Emission Estimates for Assessing Visual Air Quality on the Colorado Plateau

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ABSTRACT
An emissions inventory has been developed to support the visibility modeling and emission management evaluation activities that are currently underway to produce the information needed by the Grand Canyon Visibility Transport Commission. Meeting the emissions inventory requirements for the Commission started with merging U.S. Environmental Protection Agency's (EPA) 1990 Interim Inventory with point source data from EPA's AIRS database. A number of improvements were also made to the inventory to account for key missing source categories and compounds. The source categories represented in the inventory include anthropogenic point, area, and mobile sources; biogenics; forest fires, forest management, and other waste burning; and fugitive sources, such as entrained road dust and windblown dust. The emissions database contains eight inventoried compounds: \( \text{SO}_2 \), V0C, \( \text{NO}_x \), \( \text{NH}_3 \), \( \text{PM}_{2.5} \), CO, and organic and elemental carbon particulate. The inventory has a 1990 base year with annual average emission estimates and average weekday estimates for each season of the year. Tabular summaries of the emission results are presented. The magnitude of the dominant emission sources is discussed by compound.

IMPLICATIONS
The National Research Council has concluded that no single emission source category dominates visibility impairment on hazy days in the western United States. Rather, emissions from a variety of urban and natural sources mix together during transport to form what is termed “regional haze”. This emissions inventory is a key element for the visual air quality analyses performed by the Grand Canyon Visibility Transport Commission. The inventory was used to assess the distribution of emissions among source categories, to support regional air quality modeling analyses, and to support assessment of options for managing air pollutant emissions that impair visibility in 16 national parks and wilderness areas on the Colorado Plateau.

INTRODUCTION
An emissions inventory was developed for the western United States to enable an evaluation of emission-visibility relationships for Class I areas on the Colorado Plateau. The primary study domain includes the 11 western states, Texas, southwestern Canada, and northern Mexico. The inventory was developed for the Western Governor's Association in conjunction with Project VARED (Visibility Assessment of Regional Emissions Distributions) to support the visibility modeling and emission management evaluation activities of the Grand Canyon Visibility Transport Commission. Figure 1 illustrates the VARED emissions and air quality modeling domain.

Current scientific research indicates that visibility impairment in the western United States is caused primarily by sulfates, organic matter (i.e., organic carbon), soot (i.e., elemental carbon), nitrates, and crustal material (i.e., soil dust). Some of these aerosols, such as elemental carbon produced by combustion sources and crustal material from wind blown dust, are emitted directly into the atmosphere. Other aerosols, such as sulfates and nitrates, are formed in the atmosphere from gas-phase reactions. Directly emitted aerosols are termed “primary” aerosols, and aerosols formed in the atmosphere from gas-phase reactions are termed “secondary” aerosols, such as the conversion

Figure 1. Project VARED modeling domain.
of sulfur dioxide ($\text{SO}_2$) to ammonium sulfate. Consequently, the inventory consists of $\text{SO}_2$, volatile organic compounds (VOCs), elemental and organic carbon particulate (EC/OC), particulate matter (PM) less than 2.5 micrometers in aerodynamic diameter ($\text{PM}_{2.5}$), oxides of nitrogen ($\text{NO}_x$), carbon monoxide (CO), and ammonia ($\text{NH}_3$). The Commission’s Technical Committee requested that higher priority be given to $\text{SO}_2$, EC/OC, and VOC emission sources in the development of the inventory. The attributes of the inventory (Table 1) reflect the air quality modeling and emission management option analysis needs of the Commission.

The development of the inventory is described in the following sections. Emission summaries are presented at the end of the paper.

### Data Acquisition and Processing

The species and spatial requirements of the inventory necessitated the merging of numerous data sets because at the time the inventory was developed one data set did not meet the air quality modeling needs of the study. Table 2 lists each of the data sets acquired during the development of the inventory. These data sets were used in the following descending order of priority:

- State-derived data available from the 11 western states and Texas.
- The 1990 U.S. EPA Interim Inventory\(^5\) to fill geographical gaps in the state inventories.
- The 1985 National Acid Precipitation Assessment Program (NAPAP) inventory\(^5\) to fill pollutant gaps (i.e., PM and $\text{NH}_3$ for both inventories).

The EPA’s Interim Inventory consists of $\text{SO}_2$, VOC, CO, and $\text{NO}_x$; it does not contain PM or $\text{NH}_3$. The EPA developed the Interim Inventory from the 1985 NAPAP inventory by performing several key updates:

1. Area source solvent emissions were recalculated for 1990 conditions.
2. Off-road mobile source emissions calculated by the EPA Office of Mobile Sources for certain ozone nonattainment areas were extrapolated to all regions.
3. On-road motor vehicle emissions were recalculated for 1990 conditions using EPA’s MOBILES emission factor model and vehicle miles traveled (VMT) data obtained from the Highway Performance Monitoring System (HPMS).
4. Electric utility emissions were recalculated using information submitted to the Department of Energy.
5. Area source emissions for railroads, residential fuel combustion, aircraft ($\text{SO}_2$ only), and motor vehicle refueling were recalculated using updated emissions factors and changes in Reid vapor pressure and projected NAPAP activity data.
6. Emission estimates from all other sources were updated from 1985 to 1990 conditions using emission projection techniques (i.e., growth factors).

