Washington State Regional Haze SIP

Appendix M

Model Performance Evaluation

Overview

The Western Regional Air Partnerships (WRAPs) Regional Modeling Center (RMC) evaluated the performance of the Community Multi-Scale Air Quality (CMAQ) model for modeling visibility in the WRAP region. The key finding of the RMC's model performance evaluation is that CMAQ modeling can be used in combination with the Relative Response Factor (RRF) approach for the following purposes:

(1) Evaluation of emission reduction strategies for all particulate matter species except for coarse mass
(2) Projection of visibility changes at Class I Areas for regional haze planning purposes

Under the RRF approach, the projected concentration at an Interagency Monitoring of Protected Visual Environments (IMPROVE) monitoring site is calculated by applying a RRF to the measured baseline period concentration. The RRF is the ratio of the future-year modeling result to the current-year modeling result.

The RMC compared CMAQ model-simulated concentrations with 2002 ambient monitoring data from a large number of sites to determine that the CMAQ model's performance was sufficiently accurate to justify use of the model for simulating future conditions. The "Final Report for the WRAP 2002 Visibility Model Performance Evaluation" (Tonnesen, et al, 2006) discusses the model performance evaluation in detail.

This appendix presents additional analysis performed by Ecology on CMAQ visibility modeling for the mandatory Class I Areas in Washington. Ecology performed a 3-step process. As the first two steps, Ecology examined two sets of WRAP-produced graphics for mandatory Class I Areas in Washington:

(1) Time-series concentrations of visibility-impairing pollutants from IMPROVE monitoring of each of the mandatory Class I Areas in Washington for the 2000-2004 baseline period
(2) IMPROVE monitoring data and CMAQ modeling results for each of the mandatory Class I Areas in Washington for 2002

Using these graphics, Ecology performed a basic analysis of the modeling results in comparison to the monitored data at the mandatory Class I Areas.

The visibility-impairing pollutants addressed in the Appendix are Sulfate (SO_4), Nitrate (NO_3), Organic Mass Carbon (OMC), Elemental Carbon (EC), fine soil, and Coarse Mass (CM). The graphics used in this Appendix from the WRAP's Technical Support System (TSS) refer to the visibility-impairing pollutants in a slightly different way. Table M-1 below provides a cross-walk.

Table M-1 Crosswalk between Washington's Regional Haze State Implementation Plan and the Western Regional Air Partnership's Technical Support System

Regional Haze SIP	Technical Support System
Sulfate (SO_4)	$ammSO_4$
Nitrate (NO_3)	$ammNO_3$
Organic Mass Carbon (OMC)	OMC
Elemental Carbon (EC)	EC
Fine Soil	Soil
Coarse Mass (CM)	CM

Baseline Period Monitoring Data Time-Series Analysis

Ecology used the IMPROVE monitoring data for Washington's mandatory Class I Areas to examine monitored fluctuations of visibility-impairing pollutants over the 2000-2004 baseline period. This examination provided an understanding of the relative importance and recurring patterns of monitored concentrations. The use of multiple years of monitoring data facilitated the recognition of annual patterns of pollutant concentrations.

Overall, mandatory Class I Areas in Washington have the following characteristics:

- SO_4, OMC, and CM are the most prominent visibility-impairing pollutants (by mass)
- SO_4, OMC, and CM exhibit seasonality with the highest concentrations occurring in the summer.
- Generally NO_3 is a relatively minor visibility-impairing pollutant that lacks clear seasonality.
- The three northern mandatory Class I Areas (North Cascades National Park, Glacier Peak Wilderness, and Pasayten Wilderness) exhibit fine soil concentration spikes.

A more detailed discussion of each mandatory Class I Area is provided in Chapter 5.

Comparison of 2002 Monitoring Data and Modeling Results

Ecology compared IMPROVE monitoring data from 2002 to CMAQ modeling results for 2002 for each IMPROVE site in Washington to gain an understanding of how well CMAQ simulated monitored concentrations of visibility-impairing pollutants. The CMAQ results are from the simulation of the Plan02d inventory, which is a later, improved version of the BASE02a inventory used by the RMC to conclude that CMAQ was suitable for visibility modeling. The Plan02d simulation did not include CM. The RMC had found such significant model performance issues with the simulation of CM in its model performance evaluation of the Base02a CMAQ modeling results that CM modeling was discontinued.

Monitoring data and corresponding modeling results for each IMPROVE site are shown in Figures M-1 through-M-6. These figures use monitoring and modeling graphics from the WRAP's TSS. The top graphic shows monitoring data for the IMPROVE site and the bottom graphic, the corresponding CMAQ modeling results.

Some caution must be taken in reviewing the figures. While IMPROVE sampling is scheduled to occur every third day, the actual monitoring record may have missing days due to missing or invalidated samples, sampler malfunction, or other reasons. TSS spaces the available IMPROVE record across the page. The CMAQ results, on the other hand, reflect all *scheduled* IMPROVE sampling days (every third day). As a result, a monitoring day may not be lined up (be directly above) the corresponding modeled day.

Overall, the comparison of IMPROVE monitoring data to modeling results may be characterized as follows:

- The seasonality of higher SO_4 and OMC in the summer found in the IMPROVE monitoring record may be less evident or absent from the modeling results.
- The modeling results have spikes and periods of high NO_3 and sometimes soil that are not consistent with the IMPROVE monitoring results.
- The days and relative size of peak concentrations generated by the CMAQ modeling simulation may differ from those measured by the IMPROVE monitoring results.

A review of each IMPROVE site is provided below.

