Chapter 7 Western Regional Air Partnership Modeling

This chapter describes the types of models used by the Western Regional Air Partnership (WRAP) to characterize its region. Washington relied upon WRAP modeling for this foundational Regional Haze (RH) State Implementation Plan (SIP). Results from these models are presented in subsequent chapters.

7.1 Overview

Visibility impairment occurs when air borne particles in the atmosphere scatter or absorb light to create haze. Particulates can be directly emitted into atmosphere as primary particulates. Particulates may also be produced in the atmosphere as secondary particulates by photochemical reactions and condensation. Pollutants can also remain suspended for long periods, be transported long distances, and be lost from the atmospheric suspension through wet and dry deposition.

As a result emission inventories alone are not sufficient to determine which pollutants should be controlled to improve visibility at mandatory Class I Areas. Computer air quality models provide a better understanding of the sources of fine particulates by simulating emissions, meteorological processes, atmospheric chemical transformations, transport, and deposition. The WRAP used air quality models to analyze baseline period visibility, identify significant source areas and source categories of visibility-impairing emissions, and project future visibility impairment and potential visibility improvement from emissions reduction strategies.

7.2 Regional Haze Modeling

The primary tool relied upon by the WRAP for modeling visibility was the Community Multi-Scale Air Quality (CMAQ) model. The modeling was conducted by the Regional Modeling Center (RMC) at the University of California Riverside under the oversight of the WRAP Modeling Forum. All WRAP states are using this modeling.

The CMAQ model was designed as a “one atmosphere” modeling system to encompass modeling of multiple pollutants and issues, including ozone, particulate matter (PM), visibility, and air toxics. This is in contrast to many earlier air quality models that focused on single pollutants. The CMAQ model takes into account emissions, advection and dispersion, photochemical transformation, aerosol thermodynamics and phase transfer, aqueous chemistry, and wet and dry deposition of trace species.

The CMAQ model requires inputs of three-dimensional gridded wind, temperature, humidity, cloud/precipitation, and boundary layer parameters. The version of CMAQ used for the WRAP modeling utilized gridded meteorological data from the Meteorological Mesoscale 5 (MM5) model for its meteorological inputs. The MM5 model was developed as a state-of-the-science model that has been proven useful for air quality applications. MM5 has been used extensively for local, state, regional, and national modeling efforts. MM5 has undergone extensive peer-review and all of its components have undergone continual development and scrutiny by the weather prediction and modeling communities.

The RMC developed the air quality modeling inputs including annual meteorology and emissions inventories for a 2002 actual emissions base case, a planning case to represent the 2000-04 regional haze baseline period using averages for key emissions categories, and 2018 projected cases representing base case projected emissions and emissions from preliminary reasonable progress scenarios. The modeling emissions inputs were developed from the emission inventories using the Sparse Matrix Operator Kernel Emissions (SMOKE) modeling system.

CMAQ modeling of the WRAP region required other emission inventories besides those developed for the WRAP region. The RMC developed Pacific offshore commercial marine vessel inventories from a variety of sources. The RMC also gathered the latest and best representative emission estimates from the Central Regional Air Planning Association (CENRAP), the eastern United States, Mexico, and Canada. Results can be found on the WRAP Technical Support System (TSS) website at http://vista.cira.colostate.edu/TSS/Results/HazePlanning.aspx

The CMAQ model also requires that the concentrations of visibility-impairing pollutants at the 4 lateral boundaries of the modeling domain be specified. These boundary conditions represent visibility-impairing pollutants reaching North America from the rest of the world. Boundary conditions were developed from the GOES-CHEM global chemical transport model by a project commissioned by the Visibility Improvement State and Tribal Association of the Southeast (VISTAS) regional planning organization on behalf of all five regional planning organizations implementing the Regional Haze Rule (RHR).

Visibility projections for 2018 were developed from projected concentrations of visibility-impairing pollutants at Interagency Monitoring of Protected Visual Environments (IMPROVE) monitoring sites representing mandatory Class I Areas through the use of the revised IMPROVE equation. Projected concentrations were calculated by applying a Relative Response Factor (RRF) to the measured baseline period concentration at the IMPROVE site. The RRF is the ratio of the future-year modeling results to the current-year modeling results. The RRFs were developed from modeling the Plan02d baseline period and PRP18a projected 2018 emission inventories.