A large amount of data processing was required to merge the data sets listed in Table 2. Numerous technical improvements were also made to fill key gaps in the existing data sets.

Data sets obtained from EPA and individual states were merged and processed in the Geocoded Emissions Modeling

### Table 1. Inventory attributes.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base year</td>
<td>Generally 1990. All area and mobile source data have a base year of 1990. Some point source data reflective of 1991 and 1992 conditions.</td>
</tr>
<tr>
<td>Domain</td>
<td>11 western states, Texas, Southwestern Canada, and Northern Mexico.</td>
</tr>
<tr>
<td>Source categories</td>
<td>Anthropogenic point sources (e.g., smelters, power plants, and refineries). Area sources (e.g., residential fuel combustion and agricultural-related activities including fertilizing and tilling operations). Mobile sources (on-road and non-road sources). Biogenic (urban, natural, and agricultural biomass). Forest fires, forest management, and other waste burning. Fugitive sources such as road dust and windblown dust.</td>
</tr>
<tr>
<td>Compounds(^a)</td>
<td>1. $\text{SO}<em>2$, VOC, EC/OC. 2. $\text{PM}</em>{2.5}$. 3. $\text{NO}_x$ and $\text{NH}_3$.</td>
</tr>
<tr>
<td>Spatial coverage and resolution</td>
<td>Inventory domain extends from the Mississippi River to the Pacific Ocean in the east-west direction, and from southern Canada to northern Mexico in the north-south direction. Annual average inventory: County-level area source emissions for 11 western states; state-level area source emissions for other states and southern Canada; latitude/longitude coordinates for point sources. Modeling inventory: 50-km grid cells using polar stereographic map projection.</td>
</tr>
<tr>
<td>Temporal resolution</td>
<td>Annual average for base inventory. Hourly, seasonal weekday for modeling inventory.</td>
</tr>
</tbody>
</table>

\(^a\) Compounds listed in order of priority.
and Projections (GEMAP) system, Version 2.0, so that geographical and pollutant gaps were eliminated. For example, the 1985 NAPAP inventory was the only data set at the time that contained NH₃. Therefore, NH₃ emission estimates from the 1985 NAPAP inventory were extracted and merged with the state-supplied data. Similarly, PM and NH₃ from the NAPAP files were merged with the SO₂, VOC, NOₓ, and CO emissions in the Interim Inventory. Elemental and organic carbon particulate emissions were calculated from the PM emission estimates as described above.

**Inventory Improvements**

After merging emissions information available from the California Air Resources Board (ARB), Oregon Department of Environmental Quality (DEQ), and the EPA 1990 Interim Inventory, several important source categories, source regions, and pollutants were still missing. The improvements that were used to fill these gaps are summarized below. Additional work was also performed to characterize emission estimates for key SO₂ point sources in Northern Mexico.

**Motor Vehicle SO₂ Emission Estimates**

SO₂ emissions from on-road U.S. motor vehicles were estimated from fleet average fuel consumption assuming that all sulfur in motor fuel is converted to SO₂ (and expressed as SO₂), as follows:

\[
EF_{\text{veh, class}} (\text{kg/VMT}) = \frac{\text{FC}_{\text{veh, class}} \times \text{sulfur level}_{\text{veh, class}} \times \text{wt}_{\text{SO}_2}}{\text{wt}_s} \tag{1}
\]

Table 2. Data acquisition.

<table>
<thead>
<tr>
<th>Data Set</th>
<th>Attributes</th>
<th>Base Year</th>
<th>Pollutants</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clark County, Nevada Ozone Modeling Inventory</td>
<td>Point and area source emission estimates formatted for use in the Emissions Preprocessor System. Emissions cover the Las Vegas valley only.</td>
<td>1990</td>
<td>VOC, NOₓ, and CO</td>
<td>Clark County Department of Comprehensive Planning and Clark County Health District, Air Pollution Control Division, Clark County Department of Environmental Services</td>
</tr>
<tr>
<td>California Statewide Inventory</td>
<td>County-level area source and individual point source emission estimates for California.</td>
<td>1990</td>
<td>SO₂, NOₓ, VOC, CO, and TSP</td>
<td>ARB</td>
</tr>
<tr>
<td>Oregon Statewide Inventory</td>
<td>County-level area source and individual point source emission estimates for Oregon.</td>
<td>1990</td>
<td>SO₂, NOₓ, VOC, CO, and PM₁₀</td>
<td>DEQ</td>
</tr>
<tr>
<td>AIRS/AFS Point Source Data</td>
<td>Point source files for AZ, CO, MT, NM, NV, TX, UT, WA, and WY.</td>
<td>Varies between 1990 and 1992</td>
<td>SO₂, NOₓ, VOC, CO, and PM/PM₁₀</td>
<td>U.S. EPA</td>
</tr>
<tr>
<td>Prescribed Fire Emission Estimates</td>
<td>County-level emission estimates for AZ, CA, CO, NM, NV, UT, ID, MT, OR, WA, and WY.</td>
<td>1988</td>
<td>VOC, NOₓ, PM₁₀, PM₂.₅, F₅₋₁₀, and OC₂.₅</td>
<td>U.S. Forest Service</td>
</tr>
<tr>
<td>1990 EPA Interim Inventory</td>
<td>County-level area source and individual point source emission estimates for the United States and western Canada.</td>
<td>1990</td>
<td>SO₂, NOₓ, VOC, and CO</td>
<td>U.S. EPA</td>
</tr>
<tr>
<td>NAPAP Annual Average Emission Estimates</td>
<td>County-level area source and individual point source emission estimates for the United States and Canada.</td>
<td>1985</td>
<td>SO₂, NOₓ, VOC, CO, TSP, SO₄, and NH₃</td>
<td>U.S. EPA</td>
</tr>
<tr>
<td>NAPAP Natural Source Emission Estimates</td>
<td>County-level PM emission estimates for the United States and Canada. Source categories included in data set are windblown dust, entrained road dust for unpaved roads, and dust devils.</td>
<td>1985</td>
<td>TSP and alkaline particulates</td>
<td>NTIS</td>
</tr>
<tr>
<td>Biogenic Emissions Estimates</td>
<td>County-level and seasonally adjusted emission estimates for natural, urban, and agricultural biomass.</td>
<td>NA</td>
<td>Biogenic hydrocarbons</td>
<td>Washington State University</td>
</tr>
</tbody>
</table>