The CMAQ modeling results for the OLYM1 site representing Olympic National Park show winter seasonality for NO_3 that is not reflected in the IMPROVE monitoring data (Figure M-1). Soil is another prominent feature of the CMAQ modeling results that is not reflected in the IMPROVE monitoring data. The CMAQ model is forecasting different and higher spikes and periods of high concentrations than the IMPROVE monitoring data, especially in the latter months of the year.

The CMAQ modeling results for the NOCA1 site representing North Cascades National Park and Glacier Peak Wilderness have a different pattern of peak concentrations from the IMPROVE monitoring data (Figure M-2). The summer seasonality of SO_4 and OMC concentrations is not so apparent in the CMAQ results. While NO_3 concentrations are almost always a fairly insignificant part of the total IMPROVE monitored mass, CMAQ modeling results show NO_3 to be a small but significant part of the total mass virtually throughout the year.

The CMAQ modeling results for the SNPA1 site representing Alpine Lakes Wilderness have a different pattern of peak concentrations from the IMPROVE monitoring data (Figure M-3). NO_3 concentrations are a prominent part of the IMPROVE monitoring data in November and part of December. In contrast, the CMAQ modeling results indicate the NO_3 is a significant part of the total mass virtually throughout the year.

The IMPROVE monitoring data and the CMAQ monitoring results for the MORA1 site representing Mount Rainier National Park have different patterns of high concentrations (Figure M-4). The CMAQ modeling results indicate high peak concentrations in the fall and winter that are not reflected in the IMPROVE monitoring results. Both NO_3 and soil have a more significant role in the CMAQ modeling results than in the IMPROVE monitoring data.

The IMPROVE monitoring data and the CMAQ modeling results for the WHPA1 site representing Goat Rocks Wilderness and Mount Adams Wilderness have different patterns of high concentrations (Figure M-5). The CMAQ modeling results indicate relatively high NO_3 concentrations during the first and fourth quarters of the year (the winter season). The CMAQ modeling results are not reflected in the IMPROVE monitoring data. The CMAQ modeling results predict higher OMC concentrations than is measured by the IMPROVE monitoring data.

The IMPROVE monitoring data and the CMAQ modeling results for the PASA1 site representing Pasayten Wilderness have different patterns of high concentrations (Figure M-6). The CMAQ results show a single day of high concentration composed mainly of OMC on September 26. The IMPROVE monitoring data have, in declining order, lesser peaks mainly of OMC on October 17, July 25, November 13, and September 26. The CMAQ modeling results indicate winter NO_3 seasonality that is absent from the IMPROVE monitoring data. The CMAQ model results indicate generally higher concentrations at the beginning and end of the year.

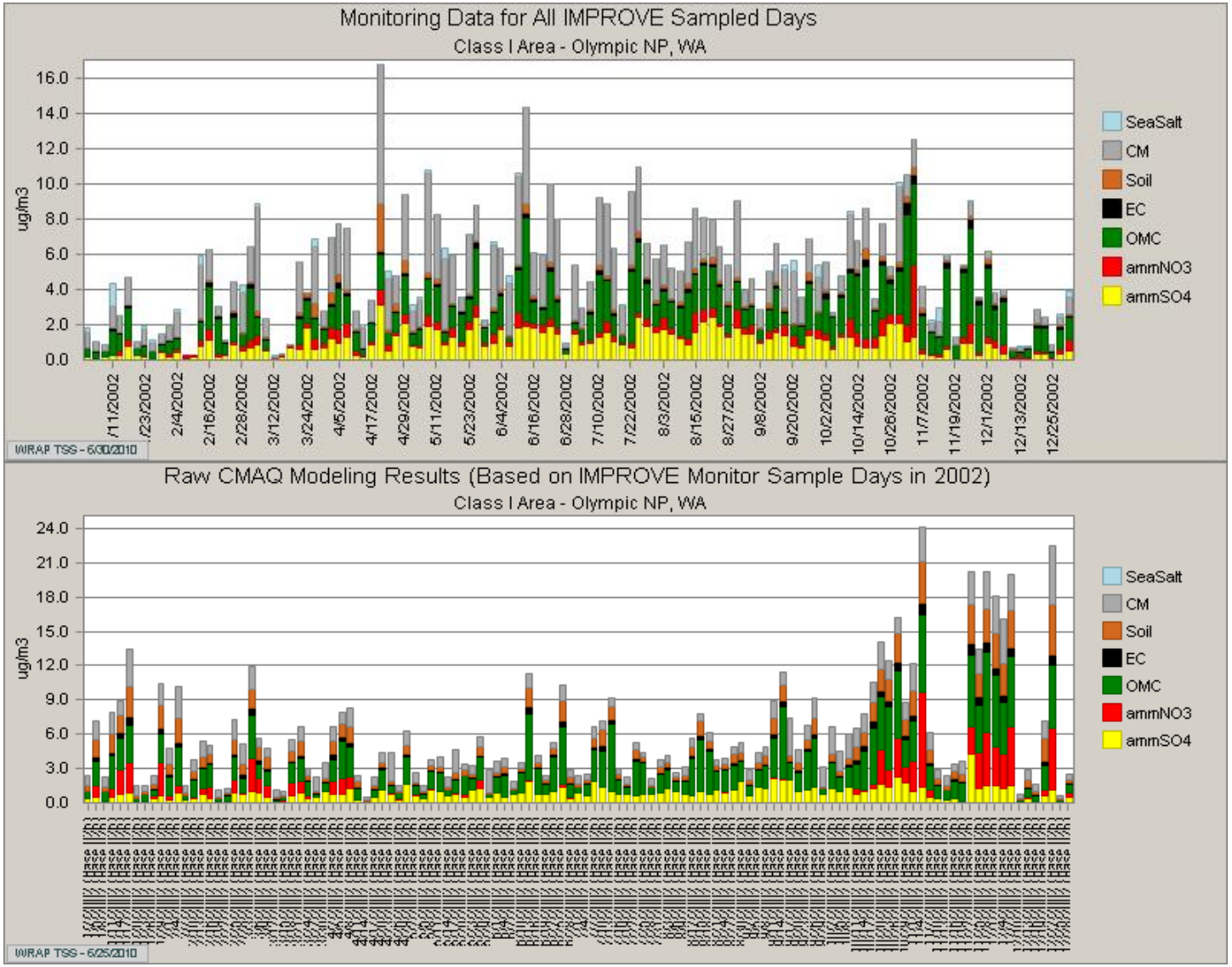

Figure M-1 OLYM1 Interagency Monitoring of Protected Visual Environments Monitoring Data and Community Multi-Scale Air Quality Model
Modeling Results for 2002