7.3 Model Performance

The WRAP's RMC evaluated the performance of the CMAQ model for modeling visibility in the WRAP region. The objective of the model performance evaluation was to compare CMAQ model-simulated concentrations with 2002 ambient monitoring data from a large number of sites to determine whether the CMAQ model's performance was sufficiently accurate to justify use of the model for simulating future conditions. The RMC used the Base02a emissions inventory for the simulation. The CMAQ model was evaluated for both the Most Impaired Days and the Least Impaired Days. The "Final Report for the WRAP 2002 Visibility Model Performance Evaluation" (Tonnesen, et al, 2006) discusses the model performance evaluation in detail.

The key finding of the RMC's model performance evaluation is that CMAQ modeling can be used in combination with the RRF approach to evaluate the benefits of emission reduction strategies for all particulate matter species except for coarse mass and project visibility changes at Class I Areas for regional haze planning purposes.

The RMC model performance evaluation dealt the with entire WRAP region. Ecology decided to do a further evaluation of model performance specifically for mandatory Class I Areas in the state of Washington. Ecology performed a 3-step process. As the first two steps, Ecology examined two sets of 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

Finally, Ecology performed a basic analysis of the modeling results in comparison to the monitored data at the mandatory Class I Areas. Details on the 3 steps and their results are described in Appendix M.

Ecology drew 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:

- Ammonium Sulfate (SO_4) especially on the Most Impaired Days
- Organic Matter Carbon (OMC) on the Most Impaired Days
- Elemental Carbon (EC)
- Coarse Matter (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:

- Ammonium Nitrate (NO_3)
- OMC on the Least Impaired Days
- Soil
- CM on the Most Impaired Days

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 RH SIP. Pollutant concentrations and hence visibility are likely to be over predicted on the Least Impaired Days. The impact of modeling is not so clear for the Most Impaired Days. CMAQ modeling results for sulfate and OMC, 2 of the most important pollutants affecting visibility, are

generally expected to be acceptable, but concentrations of nitrate, the other important pollutant affecting visibility are likely to be over predicted.

7.4 Source Apportionment Analysis Using Particulate Matter Source Apportionment Technology and Weighted Emissions Potential

In order to determine the significant sources contributing to haze in Washington's mandatory Class I Areas, Washington has relied upon source apportionment analysis techniques provided by the WRAP for this RH plan. This information can be found on the WRAP TSS website at http://vista.cira.colostate.edu/TSS/Results/HazePlanning.aspx .

There were two techniques used for source apportionment of regional haze. One was the Particulate Matter Source Apportionment Technology (PSAT) tool, used only for the attribution of sulfate and nitrate sources. The other was the Weighted Emissions Potential (WEP) tool which was used for attribution of sources of sulfate, nitrate, organic carbon, elemental carbon, fine particles ($PM_{2.5}$), and coarse particle matter (PM_{10}).

7.4.1 Particulate Matter Source Apportionment Technology

The PSAT tool is used with the Comprehensive Air Quality Model with Extensions (CAM_X). Like the CMAQ model, the CAM_X model is a state-of-the-science, one atmosphere model. The CAM_X/PSAT model system simulates nitrate-sulfate-ammonia chemistry and applies this chemistry to a system of tracers or "tags" to track the emissions, chemical transformations, transport, and removal of Nitrogen Oxides (NO_X) and Sulfur Dioxide (SO_2). The tracer analysis used the Plan02c baseline period and Base18b projected 2018 emission inventories to identify source regions and source categories of sulfate and nitrate.

WRAP did not regenerate PSAT results for updated baseline period or projected 2018 emission inventories because of the time and resources that running CAM_X/PSAT requires. Nonetheless, because later revisions to the WRAP inventory were relatively minor as was the projected impacts on visibility in mandatory Class I Areas, the PSAT source apportionment still serves as a reliable, relative guide to source regions and source categories of sulfate and nitrate.