*AIRS/AFS data available only for certain counties; †Emission estimates for each season of the year were developed.

ARB = California Air Resources Board; DEQ = Oregon Department of Environmental Quality; NTIS = National Technical Information Service.
Using published fuel characteristics, the average gasoline sulfur level (by weight) was estimated to be 0.038% for the Rocky Mountain states, 0.036% for Texas, and 0.021% for the rest of the domain. A value of 0.3% was used for diesel fuel outside of Los Angeles, CA, and 0.08% was used for diesel fuel in Los Angeles. The weight ratio of SO₂ to sulfur was calculated from wt SO₂/wt S.

- Emissions were estimated using VMT data provided by county and vehicle class in the EPA Interim Inventory and summing over vehicle classes:

\[
\text{Emissions (kg SO}_2/\text{yr)} = \sum_{\text{veh.class}} \text{EE}_{\text{veh.class}} \times \text{VMT}_{\text{veh.class}} \times \text{WF}_{\text{veh.class}} \times \text{EF}_{\text{veh.class}} \times \text{AD}_{\text{veh.class}} \tag{2}
\]

### Particulate Matter Emission Estimates

The available particulate matter emission estimates in the various data sets were specific to either total PM or PM₁₀⁻⁻. Emission estimates of PM₂.₅, elemental carbon, and organic carbon were estimated from these emission rates. The latest version of EPA’s SPECIATE database, supplemented with profiles developed by the California Institute of Technology for the South Coast Air Basin (SoCAB), was used to develop ASCII data files containing a cross-reference table of particulate matter speciation profile numbers and source category codes (both NAPAP three-digit and eight-digit codes); a profile number description table, containing profile description and overall particle size fractions (0-2.5 µm, 0-6 µm, 0-10 µm); and a table of EC/OC size-specific mass fractions for relevant profile numbers.

The SPECIATE database contains a cross-reference table for point sources defined by eight-digit source classification codes (SCCs). A similar assignment for area sources did not exist; therefore, an assignment file was created. After the speciation profiles were selected, they were merged with the emissions file to obtain PM₂.₅ and EC/OC emission estimates in the following manner:

\[
\text{EE}_{i} = (\text{WF})^i (\text{WF}_{\text{PM}_2.5})^i (\text{EE}_{\text{TSP}})\tag{3}
\]

where

- \( \text{EE}_{i} = \) the emission estimate for species \( i \), either EC or OC
- \( \text{WF}_{i} = \) the weight fraction of the PM₂.₅ fraction for species \( i \)
- \( \text{WF}_{\text{PM}_2.5} = \) the weight fraction of PM₂.₅ in the total suspended particulate (TSP)
- \( \text{EE}_{\text{TSP}} = \) the mass emission rate of TSP for the source

The EC/OC emission estimates are for the 0-2.5 µm range.

### Estimation of Entrained Road Dust from Paved Roads

The 1985 NAPAP files contain county-level emission estimates of entrained road dust from unpaved roads only. Although entrained dust from paved and unpaved roads are not contained in the 1990 EPA Interim Inventory, they are present in the California ARB and Oregon DEQ data files. For regions outside of California and Oregon, emission estimates of PM₂.₅ for paved roads were calculated at the county level for this source category using the generic emission factors provided in EPA Report AP-42.

\[
\text{ER}_{\text{PM}_2.5} = \Sigma \{(\text{EF}) (\text{AD})\} \tag{4}
\]

where

- \( \text{ER}_{\text{PM}_2.5} = \) the emission rate of PM₂.₅ from entrained road dust (tons/year)
- \( \text{EF}_{i} = \) the emission factor for each road category, \( i \)
- \( \text{AD}_{i} = \) the activity data in VMT for each road category

The VMT data originating from the HPMS were used for the activity data. To calculate EC/OC emissions, appropriate speciation profiles were assigned. The resulting emission estimates were merged into the area source files.

