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RESEARCH AND DEVELOPMENT OF PLANNED BURNING EMISSION INVENTORIES FOR THE CENTRAL STATES REGIONAL AIR PLANNING ASSOCIATION

FINAL REPORT
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QUALITY ASSURANCE STATEMENT

This report was reviewed and approved by the project Quality Assurance (QA) Officer or his delegated representatives, as provided in the project QA Plan (Coe, 2003a).

Lyle R. Chinkin
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EXECUTIVE SUMMARY

The Central States Regional Air Planning Association (CENRAP) is researching visibility-related issues for its region and is developing a regional haze plan in response to the U.S. Environmental Protection Agency's (EPA) mandate to protect visibility in Class I areas. Agricultural and prescribed burning activities ("planned burning") contribute to episodes of impaired visibility in the CENRAP region-phenomena that the CENRAP seeks to better understand. Therefore, support of the CENRAP's need to develop a regional haze plan, Sonoma Technology, Inc. (STI) developed planned burning emission inventories for the region.

As detailed in the Methods Document, presented in Appendix A, Emission Estimation Methods for the CENRAP Planned Burning Emission Inventories (Methods Document), emissions estimates were prepared for prescribed and agricultural burning activities on federal, state, tribal, and private lands in the CENRAP region. These "bottom up" estimates were prepared by using the First-Order Fire Effects Model (FOFEM), emission factors and fuel loadings gathered from published literature, geographic information systems (GIS) databases of land cover and vegetation, and activity data gathered through telephone surveys.

Year-2002 $PM_{2.5}$ emissions of particulate matter of less than 2.5 µm aerodynamic diameter ($PM_{2.5}$) from planned burning activities in the CENRAP states were estimated to be 317,000 tons (see **Figure ES-1**)—almost 300% higher than the estimate of 110,000 tons of $PM_{2.5}$ prepared by the EPA for the 1999 National Emission Inventory (NEI). In addition, planned burning activities emitted precursors to chemically formed $PM_{2.5}$, including approximately 239,000 tons per year volatile organic compounds (VOC), 80,000 tons per year nitrogen oxides (NO_x), 47,000 tons per year ammonia (NH_3), and 35,000 tons per year sulfur oxides (SO_x). The most significant source of these emissions was the burning of private rangelands, which accounted for 50% of the annual planned burning $PM_{2.5}$ emissions in the CENRAP region. This source category was especially significant in the states of Texas, Oklahoma, and Kansas. Prescribed burning on publicly managed forest and grasslands was the second most significant source of planned burning emissions in the region, accounting for 32% of the annual planned burning $PM_{2.5}$ emissions (see **Figure ES-2**). This source category was especially important in the states of Arkansas, Louisiana, and Minnesota. (Emission estimates by source category and state are tabulated in Appendix B.)

Planned burning emissions peak in the spring. More than 25% of annual activity occurs during the month of March. A smaller peak in emissions occurs during the months of September and October (see **Figure ES-3**). Spring and fall provide the most advantageous climatological and biological conditions for prescribed burning, while agricultural burns tend to occur before spring planting or after fall harvesting.

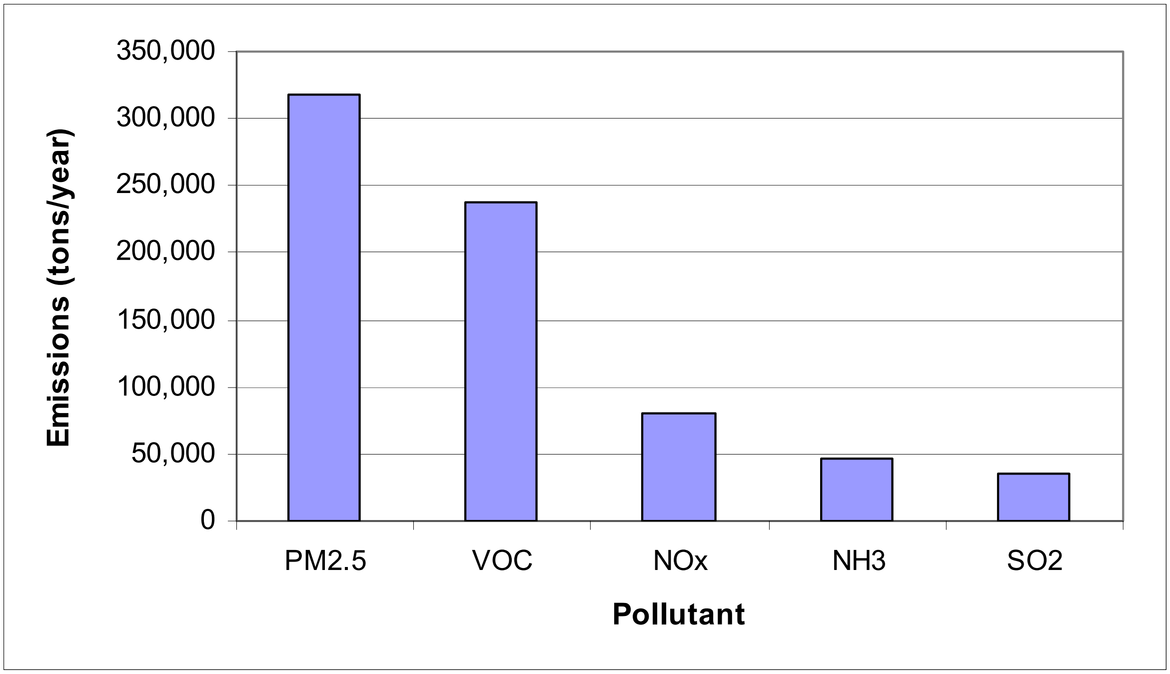

Figure ES-1. CENRAP annual planned burning emissions by pollutant.

