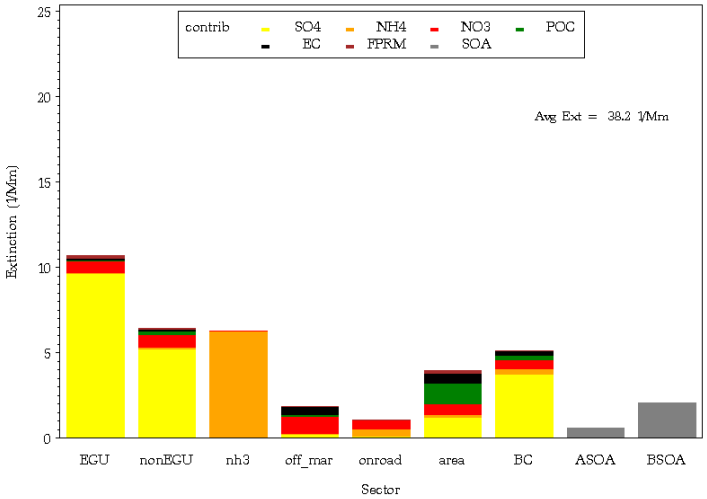
2018 (LADCO Round 5)



2005 (LADCO Round 5)



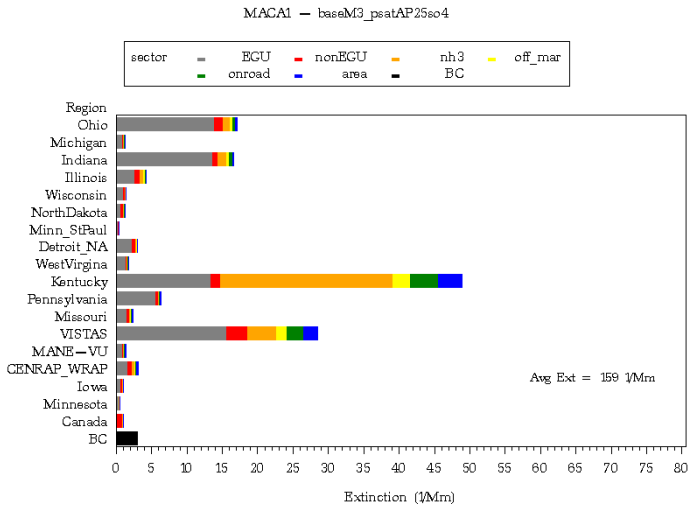
2018 (LADCO Round 5)



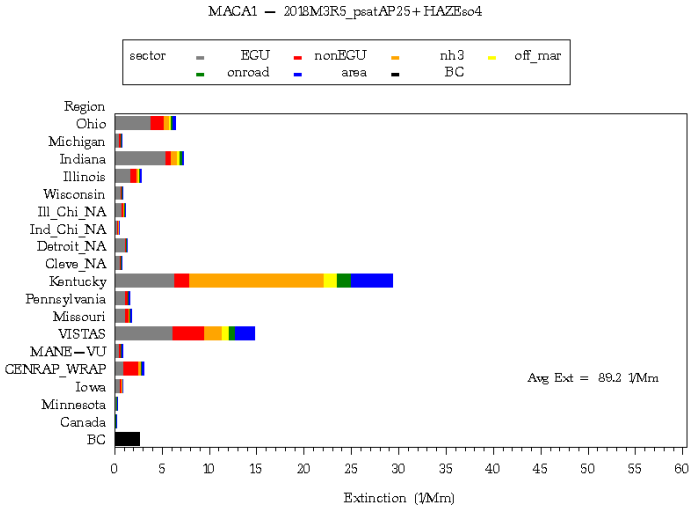
Indiana contributions to visibility impairment at Mammoth Cave, Kentucky comprise mostly of sulfates emissions from EGUs, as shown in Figure 7. Indiana's contributions to light extinction are expected to decrease through 2018 and overall light extinction at Mammoth Cave is expected to be approximately half of the light extinction modeled for 2005.