### Development of Wildland Burning Emission Estimates

A special effort was undertaken by the U.S. Department of Agriculture (USDA) Forest Service to develop emission estimates for prescribed fire and wildfires (i.e., wildland burning) in the western United States. These wildland fire databases are managed as a separate data layer within the overall inventory so that the day-specific information in the wildfire database can be maintained. The day-specific database will also facilitate air quality model sensitivity studies so that the effect of wild and prescribed fires on visual air quality can be examined. The following discussion summarizes the development of the emission estimates.

#### Prescribed Burning Emission Estimates

The prescribed fire emission estimates were developed by the Forest Service using an advanced emission estimating technique. Acres burned, fuel loading, and fuel consumption for the emission calculations originate from a recent Forest Service study by Peterson and Ward that focused on particulate matter and air toxics emissions; these data are the only consistent set available.
that covers the geographic region of interest. This extensive data set was developed through surveys and represents 1989 conditions. The emission estimates cover prescribed fires on private, state, and federal lands.

Wildfire Emission Estimates. The wildfire emission estimates were developed by the Forest Service, with data processing support from Radian. Acres burned, fuel loading, and fuel consumption for the emission calculations were obtained from the private, state, and federal land managers in the western United States. There is a great deal of natural variability in wildfire emissions from year to year. For this reason, the wildland burning database contains emission estimates by fire event for 1986 through 1992. Due to the age of the data, emission estimates for the earlier years are considered less reliable than the estimates for the more current years. The wildfire database contains approximately 8,000 fire events documenting fires greater than 100 acres in size.

Estimation of Select Mexico Point Source Emissions

Emissions of \( \text{SO}_2 \) were estimated for the Cananea Mining Company, Inc., (Cananea) and the Mexican Copper Company, Inc., (Nacozari) using mass balance emission calculation techniques. Both facilities are located south of Douglas, AZ. Based on contacts with U.S. industry and EPA sources, the more modern facility, Nacozari, was treated as a source with control technologies comparable to those operating at the Phelps-Dodge Hidalgo, NM and Magma San Manuel, AZ, facilities. Emissions from the Cananea smelter are not controlled. Emissions were also estimated for the Carboelectric Generating Stations near Peidras Negras, Coahuila, Mexico (northeastern Mexico near Eagle Pass, TX), using information from EPA Region 6.

Nacozari. The quantity of copper concentrate (CON) processed at Nacozari was estimated based on industry sources.\(^{15}\) The sulfur content of the concentrate was assumed to be 33\\%, which is consistent with U.S. concentrates from comparable deposits.\(^{15}\) A control efficiency of 85\\% was assumed for the Nacozari smelter (typical removals in the United States are approximately 95\\%). Hence, \( \text{SO}_2 \) emissions were estimated according to:

\[
\text{SO}_2 \text{ emissions} = \text{CON} \times 0.33 \times (1 - 0.85) \times \frac{\text{wt}_{\text{SO}_2}}{\text{wt}_s} \quad (5)
\]

where

\[
\frac{\text{wt}_{\text{SO}_2}}{\text{wt}_s} = \text{the weight ratio of SO}_2 \text{ to sulfur}
\]

This approach yields an emission estimate of 136 tons/day of \( \text{SO}_2 \). This estimate will be a lower limit if controls do not operate continually or properly.

Cananea. The Cananea facility is believed to be uncontrolled.\(^{15,16}\) The quantity of concentrate processed per year was estimated by Kendall,\(^{15}\) based on production. This approach yields an emission estimate of approximately 360 tons/day of \( \text{SO}_2 \). This estimate is consistent with preview estimates by SEDESOL,\(^{17}\) the Mexican equivalent of the EPA.

Carboelectric Stations. This large electric-generating facility is also known as Carbon I and II. Carbon I is an existing facility consisting of four 300-MW units, and the Carbon II facility is currently under construction. Emissions for Carbon I were based on data received from EPA Region 6.\(^{18}\) \( \text{SO}_2 \) emissions for Carbon I were estimated with the following parameters:

- Heat rate of 10,000 Btu/kW-hr.
- Heat content of coal equal to 7,800 Btu/lb.
- Sulfur content of coal equal to 0.91\\%.
- Long-term capacity utilization factor of 90\\%.

These data yield an \( \text{SO}_2 \) emission estimate of 300 tons per day. Emissions for Carbon II were not estimated because this facility was not operating in 1990.

Development of Biogenic Emission Estimates

None of the data sources used in developing the anthropogenic emission estimates for this inventory contained biogenic emission estimates (i.e., hydrocarbon emission estimates from natural, agricultural, and urban biomass). To fill this gap, biogenic hydrocarbon emission estimates were developed for this study by researchers at Washington State University in Pullman, WA.

The emission estimates were developed by species (i.e., isoprene, alpha-pinene, other identified monoterpenes, and other hydrocarbons), by season, and by county or partial county within each state climatic division using the following basic equation:

\[
\text{ER}_i = \sum A_j BF_i EF_{ij} F(S,T) \quad (6)
\]

where

- \( \text{ER}_i \) = the emission rate (µg/hr) for chemical species \( i \)
- \( A_j \) = the area (m\(^2\)) within a region of vegetation type \( j \)
- \( BF_i \) = the leaf biomass factor (g/m\(^2\)) for vegetation type \( j \)
- \( EF_{ij} \) = the chemical species-specific emission factor for vegetation type \( j \) (µg/g leaf biomass/hr)
- \( F(S,T) \) = a chemical species-specific environmental adjustment factor (unitless)
that accounts for solar radiation, leaf temperature, and leaf shading effects.