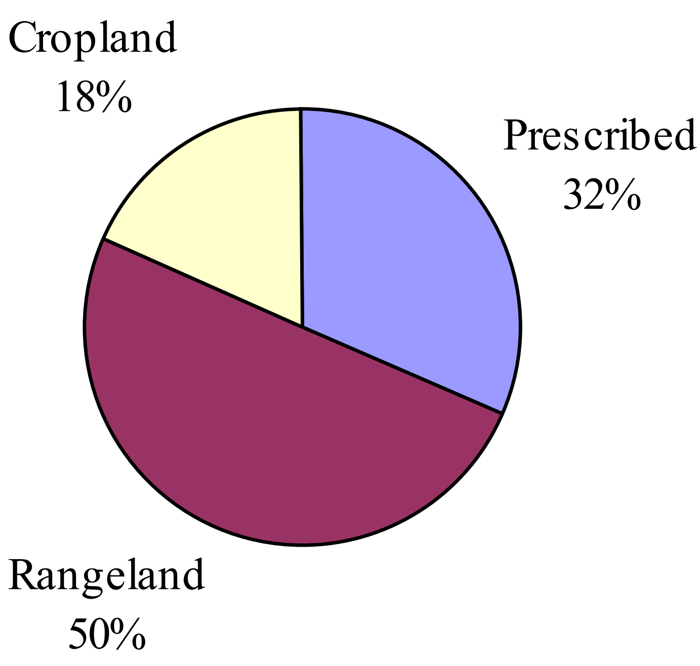

Figure ES-2. CENRAP annual planned burning $PM_{2.5}$ emissions by source category.

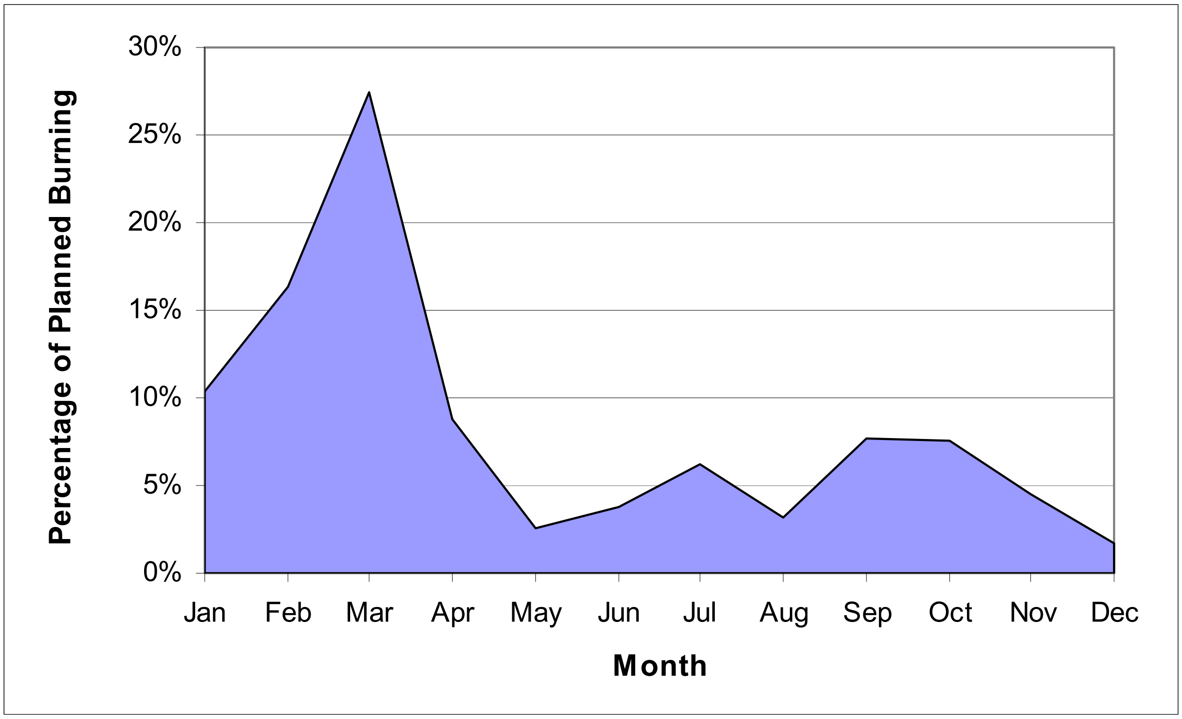

Figure ES-3. Monthly variability in total emissions for the CENRAP region.

The planned burning emission inventory and speciated $PM_{2.5}$ data from the Interagency Monitoring of Protected Visual Environments (IMPROVE) network stations located in Class I areas in the CENRAP region were used to investigate the influence of smoke on ambient $PM_{2.5}$ concentrations and whether individual burns can be detected in the air quality data of Class I areas. The emission inventory and IMPROVE data were utilized to better understand the extent to which prescribed burning affects visibility in the CENRAP region. This preliminary analysis showed that, while influence from specific burns could be seen in the monitoring data on select days when the meteorology was conducive, ammonium sulfate (a species that does not result from burning) was the dominant constituent of the $PM_{2.5}$ mass and visibility reduction, particularly on the 20% worst visibility days of the year, for the sites analyzed.