Figure 7. Mammoth Cave, Kentucky

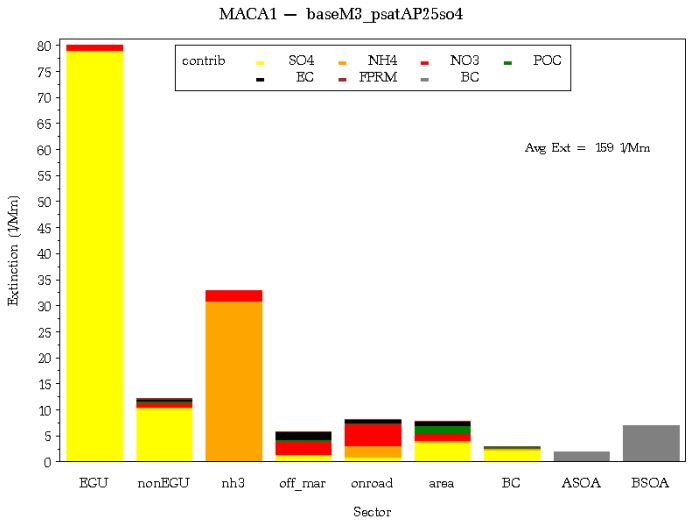
2005 (LADCO Round 5)



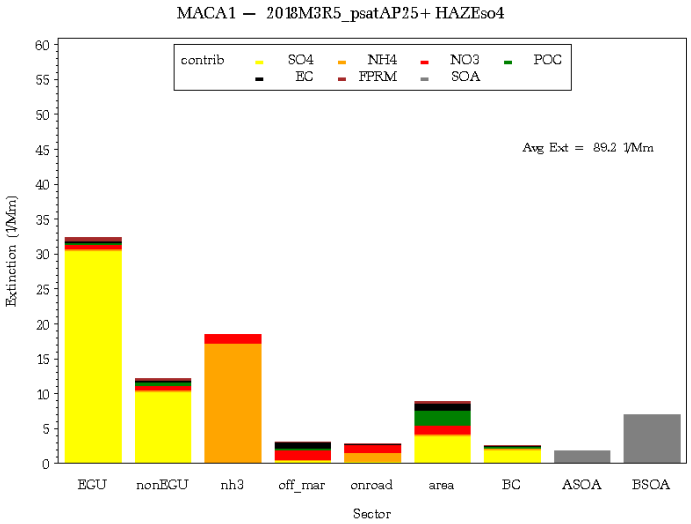
2018 (LADCO Round 5)



2005 (LADCO Round 5)



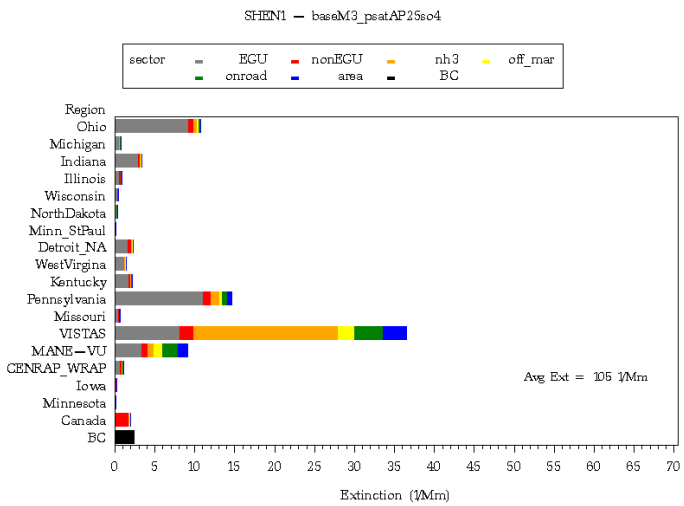
2018 (LADCO Round 5)