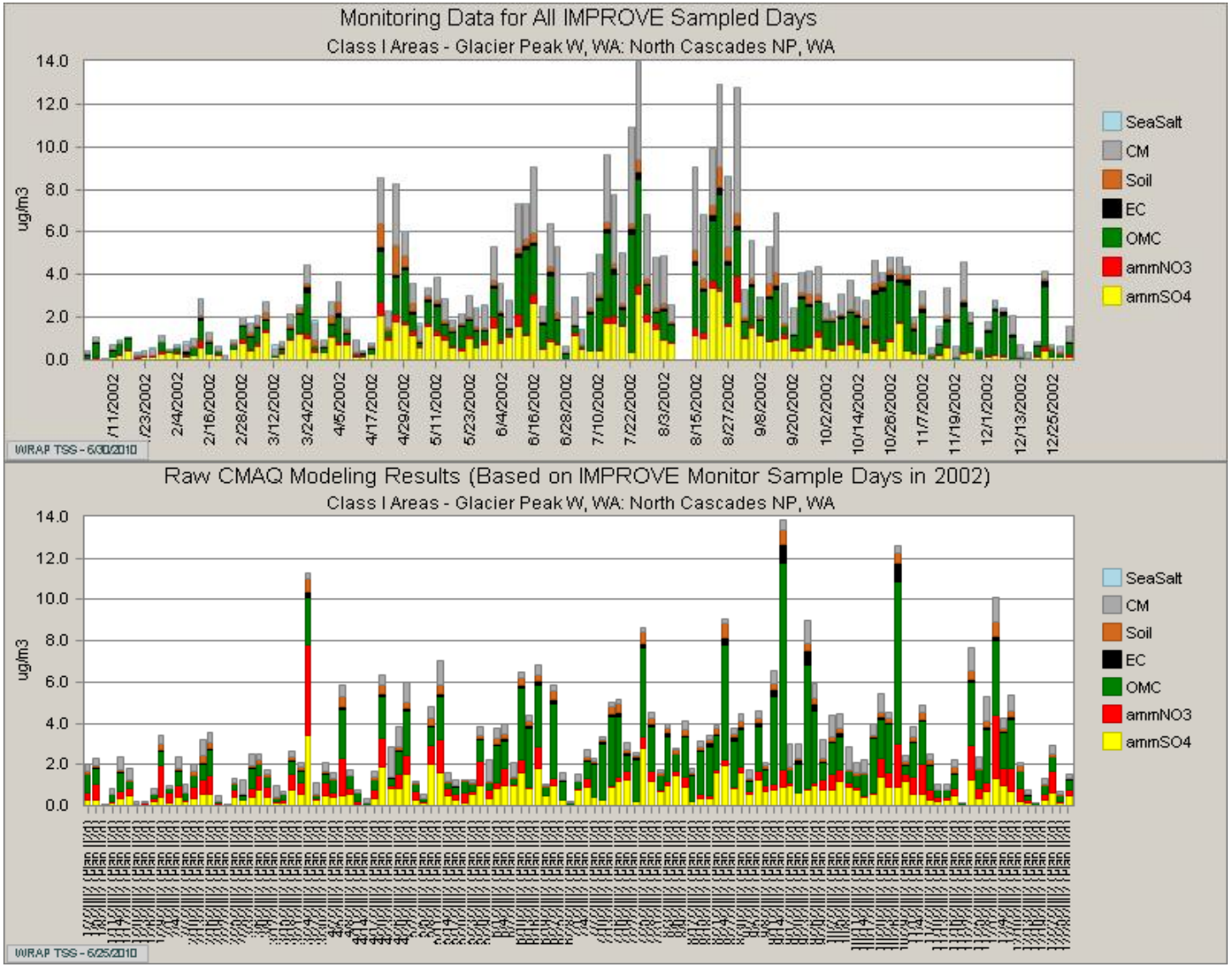

Figure M-2 NOCA1 Interagency Monitoring of Protected Visual Environments Monitoring Data and Community Multi-Scale Air Quality Model