1. INTRODUCTION

The Central States Regional Air Planning Association (CENRAP) is researching visibility-related issues for its region, which includes the states of Texas, Oklahoma, Louisiana, Arkansas, Kansas, Missouri, Nebraska, Iowa, and Minnesota, and is developing a regional haze plan in response to the U.S. Environmental Protection Agency's (EPA) mandate to protect visibility in Class I areas.[1] In order to develop an effective regional haze plan, the CENRAP ultimately must develop a conceptual model of the phenomena that lead to episodes of low visibility in the CENRAP region. Episodic combustion events (such as agricultural burning, prescribed burning, open burning of wastes, structural fires, and wildfires) sometimes contribute to regional or local haze events in the CENRAP region. Therefore, it is important to develop the emissions data necessary to assess the impacts of these events on visibility in the CENRAP region.

In support of the CENRAP's need to develop a regional haze plan, Sonoma Technology, Inc. (STI) conducted CENRAP Work Assignment Number 02-0214-RP-003-002 "Research and Development of Emission Inventories for Planned Burning Activities for the Central States Regional Air Planning Association". Consistent with the project goals presented in the Work Plan (Coe, 2003b), emissions were calculated for agricultural and prescribed burning on federal, state, tribal, and private lands.

1.1 BACKGROUND AND KEY ISSUES

1.1.1 Fine Particulate Matter Concentrations and Impaired Visibility in Class I Areas

Regional haze is visibility impairment caused mainly by particles of less than 2.5 microns in diameter ($PM_{2.5}$). $PM_{2.5}$ may be directly emitted from emissions sources, such as sources of fugitive dust and combustion soot, which are termed sources of "primary $PM_{2.5}$". Additional mechanisms also occur allowing $PM_{2.5}$ to be formed in the atmosphere, and this phenomenon is termed "secondary formation". Examples include condensable organic aerosols which can form from air emissions of semi-volatile and heavy organic compounds and $PM_{2.5}$ that can form from photochemical reactions of gaseous precursors, including sulfur oxides (SO_x), nitrogen oxides (NO_x), volatile organic compounds (VOC), and ammonia (NH_3).

Analyses of speciated $PM_{2.5}$ samples provide an understanding of the types of emission sources that contribute to regional haze issues in different areas, as depicted in **Figure 1-1**. In urban and ammonia-depleted areas of the eastern United States, secondary sulfate contributes a more significant amount of $PM_{2.5}$ than it does in the western United States. Conversely, secondary nitrate is more important in urban and ammonia-rich areas of the western United States than it is in eastern areas. In both the eastern and western United States, the carbonaceous fraction of $PM_{2.5}$ is significant in urban areas. In rural areas, geologic dust can also be an important contributor to $PM_{2.5}$.

[1] Class I lands include areas such as national parks, wilderness areas, and national monuments. These areas have been granted special air quality protections under the Federal Clean Air Act.

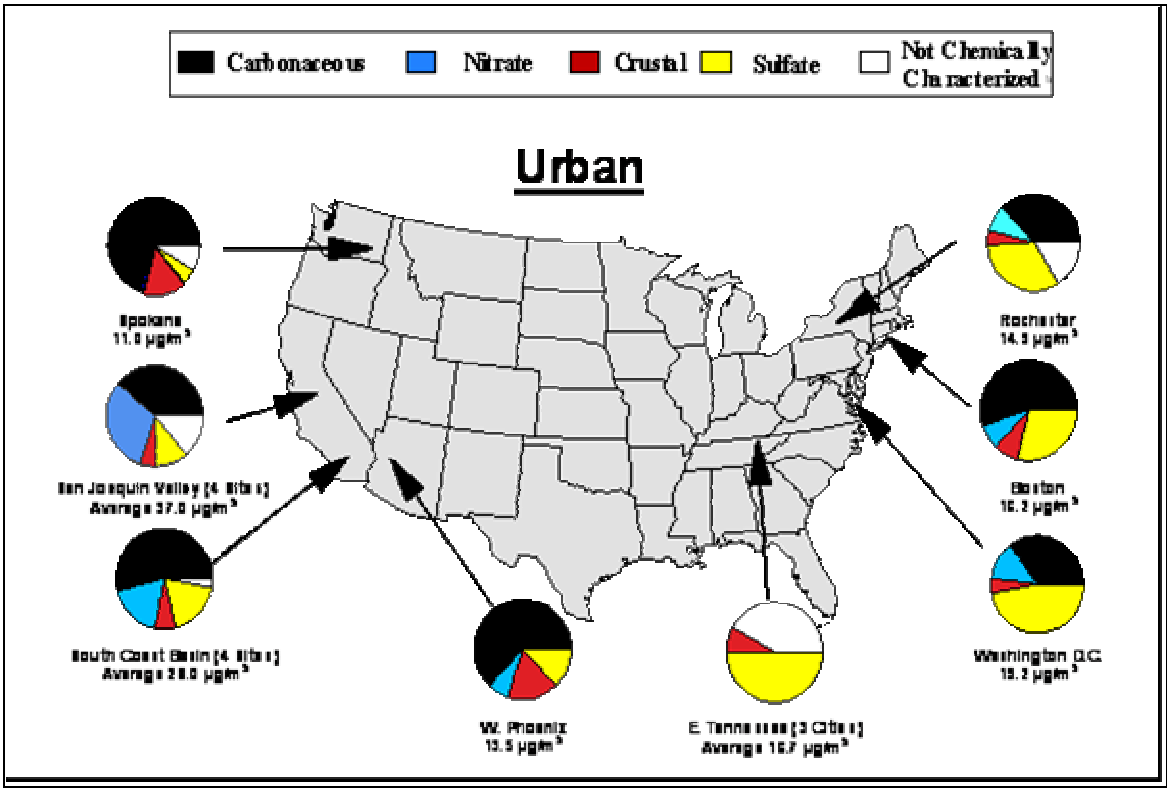

Figure 1-1. Compositions of annual average concentrations of $PM_{2.5}$ observations in urban locations (U.S. Environmental Protection Agency, 1998).