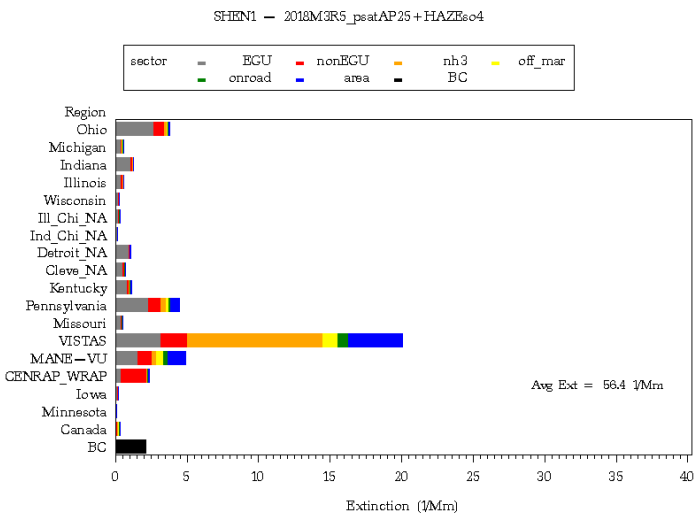
Indiana contributions to visibility impairment at Shenandoah National Park, Virginia comprise mostly of sulfate emissions from EGUs, as shown in Figure 8. Indiana's contributions to light extinction are predicted to decrease through 2018 and overall light extinction at Shenandoah is expected to be approximately half of the light extinction modeled for 2005.

Figure 8. Shenandoah, Virginia

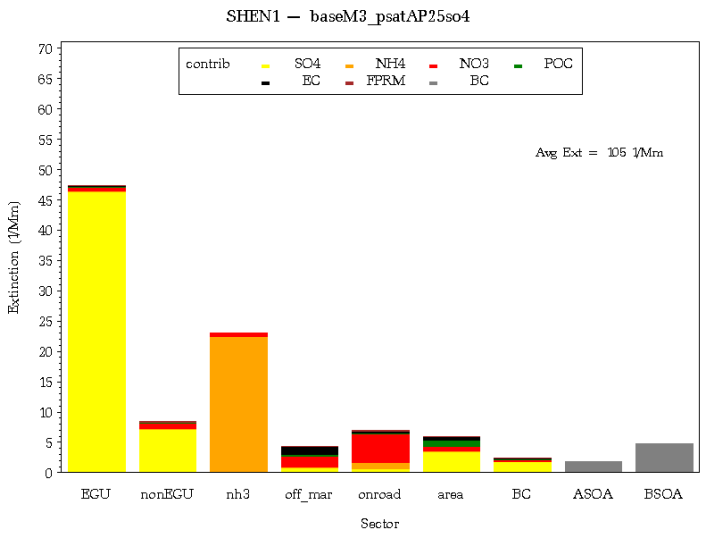
2005 (LADCO Round 5)



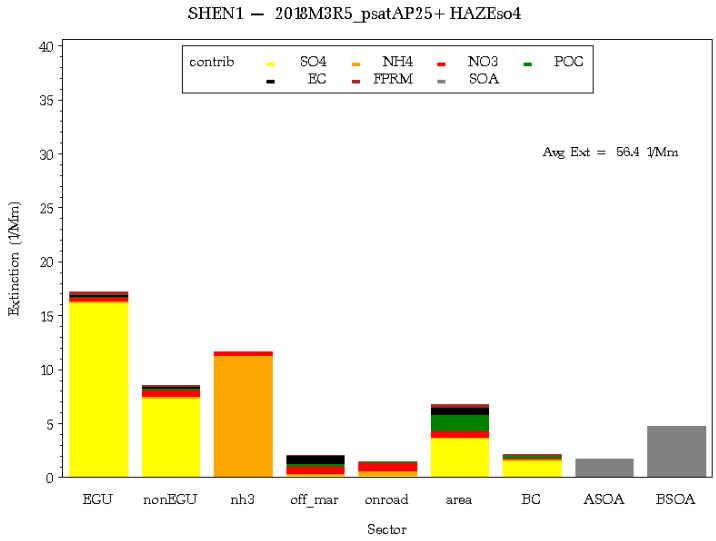
2018 (LADCO Round 5)



2005 (LADCO Round 5)