Sulfate and nitrate are important because not only do they usually originate from anthropogenic (human-caused) sources but they have major impacts on visibility at mandatory Class I Areas. The results from the PSAT analysis can be useful in determining contributing sources that may be controllable within Washington and in identifying potentially controllable sources, or the need for controls, in other jurisdictions (neighboring states, Canada, and Pacific offshore). While the PSAT results show contributions in terms of mass ($\mu g/m^3$), these do not directly represent actual sulfate and nitrate measurements, nor can they accurately be transformed into extinction values.

Examples of PSAT analysis are shown below in Figures 7-1 and 7-2. The PSAT analyses for each of Washington's mandatory Class I Areas are discussed in Chapter 8.

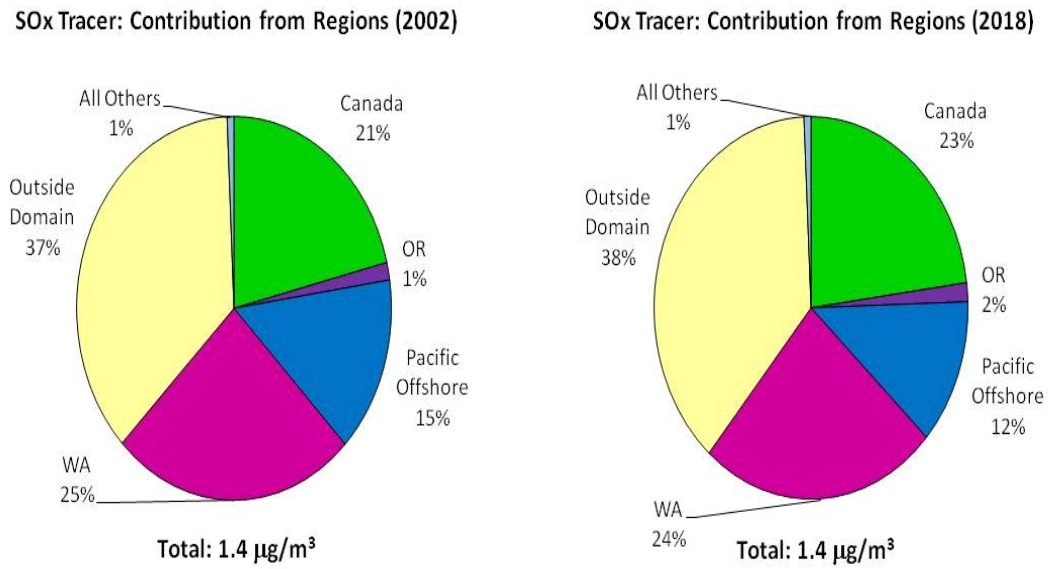

Figure 7-1 Example of Particulate Matter Source Apportionment Technology Tool Identification of Source Regions