Of particular interest in the CENRAP region is the contribution of $PM_{2.5}$ from wood and grassland burning to visibility impairment in Class I areas. Smoke from these fires emit organic carbon (OC) and elemental carbon (EC); the latter is sometimes referred to as soot or black carbon (BC). OC comes from many sources, both combustion and evaporative, while EC only originates from combustion sources, such as fossil fuel combustion (power plants, car exhaust, etc.) or woodland or grassland burning. Potassium (K) is also emitted during burning of natural materials and can be used as a marker for woodland or grassland burning.

1.1.2 Status of Existing Planned Burning Inventories

Historically, few areas of the CENRAP region have experienced significant air quality problems and, therefore, have not been required to perform air quality monitoring or develop emission inventories. The most comprehensive source of emissions estimates currently available for the region is the EPA's National Emissions Inventory (NEI), which is used as the basis of the EPA's National Emission Trends (NET) document series and analyses. On a state level, emission inventories of burning activities have been prepared by Dennis et al. (2002) for Texas. In the NEI, estimates of $PM_{2.5}$ emissions from planned burning activities in the CENRAP region amount to 110,000 tons per year, or about 9% of the total $PM_{2.5}$ inventory for the region (see **Table 1-1**). The NEI indicates that planned burning emissions are particularly significant in the states of Louisiana and Texas.

Table 1-1. 1999 NEI estimates of $PM_{2.5}$ emissions in the CENRAP region.

State	$PM_{2.5}$ (tons)		Percent
	All Sources	Planned Burning	
Arkansas	91,294	6,735	7.4%
Iowa	108,641	402	0.4%
Kansas	158,521	9,502	6.0%
Louisiana	94,522	34,099	36.1%
Minnesota	163,542	2,874	1.8%
Missouri	183,245	1,147	0.6%
Nebraska	131,486	2,576	2.0%
Oklahoma	149,015	7,137	4.8%
Texas	223,427	45,748	20.5%
Total	1,303,694	110,220	8.5%

As part of its research into regional haze, CENRAP has decided to conduct comprehensive air quality modeling of visibility in 2002. To support this modeling, a bottom-up planned burning emission inventory, which incorporated year-2002-specific fire history data and addressed the uncertainties of the NEI (see below) is required.

Some uncertainties are inherent to the NEI:

- Prescribed burning activities fluctuate dramatically from year to year. Fluctuations are due to policy decisions about the need for wildfire risk management, current climate conditions (drought versus wet conditions), and densities of undergrowth and fuel. Because of these wide fluctuations, emission inventories of prescribed burning are nearly impossible to predict or project on the basis of historical inventories or trends.
- The NEI is estimated on an annual average basis. Regional haze has a seasonal character and is partly driven by photochemical processes. Adjustments are necessary to develop seasonal, diurnal, and, possibly, day-of-week emission estimates.

To support modeling sensitivity runs, measures of uncertainty for all emission estimates are highly valuable for policy decisions and prioritization of future research efforts. To the extent possible, we provide estimates of uncertainty for emissions associated with planned burning activity data that were gathered for this project.

1.2 CURRENT STATUS OF THE CENRAP EMISSION INVENTORY

As detailed in the attached Methods Document (Appendix A), emissions estimates were prepared for prescribed and agricultural burning activities on federal, state, tribal, and private lands in the CENRAP region. These “bottom up” estimates were prepared by using the First-Order Fire Effects Model (FOFEM), emission factors and fuel loadings gathered from published literature, geographic information systems (GIS) databases of land cover and vegetation, and activity data gathered through telephone surveys.

The FOFEM model, a computing tool developed through the Joint Fire Science Program (JFSP), was used to generate estimates of fuel loadings and emission rates for prescribed burns. FOFEM was run for local vegetation types using fuel moisture inputs from the Weather Information Management System (WIMS), a database of daily weather observations gathered from about 1500 fire weather stations throughout the United States. Outputs from FOFEM were then used in conjunction with prescribed burning history information to calculate emissions.

For agricultural burning, emission factors and fuel-loading factors for a variety of crop types are available in the EPA's guidance document, "Compilation of Air Pollutant Emission Factors (AP-42)" (U.S. Environmental Protection Agency, 2003) and from Jenkins et al. (1996). From these sources, we identified fuel loading factors and emission factors for a wide variety crop types and applied these factors to county-specific agricultural burning activity data to generate emissions estimates. The activity data were obtained through systematic telephone surveys of county agricultural extension services (AES).

For both prescribed and agricultural burning activities, the EPA's Biogenic Emissions Landcover Database (BELD) Version 3 (U.S. Environmental Protection Agency, 2001) was used to generate spatial distributions of vegetation types, which in turn were used to select vegetation-specific fuel loading factors output by FOFEM. To do this, cross-walks were established to link the vegetation types in the BELD database with (a) vegetation types in FOFEM and (b) crop types for which emissions factors and fuel loadings are available.

Once a map of vegetation and crop types was developed, we overlaid histories of planned fires, identified the vegetation types associated with each fire occurrence, and applied emission factors generated through FOFEM or acquired from literature to produce county-level emission inventories of agricultural and prescribed burning.