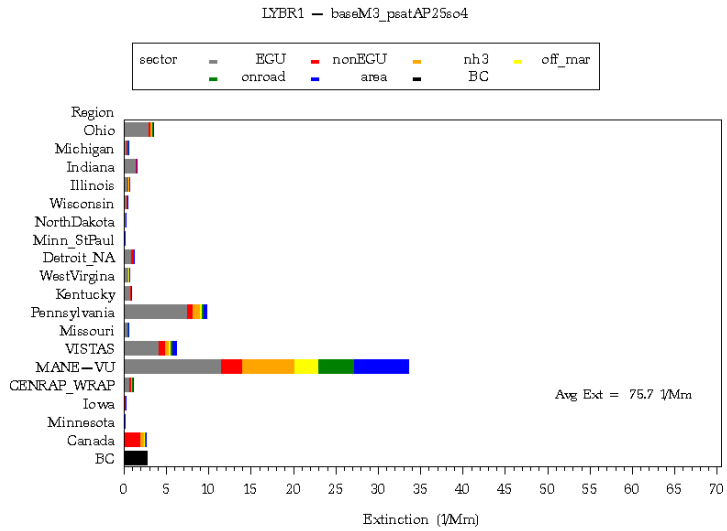
2018 (LADCO Round 5)



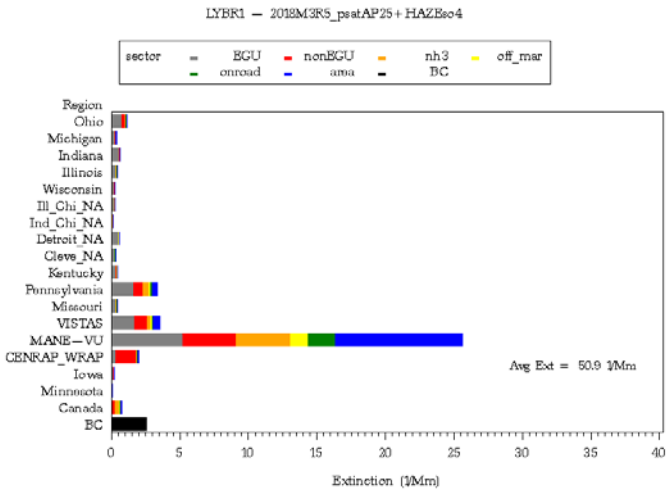
Indiana contributions to visibility impairment at Lye Brook Wilderness, Vermont comprise mostly of sulfate emissions from EGUs, as shown in Figure 9. Indiana's contributions to light extinction will decrease through 2018 and overall light extinction at Lye Brook is expected to be approximately 1/3 of the light extinction modeled for 2005.

Figure 9. Lye Brook Wilderness, Vermont

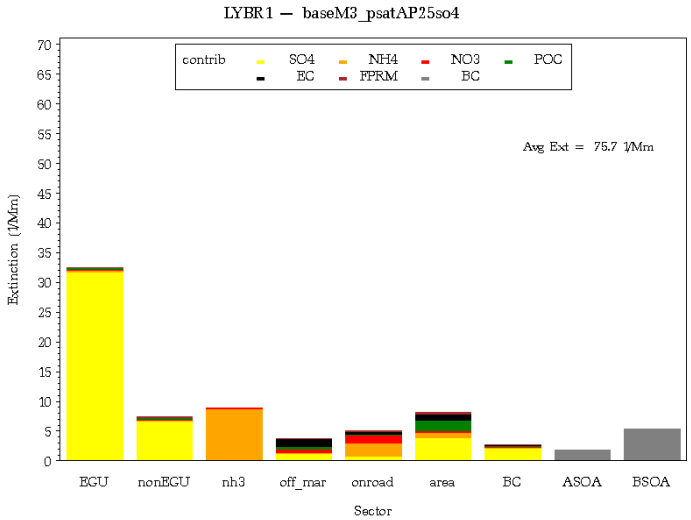
2005 (LADCO Round 5)