The emission calculations were expanded to include a leaf canopy model with geometric mean emission rate factors, as described in Lamb et al. Climatic data were taken from the Geoecology Data Base for each state climatic zone; county land use data were taken from the PC-BEIS inventory system and merged with the state climatic zone calculations. Emission estimates were calculated by state climatic zone and then apportioned to the land use areas within each county or partial county within the climatic zone. The emission calculations also take into account the first and last frost months to set deciduous and agricultural emissions to zero during the winter months.

**Estimate of Direct Sulfate Emissions**

Because of its significance to visibility impairment, estimates were made of direct sulfate emissions for three key source categories: utility coal combustion, industrial and commercial fuel combustion, and motor vehicle exhaust. The motor vehicle sulfate emission estimates were produced using a composite emission factor from the draft EPA PART5 model. Sulfate emissions for the other two categories were estimated using information from AP-42. In general, AP-42 estimates that approximately 1-5% of fuel sulfur can be emitted as primary sulfate (gaseous or particulate) from combustion sources. The PART5 model estimates that approximately 3.5% of exhaust particulate emissions can be sulfate. Based upon this limited analysis, we estimate that utility coal combustion followed by industrial and commercial fuel combustion (200 and 120 tons per day, respectively) are the two most significant sources of direct sulfate emissions in the 11 western states and Texas.

**EMISSION SUMMARIES AND DISCUSSION OF RESULTS**

Tables 3 and 4 summarize the inventory for annual average conditions (neither table includes wildland burning).

These results document the emission estimates used in the Commission's analysis. Recent advances in estimating PM\textsubscript{2.5} emissions are not reflected here. Nonetheless, these summaries provide an indication of the emission magnitude and distribution of emissions by major source type in the western United States. The summaries are categorized according to source type and state. With a few exceptions, the high level of source aggregation shown in Table 3 illustrates that several source sectors in the 11 western states and Texas contribute to the overall emissions of the key species of interest (i.e., SO\textsubscript{2}, VOC, EC/OC, and PM\textsubscript{2.5}).

- SO\textsubscript{2} emissions are dominated by stationary fuel combustion. Electric utilities are the largest source sector, emitting approximately 38% of the SO\textsubscript{2}.
- Industrial and commercial fuel combustion

### Table 3. 1990 emission summary for the 11 western states and Texas\textsuperscript{ab} (tons/day).

<table>
<thead>
<tr>
<th>Sector</th>
<th>SO\textsubscript{2}</th>
<th>NO\textsubscript{x}</th>
<th>TSP</th>
<th>PM\textsubscript{2.5}</th>
<th>EC\textsubscript{2.5}</th>
<th>OC\textsubscript{2.5}</th>
<th>VOC</th>
<th>BIO\textsuperscript{c}</th>
<th>CO</th>
<th>NH\textsubscript{3}</th>
</tr>
</thead>
<tbody>
<tr>
<td>01 Utility Coal Combustion</td>
<td>2,707</td>
<td>2,539</td>
<td>249</td>
<td>72</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>17</td>
<td>180</td>
<td>&lt;1</td>
<td></td>
</tr>
<tr>
<td>02 Industrial &amp; Commercial Fuel</td>
<td>1,523</td>
<td>4,511</td>
<td>270</td>
<td>170</td>
<td>11</td>
<td>10</td>
<td>265</td>
<td>1,066</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>03 Copper Smelters</td>
<td>474</td>
<td>13</td>
<td>13</td>
<td>11</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>3,075</td>
<td>2,398</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>04 Residential Fuel Combustion</td>
<td>29</td>
<td>201</td>
<td>442</td>
<td>426</td>
<td>43</td>
<td>198</td>
<td>199</td>
<td>3,075</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>05 Solvent Use</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>2</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>2,911</td>
<td>966</td>
<td>49</td>
<td></td>
</tr>
<tr>
<td>06 Petroleum and Other Chemicals</td>
<td>891</td>
<td>613</td>
<td>70</td>
<td>19</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>6,357</td>
<td>53,055</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>07 Mobile Sources\textsuperscript{d}</td>
<td>799</td>
<td>8,444</td>
<td>40,680</td>
<td>11,069</td>
<td>272</td>
<td>594</td>
<td>6,637</td>
<td>53,055</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>08 Manufacturing</td>
<td>177</td>
<td>266</td>
<td>426</td>
<td>155</td>
<td>2</td>
<td>28</td>
<td>122</td>
<td>280</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>09 Prescribed and Natural Burning</td>
<td>5</td>
<td>28</td>
<td>1,151</td>
<td>234</td>
<td>10</td>
<td>62</td>
<td>1,872</td>
<td>1,094</td>
<td>52</td>
<td></td>
</tr>
<tr>
<td>10 Natural Sources</td>
<td>33,777</td>
<td>676</td>
<td>&lt;1</td>
<td>5</td>
<td>31</td>
<td>43,929</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11 Miscellaneous\textsuperscript{e}</td>
<td>272</td>
<td>854</td>
<td>406</td>
<td>153</td>
<td>3</td>
<td>7</td>
<td>510</td>
<td>1,588</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>99 Unspecified Sources\textsuperscript{f}</td>
<td>3</td>
<td>25</td>
<td>728</td>
<td>502</td>
<td>80</td>
<td>116</td>
<td>151</td>
<td>112</td>
<td>1,012</td>
<td></td>
</tr>
<tr>
<td>Region Total</td>
<td>6,879</td>
<td>17,496</td>
<td>78,213</td>
<td>13,487</td>
<td>421</td>
<td>1,021</td>
<td>15,791</td>
<td>43,929</td>
<td>60,745</td>
<td>1,171</td>
</tr>
</tbody>
</table>