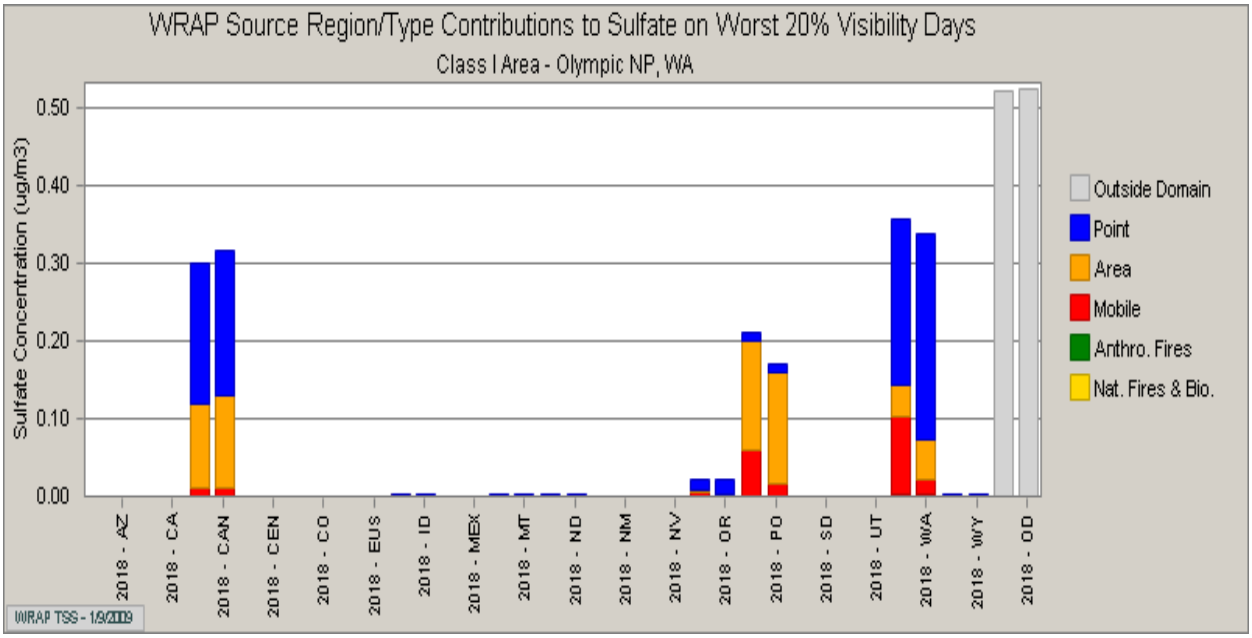

Figure 7-2 Example of Particulate Matter Source Apportionment Technology Tool Identification of Source Regions and Source Categories

7.4.2 Weighted Emissions Potential

WEP is a screening tool that helps to identify source regions that have the potential to contribute to haze formation at specific mandatory Class I Areas. Unlike PSAT, this method does not account for chemistry or deposition and thus is more qualitative. WEP combines emission inventories, wind patterns, and residence time of an air mass over each meteorological model

grid cell, to estimate the potential for a visibility-impairing pollutant to affect a specific mandatory Class I Area. The WEP tool was used to estimate source areas for SOx, NOx, primary organic aerosol, EC, $PM_{2.5}$, and PM_{10}.

Similar to PSAT, the WEP tool evaluates contributing source areas for both the 2000-2004 baseline period and the 2018 projection. The WEP tool is available in TSS for various combinations of the baseline period Plan02d inventory and projected 2018 inventories. This foundational regional haze SIP used Plan02d and PRP18a inventories.

An example of WEP analysis is shown below in Figure 7-3. Selected WEP analyses for Washington's mandatory Class I Areas are discussed in Chapter 8.