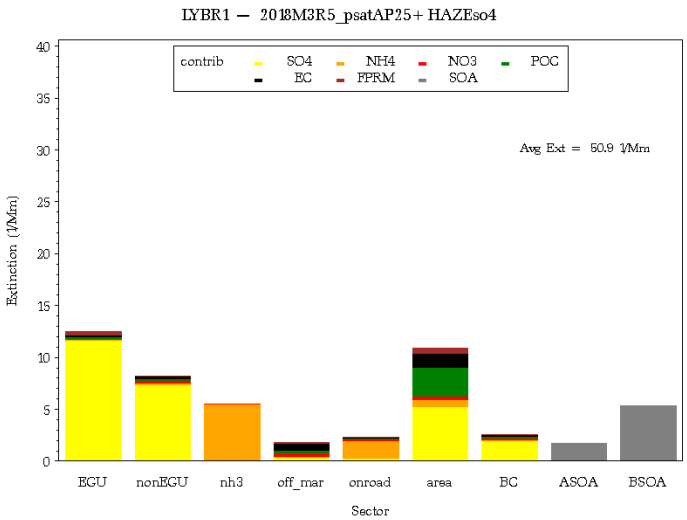
2018 (LADCO Round 5)



2005 (LADCO Round 5)



2018 (LADCO Round 5)



Indiana contributions to visibility impairment at all the Class 1 areas analyzed were less than 5 Mm^{-1} with the exception of Indiana's contribution to visibility at Mammoth Cave National Park in Kentucky. The future year modeling shows that Indiana is projected to have reduced its contribution on Mammoth Caves' visibility impairment by approximately 50% by 2018.

LADCO conducted back trajectory analyses to determine which states were culpable during bad visibility days at each of the northern Class 1 area analyzed. Table 1 shows the percentage of light extinction culpability from states in the eastern United States at the northern Class 1 areas. Indiana is shown to contribute less than 3 % light extinction at Boundary Waters Canoe Area, MN and Seney Wilderness, MI and no appreciable contribution to light extinction at Voyageurs National Park, MN.

Table 1. LADCO's Back Trajectory Analysis -1997-2001 (percent of light extinction)

Region		Boundary Waters Light Extinction			Voyageurs Light Extinction			Seney Light Extinction		
		Best	All Days	Worst	Best	All Days	Worst	Best	All Days	Worst
US	Alabama		0.03						0.2	0.39
	Arkansas		0.3	0.4		0.1	0.19		1.54	2.93
	Florida								0.09	0.17
	Georgia								0.21	0.39
	Illinois		1.68	2.74		0.5	1.22		4.99	7.43
	Indiana		**0.57**	**1.18**					**1.67**	**2.17**
	Iowa		5.14	7.44		6.12	10.24		5.27	5.66
	Kentucky								1.14	2.18
	Louisiana		0.12	0.23		0.03	0.06		0.78	1.23
	Michigan	0.78	1.17	0.66	0.27	1.22	1.57	14.51	13.68	14.68
	Minnesota	22.04	34.75	37.63	20.96	34.6	36.88	1.46	5.41	3.79
	Mississippi		0.06						0.62	1.04
	Missouri		2.17	3.26		1.02	0.3		2.42	3.17
	New Hampshire								0.02	
	New York								0.07	0.1
	North Carolina		0.09						0.19	0.36
	North Dakota	1.21	5.13	5.91	1.59	6.51	7.11		1.26	0.64
	Ohio		0.19	0.23				0.07	1.61	2.8
	Pennsylvania							0.49	0.15	0.26
	South Carolina								0.21	0.39
	South Dakota	0.45	3.06	4.38		4.08	6.93		1.13	1.12
	Tennessee			0.01					0.47	0.85
	Vermont								0.02	
	Virginia		0.03						0.17	0.33
	West Virginia		0.05						0.54	1.02
	Wisconsin	1.31	7.86	10.06		5.5	9.66	0.26	10.63	8.44
	Western States	1.1	4.31	5.74		7.05	9.53		5.8	5.9
Canada	Manitoba	9.95	7.45	3.71	17.65	10.35	6.04	3.77	2.37	0.77
	Ontario	47.52	15.96	8.92	49.56	13.59	4.98	50.97	12.86	7.66
	Quebec	1.77	0.15		0.21	0.01		0.97	0.93	0.41
	Other Provinces	2.27	3.73	2.46	6.05	6.29	2.35	0.86	1.72	2.28
Other	(over water, etc)	11.61	6.02	5.05	3.72	3.05	2.94	26.65	21.86	21.44
Total		100	100	100	100	100	100	100	100	100