\textsuperscript{a} Eleven western states = AZ, CA, CO, ID, MT, NV, NM, OR, UT, WA, and WY.

\textsuperscript{b} Estimates exclude wildland burning.

\textsuperscript{c} Biogenic hydrocarbons from natural, agricultural, and urban biomass.

\textsuperscript{d} This sector consists of both nonroad and onroad sources.

\textsuperscript{e} This sector consists of fugitive dust, construction, agriculture and forestry, and other miscellaneous sources.

\textsuperscript{f} The summary categorization scheme used in this report originates from U.S. EPA's Tier 1 and Tier 2 summary scheme. Point and area source SCC codes not assigned in the U.S. EPA look-up table have been placed under the heading of unspecified sources.
accounts for 23% of the total estimated SO$_2$ emitted. On-road and off-road mobile sources together comprise about 12% of the SO$_2$ estimated emissions.

- Copper smelting accounts for approximately 7% of the SO$_2$. This contribution will decrease with post-1990 plant modifications implemented at the Asarco (Texas), Cyprus (Miami), and Kennecott smelters.

- Figure 2 illustrates the location of the largest SO$_2$ point sources in the 11 western states. This figure also illustrates the emissions from the two Mexican copper smelters and the Carboelectric utility. The size of each dot is scaled according to the magnitude of the annual emissions. Within the 11 western states and northern Mexico, the two largest SO$_2$ sources are the Cananea copper smelter and the Carboelectric utility, respectively. Neither of these facilities has SO$_2$ emission controls. The Navajo Generating Station (NGS) is the third largest SO$_2$ emission source in the 11 western states and Northern Mexico. Scrubbers that will reduce SO$_2$ emissions are currently being installed at NGS.

- The two most significant sources of direct sulfate emissions are utility coal combustion and industrial and commercial fuel combustion. Directly emitted sulfate from these two source sectors represent about five percent of the SO$_4$ emitted from utility, industrial, and commercial sources.

- Anthropogenic VOC emissions are distributed among several different source categories. Mobile sources are the largest emitters of VOC in the western states, emitting approximately 42% of the VOCs. Most of this VOC is attributable to on-road sources. Solvent use and petroleum processes contribute approximately 19 and 18%, respectively, of the emitted VOCs.

- For total VOC emissions (biogenic and anthropogenic), biogenic sources dominate, contributing 70% of the total VOC. The current emissions database shows an unusually large amount of biogenic emissions in Arizona. The major land use/land cover (LULC) category in Arizona is

![Figure 2. Location of largest SO$_2$ point sources in the 11 western states and northern Mexico.](image)