The resulting emission inventory is illustrated in **Figures 1-2 and 1-3** and tabulated in Appendix B. In all cases, we applied generally accepted emission factors and the most complete and up-to-date activity data sets that could be identified and acquired. However, we acknowledge that available emission factors are uncertain and they continue to be the subject of research.

The emission source type in the inventory that we qualitatively consider to contribute the greatest degrees of uncertainty to the total estimated emissions is prescribed burning on privately-held lands performed by the forestry industry. Since new information will be needed to reduce uncertainties in the future, we have provided the CENRAP with an inventory and system of data files that can be updated with revised emission factors and activity data as new information becomes available (see Appendix D).

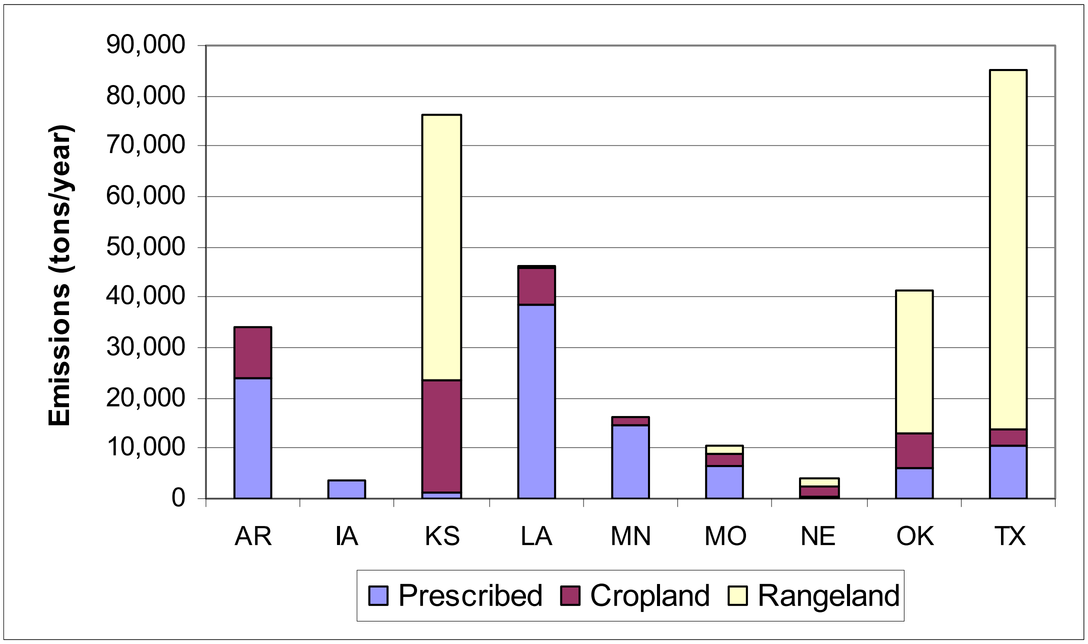

Figure 1-2. Total annual $PM_{2.5}$ emissions by type of planned burning for each state in the CENRAP region.

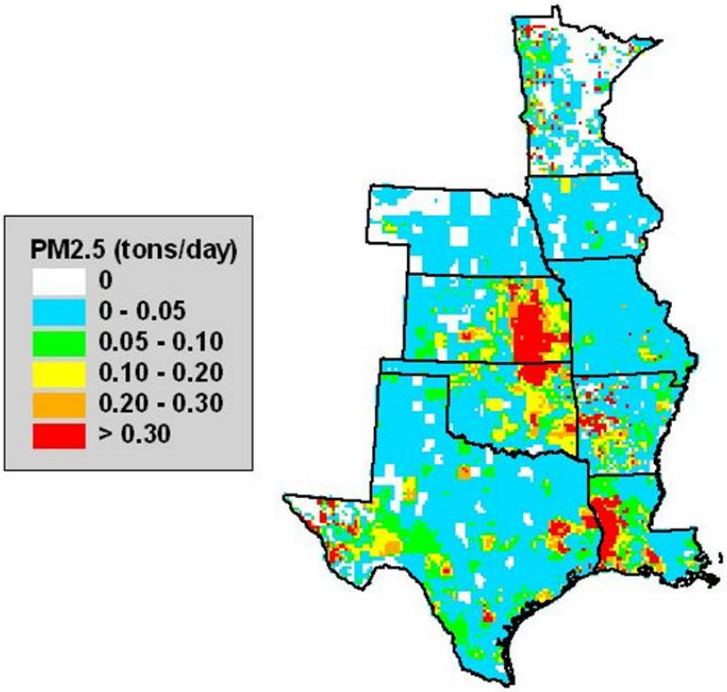

Figure 1-3. Example map of daily emission densities for the CENRAP region (for April 10, 2002).

2. SUMMARY AND ASSESSMENT OF THE INVENTORY

STI calculated emissions as detailed in Appendix A, Emission Estimation Methods for the CENRAP Planned Burning Emission Inventories, with results tabulated in Appendix B, Tabulation of Planned Burning Emissions Estimates for the CENRAP Region. In addition, STI carried out quality assurance procedures as provided in the Quality Assurance Plan and as detailed in this section. In summary, the most important source categories are estimated to be rangeland burning and prescribed burning on publicly managed lands. Total emissions vary seasonally by a factor of three, with peaks occurring in the spring and fall. Prescribed burning performed on privately held lands by the forestry industry is considered to be the greatest source of uncertainty in the overall inventory.