LADCO summarized its back trajectory, Round 4 and Round 5 PSAT analyses along with the CENRAP and MPCA PSAT modeling results to show the state culpabilities on the northern Class 1 areas. As can be seen, Indiana's impacts on the Boundary Waters, Voyageurs and Isle Royale Class 1 areas are less than 6% of the total visibility impairment. Indiana is modeled to have a slightly higher impact at Seney, with modeled results less than 12% of total visibility impairment. Emission reductions that are projected through future year 2018 PSAT modeling show Indiana's impact will be reduced approximately 20% or more, decreasing Indiana's impact on future year visibility at Seney.

Table 2. State Culpabilities Based on PSAT Modeling and Trajectory Analysis

	Boundary Waters					Seney		
State/Region	**LADCO Rnd 4 PSAT**	**LADCO Rnd 5 PSAT**	**MPCA-PSAT**	**CENRAP PSAT**	**LADCO-Traj Analysis**	**LADCO Rnd 4 PSAT**	**LADCO Rnd 5 PSAT**	**LADCO Traj Analysis**
Michigan	3.40%	4.80%	3.00%	1.90%	0.70%	13.80%	18.10%	14.70%
Minnesota	30.50%	23.50%	28.00%	30.60%	37.60%	4.80%	1.60%	3.80%
Wisconsin	10.40%	10.90%	10.00%	6.40%	10.60%	12.60%	10.90%	8.40%
Illinois	5.20%	5.10%	6.00%	3.50%	2.70%	13.00%	14.30%	7.40%
Indiana	**2.90%**	**3.90%**	**3.00%**	**1.80%**	**1.20%**	**9.60%**	**11.60%**	**2.20%**
Iowa	7.60%	8.30%	8.00%	2.50%	7.40%	6.20%	3.80%	5.70%
Missouri	5.20%	3.40%	6.00%	2.10%	3.30%	6.50%	4.80%	3.20%
N. Dakota	5.70%	1.10%	6.00%	4.60%	5.90%	1.50%	0.10%	0.60%
Canada	1.90%	2.70%	3.00%	12.50%	15.10%	2.10%	1.20%	11.10%
CENRAP-WRAP	10.90%	13.50%		4.20%	10.10%	13.10%	10.00%	7.00%
TOTAL	83.60%	77.20%	73.00%	70.20%	94.60%	83.30%	76.40%	64.10%

	Voyageurs					Isle Royale	
State/Region	**LADCO Rnd 4 PSAT**	**LADCO Rnd 5 PSAT**	**MPCA-PSAT**	**CENRAP PSAT**	**LADCO-Traj Analysis**	**LADCO Rnd 4 PSAT**	**LADCO Rnd 5 PSAT**
Michigan	2.00%	4.90%	2.00%	1.00%	1.60%	12.70%	13.40%
Minnesota	35.00%	20.20%	31.00%	31.50%	36.90%	14.10%	9.50%
Wisconsin	6.30%	7.90%	6.00%	3.70%	9.70%	16.30%	14.70%
Illinois	3.00%	7.10%	3.00%	1.80%	1.20%	7.00%	8.70%
Indiana	**1.60%**	**4.60%**	**2.00%**	**0.80%**		**5.60%**	**5.20%**
Iowa	7.40%	7.10%	7.00%	2.40%	10.20%	6.90%	8.30%
Missouri	4.30%	4.00%	4.00%	1.60%	0.30%	3.90%	4.60%
N. Dakota	10.30%	1.70%	13.00%	6.10%	7.10%	3.60%	0.30%
Canada	2.70%	3.30%	5.00%	17.20%	13.30%	2.20%	1.70%
CENRAP-WRAP	10.20%	13.70%	6.10%	16.50%	12.50%	12.60%	
TOTAL	82.70%	74.50%	73.00%	72.20%	96.80%	84.90%	79.00%