<table>
<thead>
<tr>
<th>Area</th>
<th>State</th>
<th>SO$_2$</th>
<th>NO$_x$</th>
<th>TSP</th>
<th>PM$_{2.5}$</th>
<th>EC$_{2.5}$</th>
<th>OC$_{2.5}$</th>
<th>VOC$^a$</th>
<th>BIO$^c$</th>
<th>CO</th>
<th>NH$_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport Region</td>
<td>Arizona</td>
<td>556</td>
<td>961</td>
<td>8,232</td>
<td>1,304</td>
<td>23</td>
<td>60</td>
<td>728</td>
<td>4,436</td>
<td>3,347</td>
<td>39</td>
</tr>
<tr>
<td></td>
<td>California</td>
<td>456</td>
<td>3,685</td>
<td>10,491</td>
<td>1,903</td>
<td>109</td>
<td>268</td>
<td>4,227</td>
<td>5,771</td>
<td>16,875</td>
<td>226</td>
</tr>
<tr>
<td></td>
<td>Colorado</td>
<td>299</td>
<td>833</td>
<td>2,482</td>
<td>457</td>
<td>22</td>
<td>63</td>
<td>661</td>
<td>2,344</td>
<td>3,588</td>
<td>96</td>
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<tr>
<td></td>
<td>Idaho</td>
<td>102</td>
<td>196</td>
<td>3,100</td>
<td>717</td>
<td>11</td>
<td>29</td>
<td>219</td>
<td>2,493</td>
<td>1,181</td>
<td>54</td>
</tr>
<tr>
<td></td>
<td>Nevada</td>
<td>156</td>
<td>307</td>
<td>5,504</td>
<td>273</td>
<td>6</td>
<td>14</td>
<td>221</td>
<td>2,962</td>
<td>1,088</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>New Mexico</td>
<td>483</td>
<td>703</td>
<td>6,236</td>
<td>784</td>
<td>16</td>
<td>41</td>
<td>380</td>
<td>3,405</td>
<td>2,966</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Oregon</td>
<td>180</td>
<td>553</td>
<td>832</td>
<td>307</td>
<td>21</td>
<td>49</td>
<td>542</td>
<td>3,230</td>
<td>3,137</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td>Utah</td>
<td>283</td>
<td>523</td>
<td>4,804</td>
<td>584</td>
<td>12</td>
<td>31</td>
<td>347</td>
<td>2,317</td>
<td>2,184</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>Wyoming</td>
<td>384</td>
<td>619</td>
<td>2,136</td>
<td>280</td>
<td>9</td>
<td>14</td>
<td>538</td>
<td>2,160</td>
<td>742</td>
<td>50</td>
</tr>
<tr>
<td>Other</td>
<td>SUBTOTAL</td>
<td>2,898</td>
<td>8,379</td>
<td>43,818</td>
<td>6,609</td>
<td>228</td>
<td>568</td>
<td>10,761</td>
<td>29,118</td>
<td>34,508</td>
<td>605</td>
</tr>
<tr>
<td></td>
<td>Montana</td>
<td>208</td>
<td>374</td>
<td>3,858</td>
<td>267</td>
<td>16</td>
<td>32</td>
<td>224</td>
<td>3,408</td>
<td>1,189</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td>Texas</td>
<td>3,366</td>
<td>7,908</td>
<td>27,589</td>
<td>5,699</td>
<td>139</td>
<td>297</td>
<td>6,677</td>
<td>9,185</td>
<td>18,994</td>
<td>418</td>
</tr>
<tr>
<td></td>
<td>Washington</td>
<td>407</td>
<td>835</td>
<td>2,948</td>
<td>912</td>
<td>37</td>
<td>124</td>
<td>1,030</td>
<td>2,218</td>
<td>6,054</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td>SUBTOTAL</td>
<td>3,981</td>
<td>9,117</td>
<td>34,395</td>
<td>6,879</td>
<td>193</td>
<td>453</td>
<td>7,930</td>
<td>14,811</td>
<td>26,237</td>
<td>566</td>
</tr>
<tr>
<td></td>
<td>GRAND</td>
<td>6,879</td>
<td>17,496</td>
<td>78,213</td>
<td>13,467</td>
<td>421</td>
<td>1,021</td>
<td>15,791</td>
<td>43,929</td>
<td>60,745</td>
<td>1,171</td>
</tr>
</tbody>
</table>

$^a$ Estimates exclude wildland burning; $^b$ Anthropogenic VOC; $^c$ Biogenic hydrocarbon emissions from natural, agricultural, and urban biomass.
scrubland (70%). Compared to other LULC types (i.e., grasslands), scrubland is assigned a relatively high biomass, resulting in Arizona having a higher biogenic emissions flux than New Mexico, for example (approximately 53% scrubland and 31% grassland). It is possible that the scrubland category for Arizona should incorporate a lower biomass than is currently used in the biogenic emissions calculations. At the time this inventory was developed, however, no other biomass data was available for this region of the domain. Further field research is warranted so that a more refined biogenic emission estimate can be developed for the arid Southwest.

• Table 3 illustrates that fine EC particulate emissions are dominated by combustion sources. Mobile sources are the largest emitters, comprising 65% of the total emissions. Most of the EC from mobile sources is emitted by diesel vehicles. On an annual basis, the residential fuel combustion sector emits another 10% of the EC. During the winter season, the contribution of EC from residential fuel combustion would be much larger due to increased heating demands.

• Emissions of fine OC particulate are also significantly influenced by combustion sources. However, entrained road dust is also a significant emitter of OC, accounting for approximately 38% of the emissions. All mobile sources, including entrained road dust, account for approximately 58% of the OC emissions. The residential fuel combustion sector emits another 19% of the OC (on an annual basis), which increases significantly during the winter season.

Table 5. Summary of prescribed burn emission estimates (tons/day).

<table>
<thead>
<tr>
<th>State</th>
<th>EC 2.5</th>
<th>OC 2.5</th>
<th>TSP</th>
<th>PM 2.5</th>
<th>VOC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arizona</td>
<td>10</td>
<td>39</td>
<td>141</td>
<td>88</td>
<td>45</td>
</tr>
<tr>
<td>California</td>
<td>6</td>
<td>28</td>
<td>99</td>
<td>60</td>
<td>31</td>
</tr>
<tr>
<td>Colorado</td>
<td>&lt;1</td>
<td>2</td>
<td>7</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Idaho</td>
<td>8</td>
<td>30</td>
<td>107</td>
<td>67</td>
<td>34</td>
</tr>
<tr>
<td>Montana</td>
<td>4</td>
<td>14</td>
<td>52</td>
<td>33</td>
<td>17</td>
</tr>
<tr>
<td>New Mexico</td>
<td>1</td>
<td>6</td>
<td>18</td>
<td>12</td>
<td>6</td>
</tr>
<tr>
<td>Nevada</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Oregon</td>
<td>14</td>
<td>64</td>
<td>219</td>
<td>140</td>
<td>71</td>
</tr>
<tr>
<td>Utah</td>
<td>&lt;1</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Washington</td>
<td>4</td>
<td>22</td>
<td>75</td>
<td>48</td>
<td>24</td>
</tr>
<tr>
<td>Wyoming</td>
<td>&lt;1</td>
<td>2</td>
<td>5</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Totals</td>
<td>48</td>
<td>208</td>
<td>727</td>
<td>458</td>
<td>233</td>
</tr>
</tbody>
</table>

a Estimates represent 1989 conditions and covers the 11 western states.