2.1 EMISSIONS FROM PRESCRIBED BURNING

2.1.1 Summary of Emissions from Prescribed Burning

Emission estimates were generated for prescribed burning activities on federal, state, tribal, and private lands. Over one million acres were burned in prescribed fires in 2002 in the CENRAP region, with consequent $PM_{2.5}$ emissions of over 100,000 tons and emissions of precursors as shown in **Table 2-1** and **Figure 2-1**.

Table 2-1. 2002 acres burned and emissions (tons) for prescribed burning in CENRAP states.

STATE	Acres Burned	PM_{10}	$PM_{2.5}$	CO	NO_x	SO_2	NH_3	VOC
Arkansas	244,146	28,130	23,838	302,219	1,961	1,577	2,910	17,444
Iowa	21,449	4,072	3,457	44,542	166	195	257	2,547
Kansas	38,106	1,450	1,226	14,424	228	114	143	881
Louisiana	350,353	45,288	38,376	486,668	3,125	2,531	4,671	28,060
Minnesota	86,642	17,222	14,609	187,853	742	836	1,150	10,740
Missouri	64,781	7,460	6,338	80,019	536	417	756	4,633
Nebraska	6,127	410	347	4,316	36	24	27	254
Oklahoma	104,749	7,322	6,196	76,615	750	479	769	4,507
Texas	137,310	12,669	10,732	134,423	1,071	757	1,427	7,824
Total	1,053,663	124,023	105,119	1,331,080	8,615	6,929	12,111	76,889

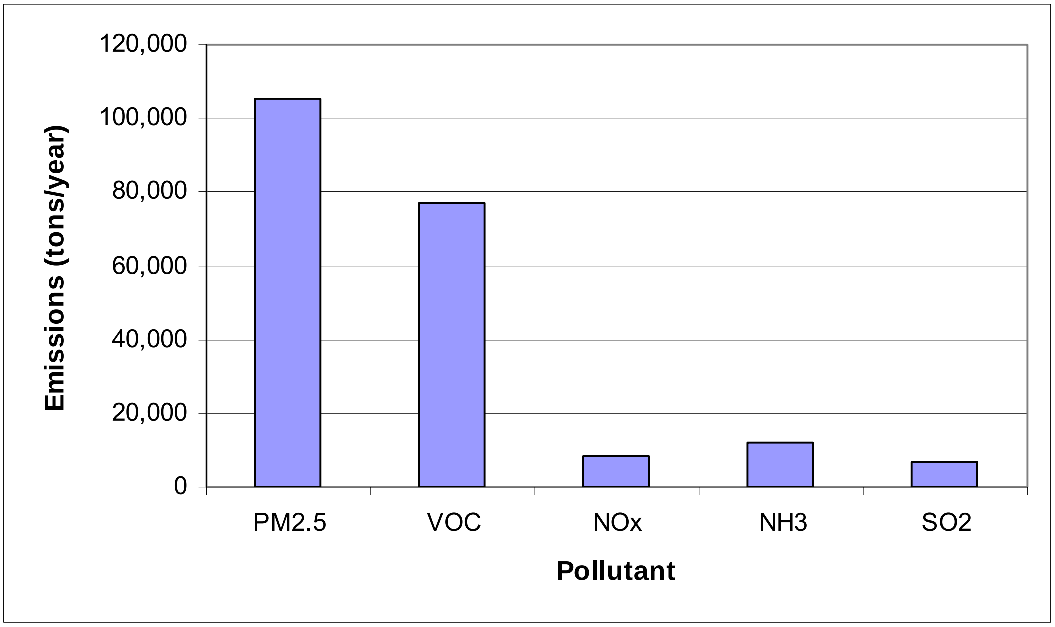

Figure 2-1. Annual prescribed burning emissions by pollutant.

Whenever possible, the exact location, start date, duration of burn, and size of burn incidents were acquired so that emissions from these incidents could be allocated spatially and temporally. The areas and locations of prescribed burn incidents were assigned to their individual centroids.[2] Prescribed burn activities that were reported as incidents (with date, duration, and area) were treated as point sources. Approximately 40% of the prescribed burning inventory was allocated spatially and temporally as point sources. Emissions from the remaining prescribed burning activities were treated as area sources. States that were able to provide "incident-level" databases of prescribed burn activity included Arkansas, Minnesota, and eastern Oklahoma.

The level of prescribed burning activities varied from state to state, as illustrated in **Figures 2-2 and 2-3**. Land managers in Arkansas and Louisiana conducted the most planned burning, and land managers in Minnesota and Texas were the second most active; only limited prescribed burning activity occurred in the states of Iowa, Kansas, and Nebraska.

The seasonal variability of prescribed burning emissions follows a bimodal pattern, with a large peak in spring and a smaller peak in fall. Factors that influence the seasonal variability of burning include weather conditions, fuel moisture content, and the intended environmental consequences of the burn (Dixon et al., 1989). Analysis of fire history records showed that all CENRAP states except Minnesota followed a similar seasonal pattern for prescribed burning. The longer winters in Minnesota delay the spring peak from March to May, while fall-season prescribed burns in Minnesota occur primarily in September rather than being spread evenly over the later summer and fall months as they are in the other states (see **Figure 2-4)**.

[2] Use of centroids to allocate burns was considered acceptable because the burn areas are typically much smaller in size than the grid resolution of the CENRAP's modeling grid.