Modeling Results for 2002

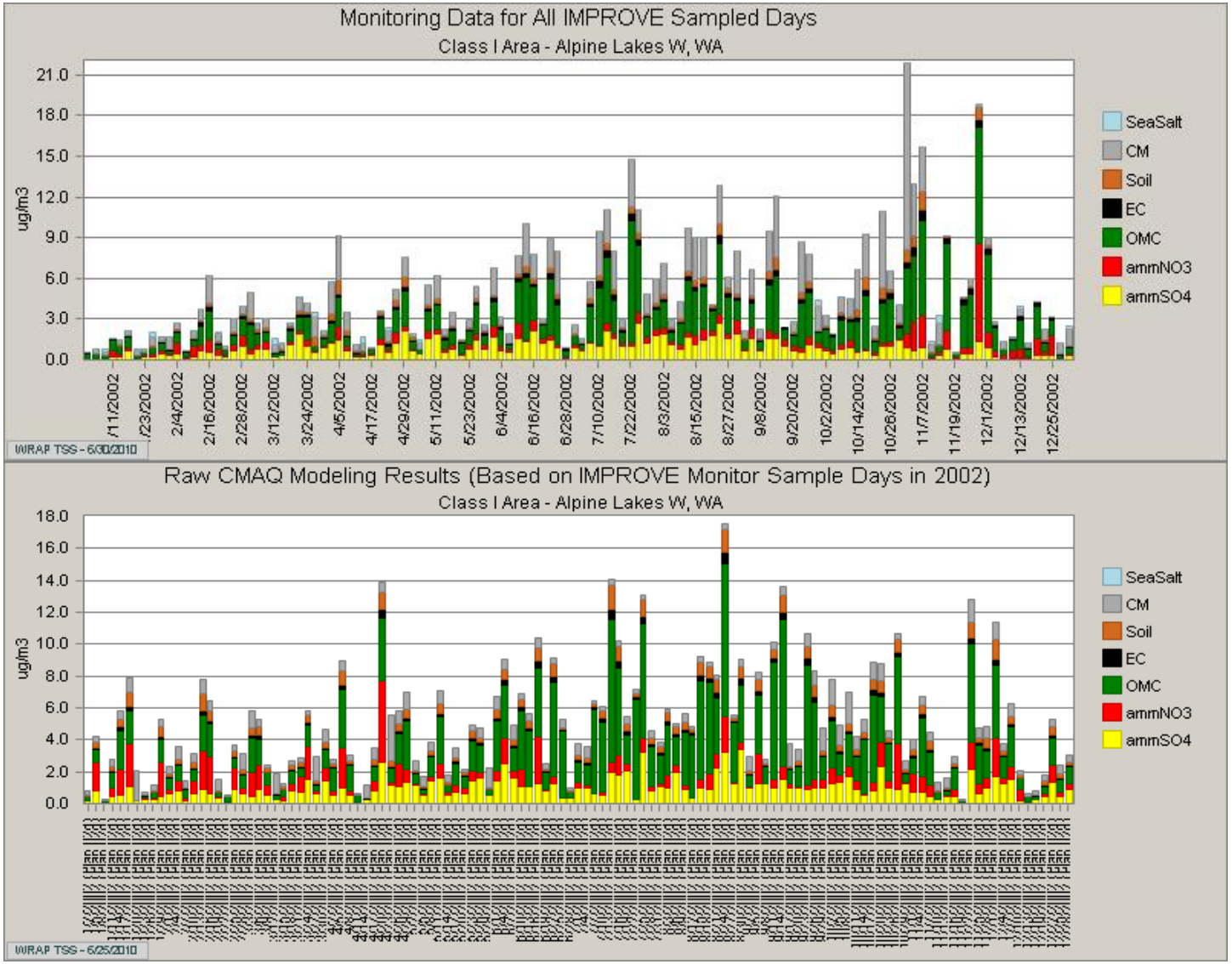

Figure M-3 SNPA1 Interagency Monitoring of Protected Visual Environments Monitoring Data and Community Multi-Scale Air Quality Model
Modeling Results for 2002