Table 6. Summary of wildfire emission estimates (tons/day).

<table>
<thead>
<tr>
<th>Year</th>
<th>EC 2.5</th>
<th>OC 2.5</th>
<th>TSP</th>
<th>PM 2.5</th>
<th>VOC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1986</td>
<td>9.3</td>
<td>88</td>
<td>250</td>
<td>160</td>
<td>79</td>
</tr>
<tr>
<td>1987</td>
<td>27</td>
<td>270</td>
<td>790</td>
<td>490</td>
<td>250</td>
</tr>
<tr>
<td>1988</td>
<td>74</td>
<td>820</td>
<td>2,400</td>
<td>1,500</td>
<td>790</td>
</tr>
<tr>
<td>1989</td>
<td>13</td>
<td>120</td>
<td>360</td>
<td>220</td>
<td>120</td>
</tr>
<tr>
<td>1990</td>
<td>11</td>
<td>110</td>
<td>330</td>
<td>200</td>
<td>100</td>
</tr>
<tr>
<td>1991</td>
<td>5.2</td>
<td>52</td>
<td>150</td>
<td>93</td>
<td>49</td>
</tr>
<tr>
<td>1992</td>
<td>11</td>
<td>110</td>
<td>330</td>
<td>190</td>
<td>100</td>
</tr>
</tbody>
</table>

b Emission estimates are for the 11 western states.

Data compiled for the Commission’s inventory indicates that mobile sources emit approximately 82% of the fine PM emissions. Entrained road dust from paved and unpaved roads are the primary emitters, contributing 22 and 64%, respectively, of the mobile source fine PM. Fine PM exhaust from gasoline motor vehicles accounts for about 6% of the mobile source PM in the Commission’s inventory. More recent work, however, indicates that the entrained road dust and motor vehicle gasoline exhaust emissions may be overstated in the Commission’s inventory. In EPA’s national particulate inventory, mobile sources account for about 54% of the fine PM for states in the western U.S. It should also be noted that an uncertainty analysis completed for the Commission’s inventory estimated the imprecision in the county-level entrained road dust emissions to be on the order of 200% for paved roads and 400% for unpaved roads. Although current estimating techniques suggest that entrained road dust comprises a large portion of the emissions budget in the western U.S., these estimates have a high degree of uncertainty. On-going research indicates these results may be overestimated.

Wind blown dust contributes 5% of the PM\(_{2.5}\) emissions. For comparison, windblown dust represents approximately 10% of the fine PM in EPA’s national particulate inventory for the western states. This difference is due to changes in calculation methodology and different data inputs to the emissions calculation.

The emission summaries by state and EPA transport region in Table 4 show that emissions are generally distributed by population. California is a major contributor of VOC, EC/OC, NO\(_x\), and fine particulate that result from urban activities. Arizona is the largest emitter of SO\(_2\) in the transport region, followed closely by New Mexico. Texas is
also a significant source of emissions. When compared to the
11 western states, Texas dominates the emissions of
nearly every species.

Tables 5 and 6 summarize the wildland burning (e.g., pre-
scribed and wildfires) emission estimates for the 11 western
states (estimates were not developed for Texas). For visibility
analyses, the key species for wildland burning are EC/OC.

- Prescribed fire emission estimates for EC$_{2.5}$ for the
  western states are less than 10% of the total esti-
mated EC$_{2.5}$ emissions from all source categories
  (i.e., prescribed fire, wildfire, and all anthropogenic
  sources). OC$_{2.5}$ emission estimates for prescribed
  fires are less than 20% of the total estimated OC$_{2.5}$
  emissions from all the other source categories.

- In 1990, wildfires accounted for less than 5% of
  the EC$_{2.5}$ and approximately 10% of OC$_{2.5}$ emitted
  in the 11 western states.

- Total wildland burning emissions of EC$_{2.5}$ are less
  than 15% of the total emissions and less than 25% of
  the OC$_{2.5}$ emissions. It is also interesting to note
  that in 1989, PM$_{2.5}$ emissions from prescribed burn-
ing were approximately twice those from wildfires.
This ratio will vary significantly from year to year.

- Wildland burning has a greater impact at the local
  level than the above figures suggest. The con-
  tributions from significant fires can greatly exceed
  routine releases of anthropogenic emissions in the
  same area. Emissions from wildland burning also
  have unpredictable temporal patterns in contrast
  to the predictable release from many anthropo-
  genic sources (e.g., dry cleaning and vehicle refu-
  eling). Wildland burning events are highly vari-
  able and occur on an episodic basis.

- At a state level, order of magnitude changes in the
  acreage burned from year to year occur within the
  wildfire database. Table 6 illustrates the recent vari-
  ability in the wildfire emission estimates. During
  the seven-year period (1986-1992), the largest
  emissions occurred during the 1988 Yellowstone
  fires in Montana and Wyoming. The year 1987
  was also a significant fire year, with numerous wild-
  fires in California.

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