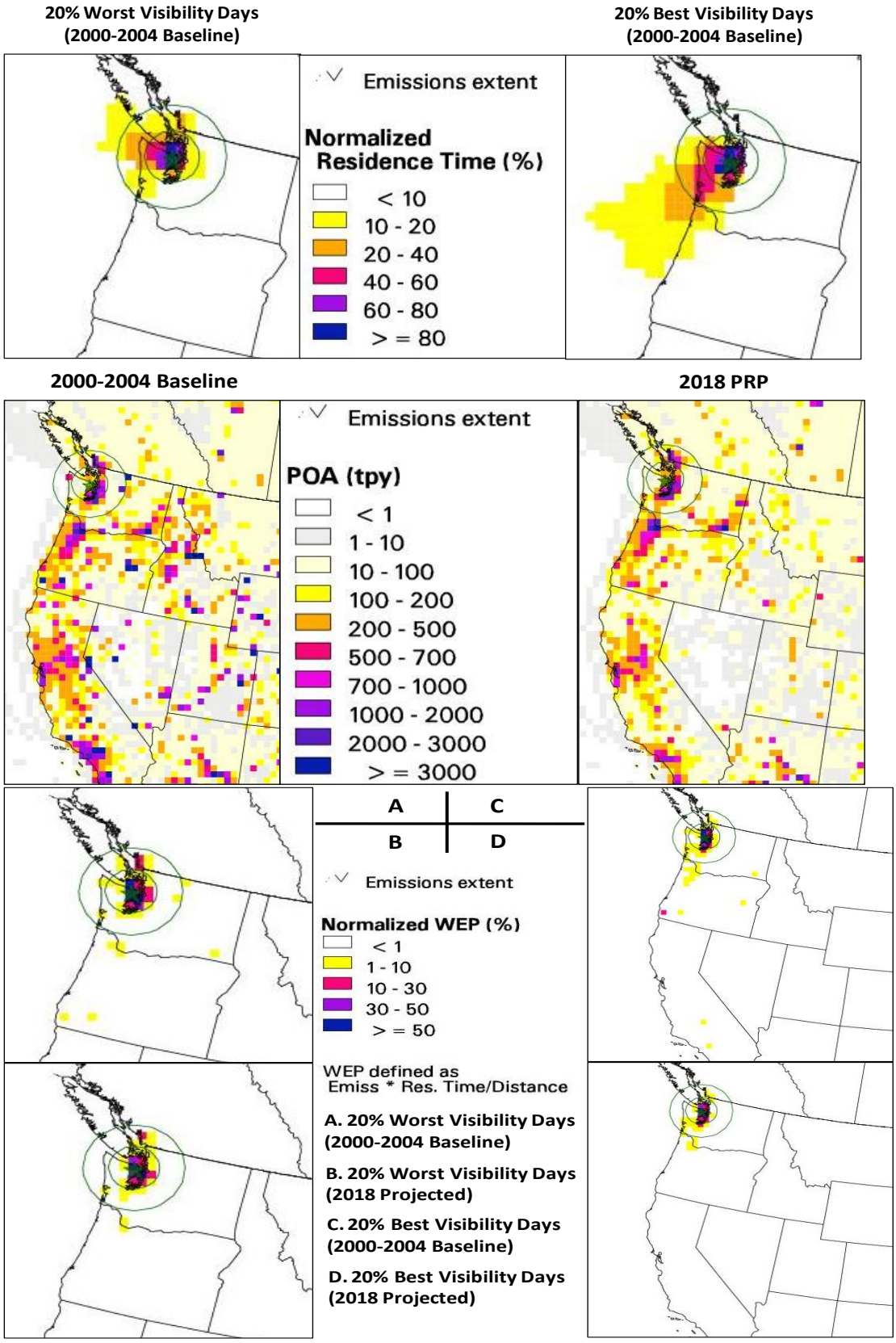

Figure 7-3 Example of Weighted Emission Potential Results for Primary Organic Aerosol

7.4.3 Differences between the Two Source Apportionment Tools

The PSAT tool was used to identify source regions and sources categories of sulfate and nitrate emissions. The PSAT modeling used the CAM_X model to account for chemistry, transport, and deposition of sulfate and nitrate. The PSAT results estimate contributions from all regions, including the WRAP states, Canada, Pacific offshore, and "outside the domain". PSAT results also estimate contributions for various source categories within the source regions.

The PSAT tool identified three geographic source regions of particular interest to the state of Washington. The three regions are outside the domain, Pacific offshore, and Canada. Outside the domain consists of the background air concentrations of visibility-impairing pollutants contributed by the rest of the world. It cannot be controlled by Washington State.

Pacific offshore emissions consist of emissions from offshore commercial marine shipping. Other marine shipping emissions include near port emissions, and in-shore emissions from cruise, reduced speed zone, and maneuvering and hotelling. Depending upon the type of emissions and where they occur, the federal government, international treaties, or the state may have or share jurisdiction for controlling emissions. The in-shore emissions in this WRAP inventory do not include Canadian vessel traffic within and just outside the Strait of Juan de Fuca, which is located along the north shore of the Olympic Peninsula though the WRAP acknowledges that these emissions affect Washington[1].

The PSAT information indicates that Canadian emissions contribute similar amounts of NO_x and SO_x as Washington state sources, as indicated in Chapter 8. These Canadian emissions primarily affect the northern four Class I areas (three of which border Canada). As with the outside the domain emissions, these emissions are part of the background entering Washington and cannot be controlled by Washington State.

WEP is a screening tool that does not address chemistry or deposition. WEP does provide a broad overview of potential contributions from within and near Washington for a much larger number of visibility-impairing pollutants than PSAT. WEP does not look at emissions from outside the domain or Pacific offshore.

Overall, while results from both tools provide relative information on sources of visibility-impairing pollutants, the PSAT results are more reliable and the WEP results more qualitative because of the way the results are developed. The PSAT results come from one-atmosphere, photochemical modeling simulations for sulfate and nitrate and thus are a modeling prediction of how emissions impact a mandatory Class I area. WEP on the other hand estimates impacts from the residence time of the area mass over an area, the total emissions in that area without any consideration of seasonality or time of day, and wind patterns. Both tools are useful so long as the limitations of each are taken into account.

[1] http://vista.cira.colostate.edu/docs/wrap/emissions/OffshoreEmissions.doc