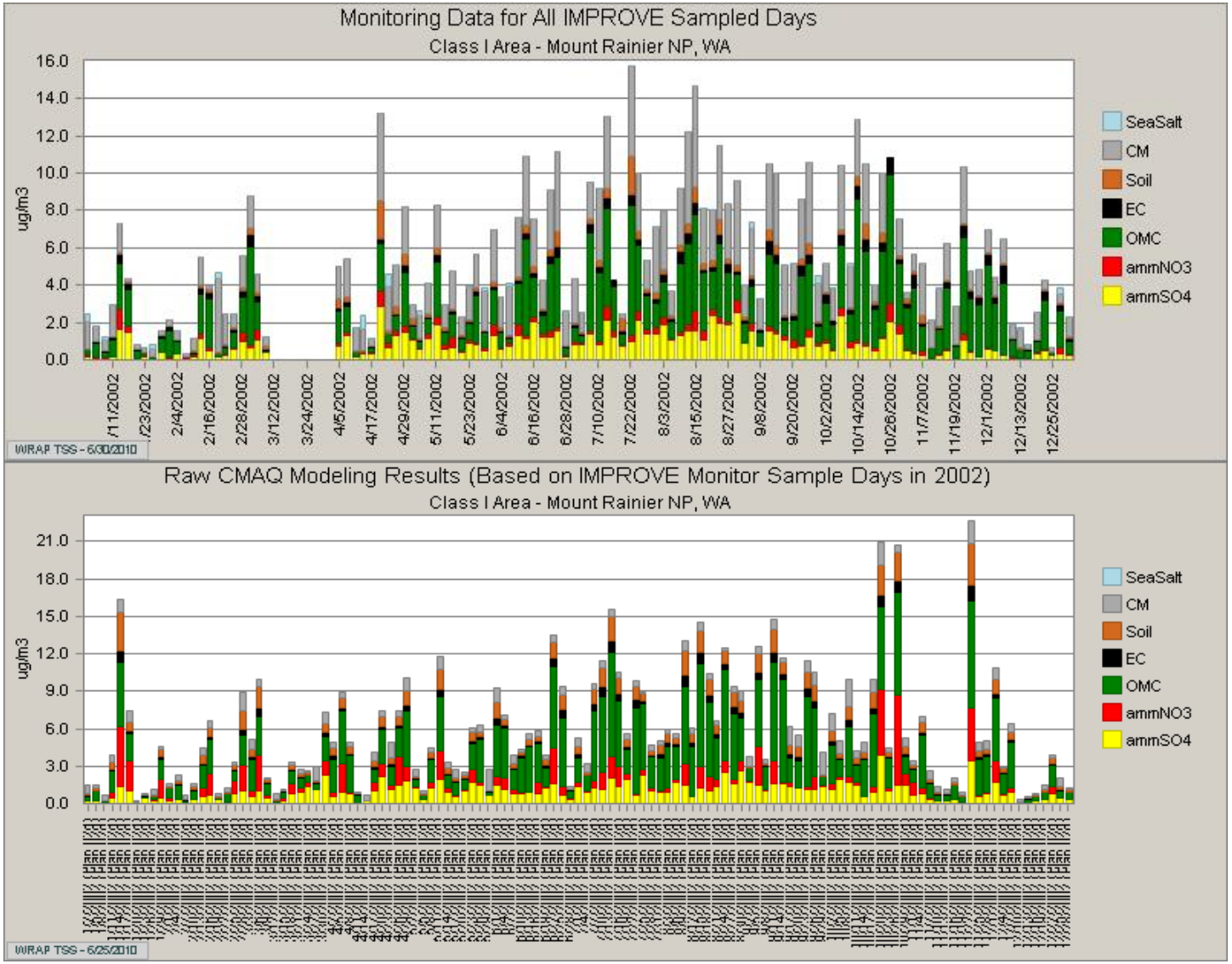

Figure M-4 MORA1 Interagency Monitoring of Protected Visual Environments Monitoring Data and Community Multi-Scale Air Quality Model
Modeling Results for 2002

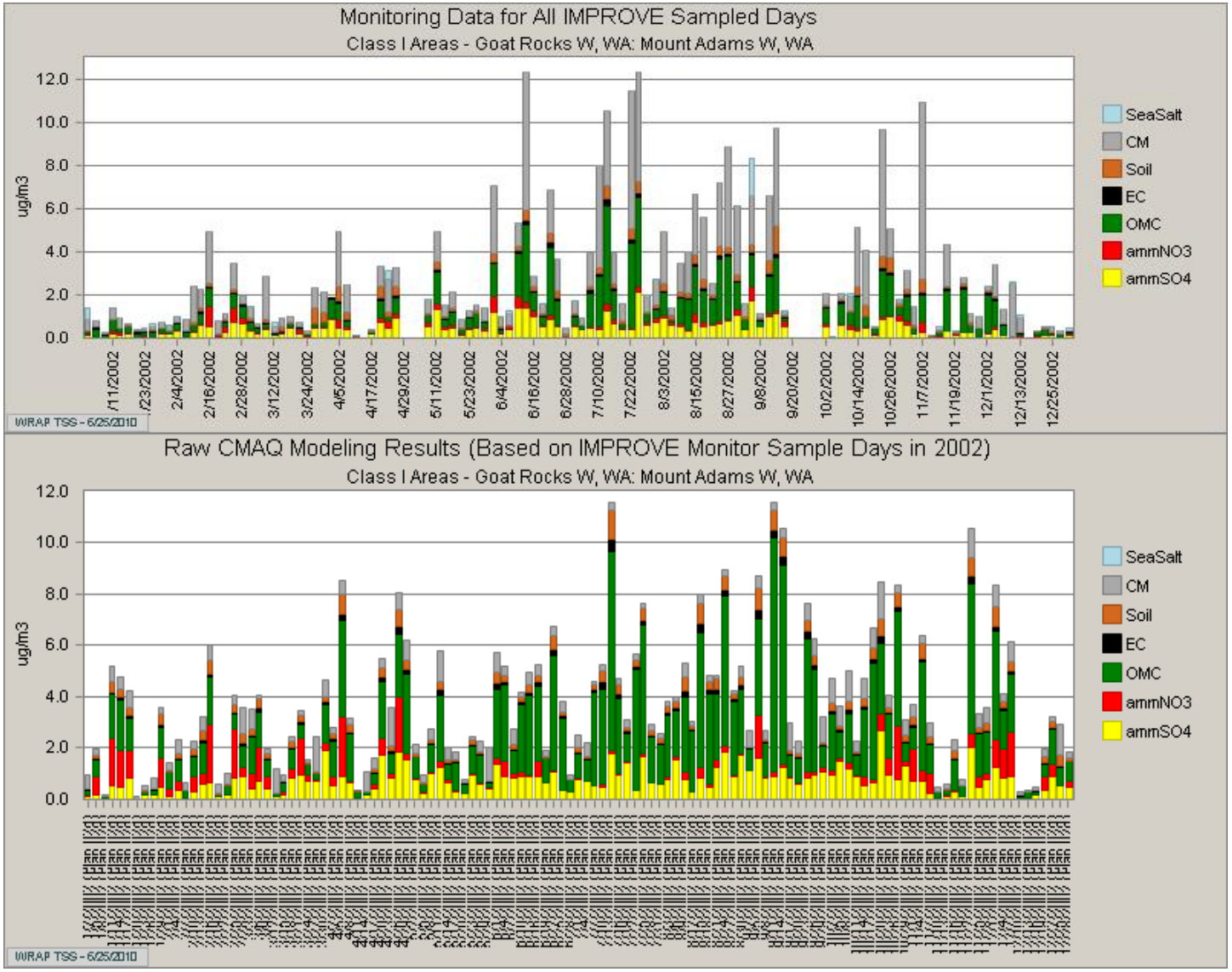

Figure M-5 WHPA1 Interagency Monitoring of Protected Visual Environments Monitoring Data and Community Multi-Scale Air Quality Model