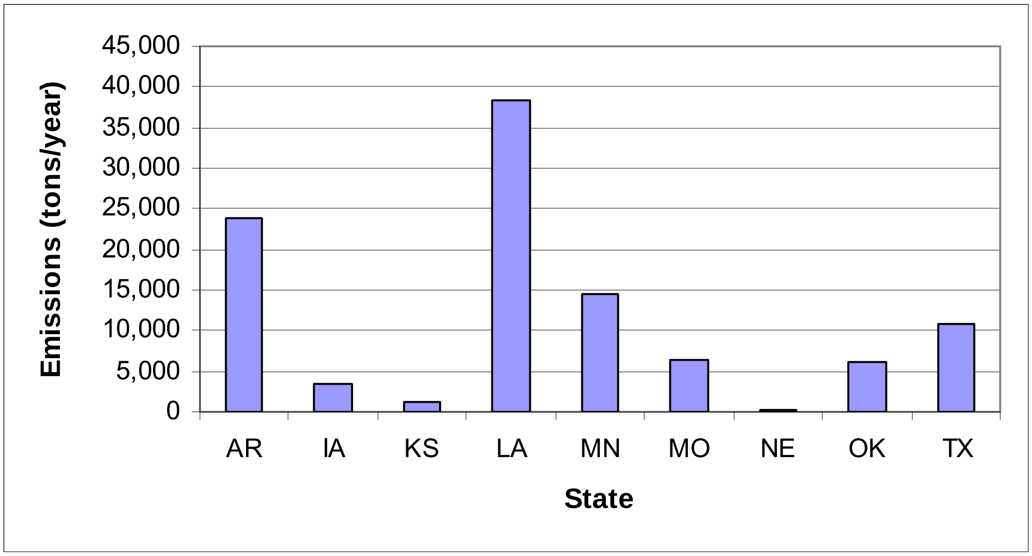

Figure 2-2. Annual prescribed burning $PM_{2.5}$ emissions by state.

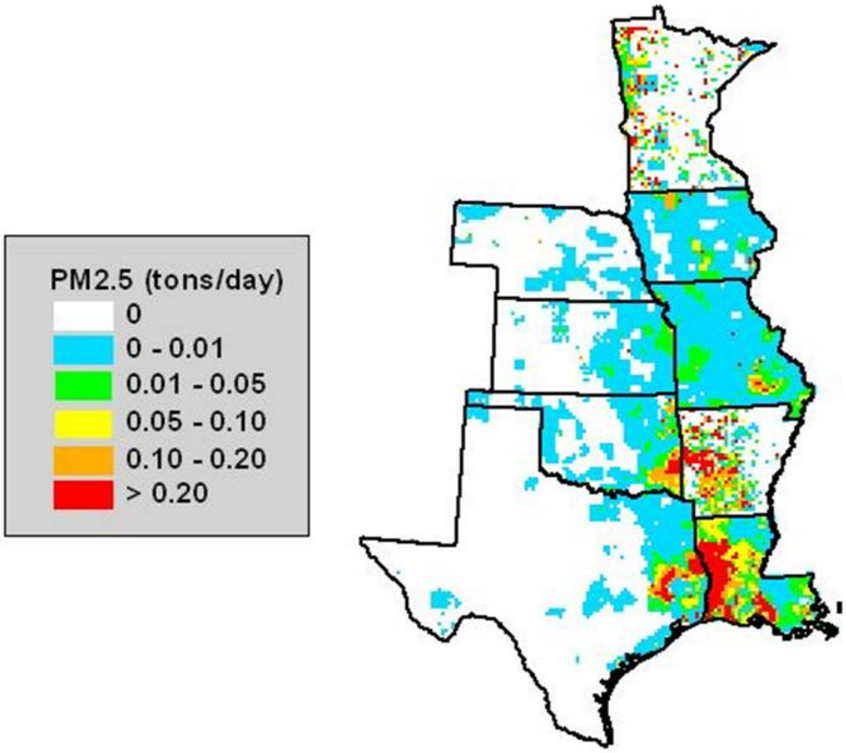

Figure 2-3. Example map of daily $PM_{2.5}$ emissions from prescribed burning (for April 10, 2002).

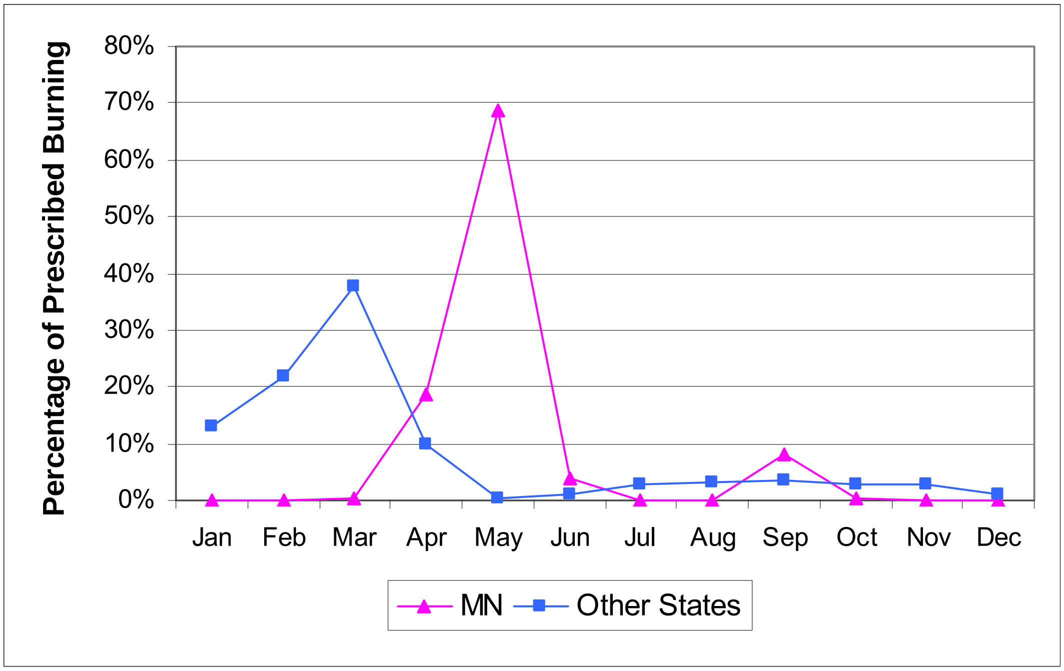

Figure 2-4. Monthly variation in emissions from prescribed burning.