Table II-2, "Regional Haze in the Upper Midwest: Summary of Technical Information" Feb 22, 2008

Baseline visibility conditions for the northern Class 1 areas, taken from 2000 through 2004, established the baseline values at the northern Class 1 areas between 18.5 and 23.5 deciviews for the 20% worst days using the old IMPROVE equation and baseline values at the northern Class 1 areas between 19.5 and 24.5 deciviews using the new IMPROVE equation. This information is used to establish the uniform rate of improvement (URI) for 2018. Table 3 shows the visibility values for the northern Class 1 area using the old and new IMPROVE equations.

Table 3. Visibility Values for the Northern Class 1 Area using the Old and New IMPROVE Equations

Old IMPROVE Equation (Cite: VIEWS, November 2005)								
	20% Worst Days					Baseline	2018	Natural
	2000	2001	2002	2003	2004	Value	URI Value	Conditions
Voyageurs	18.5	18	19	19.2	17.6	18.46	16.74	11.09
BWCA	19.85	19.99	19.68	19.73	17.65	19.38	17.47	11.21
Isle Royale	20	22	20.8	19.5	19.1	20.28	18.17	11.22
Seney	22.6	24.9	24	23.8	22.6	23.58	20.73	11.37
	20% Best Days					Baseline	Natural	
	2000	2001	2002	2003	2004	Value	Conditions	
Voyageurs	6.3	6.2	6.7	7	5.4	6.32	3.41	
BWCA	5.9	6.52	6.93	6.67	5.61	6.33	3.53	
Isle Royale	5.7	6.4	6.4	6.3	5.3	6.02	3.54	
Seney	5.8	6.1	7.3	7.5	5.8	6.5	3.69	
New IMPROVE Equation (Cite: VIEWS, March 2006)								
	20% Worst Days					Baseline	2018	Natural
	2000	2001	2002	2003	2004	Value	URI Value	Conditions
Voyageurs	19.55	18.57	20.14	20.25	18.87	19.48	17.74	12.05
BWCA	20.2	20.04	20.76	20.13	18.18	19.86	17.94	11.61
Isle Royale	20.53	23.07	21.97	22.35	20.02	21.59	19.43	12.36
Seney	22.94	25.91	25.38	24.48	23.15	24.37	21.64	12.65
	20% Best Days					Baseline	Natural	
	2000	2001	2002	2003	2004	Value	Conditions	
Voyageurs	7.01	7.12	7.53	7.68	6.37	7.14	4.26	
BWCA	6	6.92	7	6.45	5.77	6.43	3.42	
Isle Royale	6.49	7.16	7.07	6.99	6.12	6.77	3.72	
Seney	6.5	6.78	7.82	8.01	6.58	7.14	3.73	

The glide paths, as determined by LADCO's Base M modeling, show the different emission scenarios meeting the glide paths for most Class 1 areas by 2018. The different emission scenarios include:

- **R5S1a scenario** - EGU emissions as assumed by the EPA's IPM3.0 model
- **R5S1b scenario** – EPA's IPM3.0 model emissions for EGUs along with several "will do" adjustments identified by states (legally binding agreements such as consent degrees, operating permits, signed contracts, etc).

Modeling results show the deciview values resulting from the different emission rates fall in line with the glide path for each Class 1 area for the 20% worst days. Further explanation of the glide path results can be found in the "Regional Air Quality Analyses for Ozone, $PM_{2.5}$ and Regional Haze: Final Technical Support Document, April 25, 2008" page 96-100.

References:

"Regional Haze in the Upper Midwest: Summary of Technical Information Version 2.2", February 22, 2008
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"Reasonable Progress for Class I Areas in the Northern Midwest – Factor Analysis" July 18, 2007
http://www.ladco.org/reports/rpo/consultation/products/reasonable_progress_for_class_i_areas_in_the_northern_midwest-factor_analysis_draft_final_technical_memo_july_18_2007.pdf