Modeling Results for 2002

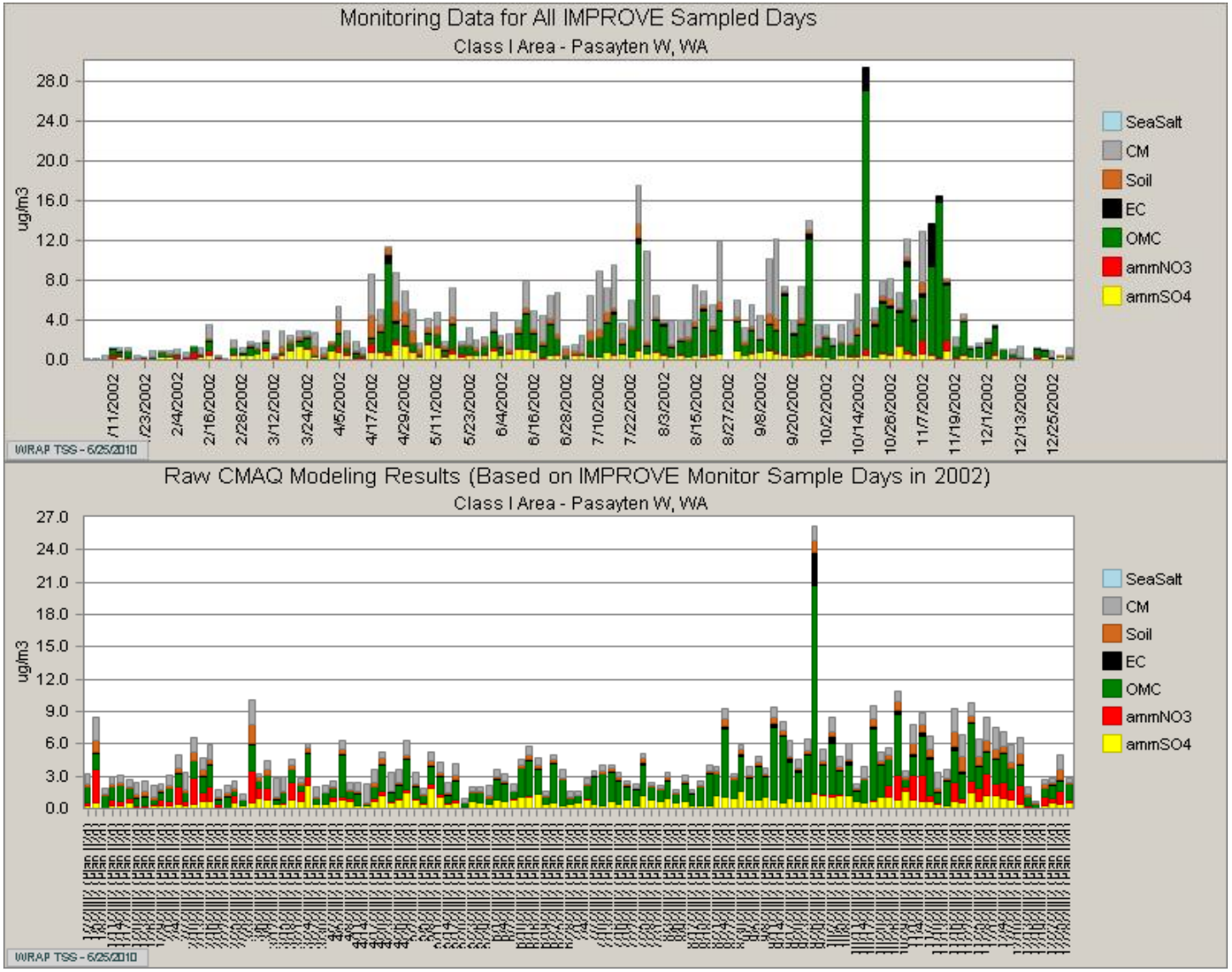

Figure M-6 PASA1 Interagency Monitoring of Protected Visual Environments Monitoring Data and Community Multi-Scale Air Quality Model
Modeling Results for 2002

Community Multi-Scale Air Quality Model Analysis

Ecology did an analysis of IMPROVE monitoring data and CMAQ modeling results for the Most Impaired Days and the Least Impaired Days to gain a better understanding of how well the CMAQ modeling results simulated the IMPROVE monitoring data. For this analysis, Ecology calculated ratios of CMAQ modeling results to IMPROVE monitored data for each of the visibility-impairing pollutants at each mandatory Class I Area. Ecology determined ratios for the Most Impaired Days, the Least Impaired Days, and winter and summer subsets of each. The winter subset consisted of the first and last quarters of the year and the summer subset, the second and third quarters. Ecology considered model performance to be acceptable if the modeled-to-monitored ratio was between 0.5 and 2.0. The results are presented in Table M-2 below.

Overall, CMAQ modeling results for SO_4 are acceptable especially on the Most Impaired Days. SO_4 meets the acceptance criteria for the Most Impaired Days and its two subsets. SO_4 meets the acceptance criteria for the Least Impaired Days except for overprediction at the SNPA1 site representing Alpine Lakes Wilderness and the WHPA1 site representing Goat Rocks Wilderness and Mount Adams Wilderness. The subsets for the Least Impaired Days show winter and summer overprediction at the PASA1 site representing Pasayten Wilderness and summer overprediction at the MORA1 site representing Mount Rainier National Park.

In contrast, CMAQ modeling results for NO_3 are usually unacceptable. NO_3 generally does not meet the acceptance criteria on either the Most Impaired Days or the Least Impaired Days. NO_3 is usually overpredicted but underprediction also occurs in the summer.

OMC generally meets the acceptance criteria on the Most Impaired Days and its winter and summer subsets. OMC concentrations tend to be overpredicted on the Least Impaired Days.

CMAQ modeling results for EC are generally acceptable. EC meets the acceptance criteria on the Most Impaired Days except for the PASA1 site representing Pasayten Wilderness, which has a ratio just below the lower acceptance criteria limit. EC meets the acceptance criteria on the Least Impaired Days except for overprediction at the OLYM1 site representing Olympic National Park and PASA1 site representing Pasayten Wilderness.

CMAQ modeling results for soil are generally unacceptable. An exception is the acceptable summer subset of the Most Impaired Days in which only modeling results for the MORA1 site representing Mount Rainier National Park are overpredicted.

CMAQ modeling results for CM are generally unacceptable on the Most Impaired Days due to underprediction. On the other hand, CMAQ modeling results for the Least Impaired Days are generally acceptable except for overprediction at SNPA1 representing Alpine Lakes Wilderness and underprediction at MORA1 representing Mount Rainier National Park. The RMC found significant model-performance issues with the simulation of CM and did not include CM in any CMAQ modeling after the Base02a model performance evaluation.

The causes of the significant under- and over-prediction by the model compared to the monitored values is difficult to discern. There are some potential causes that can be considered to contribute the poor agreement in Washington compared to other WRAP states. One consideration is how the emissions from point, mobile, and area sources are 'dispersed' into the model's input data grid cells. Another is the topographical smoothing effect caused by the selected modeling grid size. A final consideration is the location of major point sources and mobile sources. These sources often reside in either the grid cell with the monitor or in an adjacent grid cell.

Based on its general analysis of ratios of CMAQ modeling results to IMPROVE monitoring data, Ecology draws the following conclusions about the acceptability of CMAQ modeling results. CMAQ modeling results are acceptable for the following visibility-impairing pollutants and, where noted, visibility conditions:

- SO_4 especially on the Most Impaired Days
- OMC on the Most Impaired Days
- EC
- CM for the Least Impaired Days (with the caveat that the RMC found model performance for CM to be unacceptable in its model performance evaluation)

CMAQ modeling results are unacceptable for the following visibility-impairing pollutants and, where noted, visibility conditions:

- NO_3
- OMC on the Least Impaired Days
- Soil
- CM on the Most Impaired Days

Table M-2 Community Multi-Scale Air Quality Model Performance Evaluation for Interagency Monitoring of Protected Visual Environments Monitors Representing Washington's Mandatory Class I Areas

EVALUATION				RATIO MODELED/MONITORED					
THE MOST IMPAIRED DAYS									
IMPROVE Monitor	Class I Area	Year	N	SO_4	NO_3	OMC	EC	Soil	CM
OLYM1	Olympic National	2002	24	0.82	1.48	1.48	1.62	3.51	0.48
NOCA1	North Cascades NP &	2002	24	1.00	3.45	1.72	1.09	1.52	0.22
SNPA1	Alpine Lakes	2002	25	0.82	0.43	0.86	1.48	2.31	2.22
MORA1	Mount Rainier	2002	23	1.22	8.08	2.01	0.74	0.66	0.10
WHPA1	Goat Rocks W &	2002	23	1.12	2.03	2.21	1.53	1.53	0.20
PASA1	Pasayten Wilderness	2002	24	1.09	3.98	0.91	0.48	0.43	0.49
	Mean			1.01	3.24	1.53	1.16	1.66	0.62
THE LEAST IMPAIRED DAYS									
IMPROVE Monitor	Class I Area	Year	N	SO_4	NO_3	OMC	EC	$PM_{2.5}$	CM
OLYM1	Olympic National	2002	23	1.30	4.11	2.44	2.67	21.00	1.57
NOCA1	North Cascades NP &	2002	23	1.75	6.33	2.79	1.00	4.00	1.20
SNPA1	Alpine Lakes	2002	24	2.18	3.56	2.68	1.00	5.25	2.15
MORA1	Mount Rainier	2002	22	1.82	2.00	1.77	1.00	5.33	0.47
WHPA1	Goat Rocks W &	2002	22	5.88	9.00	6.30	1.67	8.00	1.59
PASA1	Pasayten Wilderness	2002	22	2.00	4.60	5.25	3.00	1.30	1.10
	Mean			2.49	4.93	3.54	1.72	7.48	1.35

outside 0.5–2.0 acceptance limit

THE MOST IMPAIRED DAYS, Winter (Q1 & Q4)

IMPROVE	Class I Area	Year	N	SO_4	NO_3	OMC	EC	$PM_{2.5}$	CM
OLYM1	Olympic National Park	2002	11	1.30	2.44	1.60	1.86	8.56	1.30
NOCA1	North Cascades NP &	2002	4	1.67	20.38	1.88	1.04	3.60	0.88
SNPA1	Alpine Lakes Wilderness	2002	8	0.94	0.56	0.63	0.41	1.38	0.29
MORA1	Mount Rainier National	2002	7	1.12	4.61	1.13	0.98	5.54	1.02
WHPA1	Goat Rocks W & Mount	2002	6	1.08	3.66	1.83	1.00	1.18	0.16
PASA1	Pasayten Wilderness	2002	8	1.04	1.26	0.61	0.98	4.68	6.24
	Mean			1.19	5.48	1.28	1.05	4.16	1.65

THE MOST IMPAIRED DAYS, Summer (Q2 & Q3)

IMPROVE	Class I Area	Year	N	SO_4	NO_3	OMC	EC	$PM_{2.5}$	CM
OLYM1	Olympic National Park	2002	13	0.58	0.14	1.33	1.21	1.42	0.21
NOCA1	North Cascades NP &	2002	20	0.91	2.17	1.70	1.10	1.38	0.18
SNPA1	Alpine Lakes Wilderness	2002	17	0.63	0.07	0.78	1.11	1.03	1.14
MORA1	Mount Rainier National	2002	16	0.88	2.07	1.74	1.18	2.16	0.46
WHPA1	Goat Rocks W & Mount	2002	17	1.13	1.21	2.28	1.69	1.62	0.21
PASA1	Pasayten Wilderness	2002	16	1.14	0.58	1.12	0.86	0.86	0.30
	Mean			0.88	1.04	1.49	1.19	1.41	0.42

outside 0.5–2.0 acceptance limit

THE LEAST IMPAIRED DAYS, Winter (Q1 & Q4)

IMPROVE Monitor	Class I Area	Year	N	SO_4	NO_3	OMC	EC	$PM_{2.5}$	CM
OLYM1	Olympic National Park	2002	18	1.65	5.88	2.88	3.00	36.00	1.91
NOCA1	North Cascades NP &	2002	19	1.91	5.00	2.86	1.00	4.00	1.32
SNPA1	Alpine Lakes	2002	16	2.50	4.63	2.75	0.86	6.33	2.03
MORA1	Mount Rainier National	2002	18	1.79	1.50	1.61	0.67	4.67	0.45
WHPA1	Goat Rocks W &	2002	18	6.50	10.50	6.18	2.00	18.00	1.61
PASA1	Pasayten Wilderness	2002	17/18	2.36	7.25	6.30	3.00	2.80	1.59
	Mean			2.78	5.79	3.76	1.75	11.97	1.48

THE LEAST IMPAIRED DAYS, Summer (Q2 & Q3)

IMPROVE Monitor	Class I Area	Year	N	SO_4	NO_3	OMC	EC	$PM_{2.5}$	CM
OLYM1	Olympic National Park	2002	5	0.82	0.18	1.26	1.50	7.00	0.89
NOCA1	North Cascades NP &	2002	5	0.89	18.00	2.92	0.67	1.40	0.61
SNPA1	Alpine Lakes	2002	8	1.78	1.92	2.43	1.13	4.00	2.47
MORA1	Mount Rainier National	2002	4	2.11	5.00	2.41	2.50	5.40	0.54
WHPA1	Goat Rocks W &	2002	4	0.84	0.38	1.01	0.45	0.74	4.61
PASA1	Pasayten Wilderness	2002	5	2.50	13.04	2.38	5.56	7.29	0.12
	Mean			1.49	6.42	2.07	1.97	4.31	1.54

outside 0.5–2.0 acceptance limit

Conclusion

IMPROVE monitoring data show that SO_4, OMC, and NO_3 are usually the largest contributors to visibility impairment in mandatory Class I Areas in Washington. Only the OLYM1 site representing Olympic National Park meets the modeling acceptance criteria for these 3 visibility-impairing pollutants on the Most Impaired Days. The NOCA1 site representing North Cascades National Park and Glacier Peak Wilderness, the SNPA1 site representing Alpine Lakes Wilderness, and the PASA1 site representing Pasayten Wilderness meet the modeling acceptance criteria for only 2 of the 3 visibility-impairing pollutants, SO_4 and OMC.

NO_3 is generally overpredicted on the Most Impaired Days for mandatory Class I Areas in Washington. Only the OLYM1 site representing Olympic National Park meets the modeling acceptance criteria. IMPROVE monitoring data show that the contribution of NO_3 to total light extinction for the Most Impaired Days is smaller than the contribution of SO_4 or OMC.

EC and soil are relatively minor contributors to visibility impairment on the Most Impaired Days for mandatory Class I Areas in Washington. EC generally meets the modeling acceptance criteria and soil does not.

Overall, OLMY1 representing Olympic National Park meets more modeling acceptance criteria on the Most Impaired Days than other mandatory Class I Areas. Olympic National Park meets the criteria for SO_4, OMC, NO_3, and EC. Yet as noted in the comparison of IMPROVE monitoring data and CMAQ modeling results, the CMAQ modeling results differ from the IMPROVE monitoring data in ways with the potential to affect projected visibility impairment:

- The CMAQ model forecasts different and higher spikes and periods of higher concentrations than the IMPROVE monitoring data, especially in the latter months of the year.
- The CMAQ modeling results indicate winter seasonality for NO_3 that is not reflected in the IMPROVE data.

The RMC concluded that the model overpredicted the concentrations of visibility-impairing pollutants on the Least Impaired Days. This appears to be generally true for mandatory Class I Areas in Washington. Only MORA1 representing Mount Rainier National Park meets the modeling acceptance criteria for all of the 4 largest contributors to visibility impairment (SO_4, OMC, NO_3, and EC) on the Least Impaired Days.

Ecology's review of IMPROVE monitoring data and CMAQ modeling results has raised questions about how well the CMAQ modeling results simulate concentrations of visibility-impairing pollutants for the mandatory Class I Areas in Washington. The RMC focused on the entire WRAP region to come to the conclusion that the CMAQ modeling could be used to project visibility changes in all Class I Areas for regional haze planning purposes.

Ecology lacks the means and resources to further evaluate the regional modeling. Ecology is using the WRAP results to forecast changes to concentrations of visibility-impairing pollutants and resultant visibility with the understanding that the CMAQ modeling results are the best tool

available to forecast concentrations of visibility-impairing pollutants and projected visibility in 2018, the end of the first control period covered by the state of Washington's Regional Haze SIP. Pollutant concentrations and hence visibility are likely to be overpredicted on the Least Impaired Days. The impact of modeling is not so clear for the Most Impaired Days. CMAQ modeling results for SO_4 and OMC, 2 of the most important pollutants affecting visibility, are generally expected to be acceptable, but concentrations of NO_3, the other important pollutant affecting visibility are likely to be overpredicted.

Reference

Tonnesen, Gail et al., Final Report for the Western Regional air Partnership (WRAP) 2002 Visibility Model Performance Evaluation, WGA Contract Number: 30203, Western Regional Partnership, Denver CO (February24, 2006).