2.1.2 Assessment of Prescribed Burning Emissions

The "bottom up" activity data gathered for the prescribed burning portion of this inventory improved the reliability of the emissions estimates. Virtually all of the burn records for federal lands (and some state burns) include fire date and location information that allows for the use of day-specific fuel moisture settings in calculating emission factors. Location information also enabled these burns to be treated as point sources for spatial allocation purposes.

As shown in Figure 2-3, emissions from prescribed burning are most significant in the region from western Arkansas/Louisiana to eastern Texas/Oklahoma. This is to be expected because prescribed burning is more widely practiced in the southern United States than in other areas (Cleaves et al., 1998). Moreover, the estimate of 137,310 acres burned on wildlands in Texas is within the range of prescribed burning estimates made for that state in 1996 and 1997, when 63,790 acres and 160,890 acres were burned, respectively (Dennis et al., 2002).

Prescribed burning accounts for about 30% of the annual planned burning $PM_{2.5}$ emissions in the CENRAP region. However, emissions from this source category actually exceed those from agricultural burning for five states: Arkansas, Iowa, Louisiana, Minnesota, and Missouri. When only those states are considered, prescribed burning accounts for about 80% of the annual planned burning $PM_{2.5}$ emissions.

Areas of uncertainty related to prescribed burning emissions estimates arise from differences in how fire activity is tracked and reported in each state. For example, for Arkansas, Minnesota, and the northeastern portion of Oklahoma, fire data is available at an "incident level," meaning a fire's date and location were listed in each fire history record. However, other states did not track this level of detail, instead reporting fire data by region and month, for example. In these cases, individual fire events could not be treated as point sources, and the geographic and temporal resolution of the final inventory was limited as a result.

Differences from state to state are even more pronounced for burns occurring on privately held lands. Such burns are performed by individuals, private companies, and organizations such as TNC and the Audubon Society. However, permitting or reporting requirements are not consistent among the nine CENRAP states, and few stable were able to provide us with reliable data on these burns.[3] Persistent attempts were made to contact private companies and organizations, but only TNC was able to provide burn data within the time limits of this project. It should be noted, though, that most burns on private lands are likely to be related to agriculture or waste management (such as the burning of logging residue by forestry companies or pile burns by land developers) (Altman, 2004; Miedtke, 2004). The former types of burns are covered by the agricultural survey, while the latter burns are not included in the scope of this project.

2.2 EMISSIONS FROM AGRICULTURAL BURNING

2.2.1 Summary of Emissions from Agricultural Burning

Emission estimates were generated for agricultural burning activities on private rangeland and cropland in each of the CENRAP states. It was determined that agricultural burning resulted in the burning of about 13 million acres in 2002 in the CENRAP region, with consequent $PM_{2.5}$ emissions of over 200,000 tons (see **Table 2-2**).

Table 2-2. 2002 acres burned and emissions (tons) for agricultural burning in CENRAP states.

STATE	Acres Burned	PM_{10}	$PM_{2.5}$	NO_x	SO_2	NH_3	VOC
Arkansas	655,307	10,771	10,227	3,692	637	2,100	6,254
Iowa	2,247	44	42	5	1	4	20
Kansas	5,015,790	99,170	75,057	29,094	10,937	11,436	54,884
Louisiana	486,441	8,384	7,888	3,845	609	2,453	7,066
Minnesota	101,925	1,944	1,729	358	69	248	1,155
Missouri	290,978	4,958	4,314	1,907	520	693	2,500
Nebraska	215,526	4,647	3,609	643	244	553	2,950
Oklahoma	2,303,359	45,231	35,228	18,645	6,653	5,124	23,992
Texas	3,798,581	104,709	74,393	13,647	8,725	12,573	63,396
Total	12,870,154	279,858	212,486	71,836	28,395	35,185	162,218

[3] Exceptions include the state of Arkansas, which was able to provide a database of virtually all burns in the state larger than 5 acres, including those occurring on private lands. The same was true for a 15-county region of Oklahoma that requires burn permits. The state of Minnesota also requires permits for all prescribed burning activities (including private burns), but does not keep centralized records of these burns.

Emissions from agricultural burning contribute 70% to total planned burning estimated $PM_{2.5}$ emissions for the CENRAP region, ranging from 1% to 99% of total planned burning emissions from state to state. The most important crop/land use types are rangeland (especially in the states of Texas, Oklahoma, and Kansas) and wheat (especially in the states of Kansas, Oklahoma, and Arkansas), although sugarcane burning is significant in the state of Louisiana. **Figures 2-5 and 2-6** illustrate the overall emission levels by state and the relative importance of each crop type in each state, and **Figure 2-7** shows the geographic allocation of agricultural burning emissions throughout the CENRAP region.

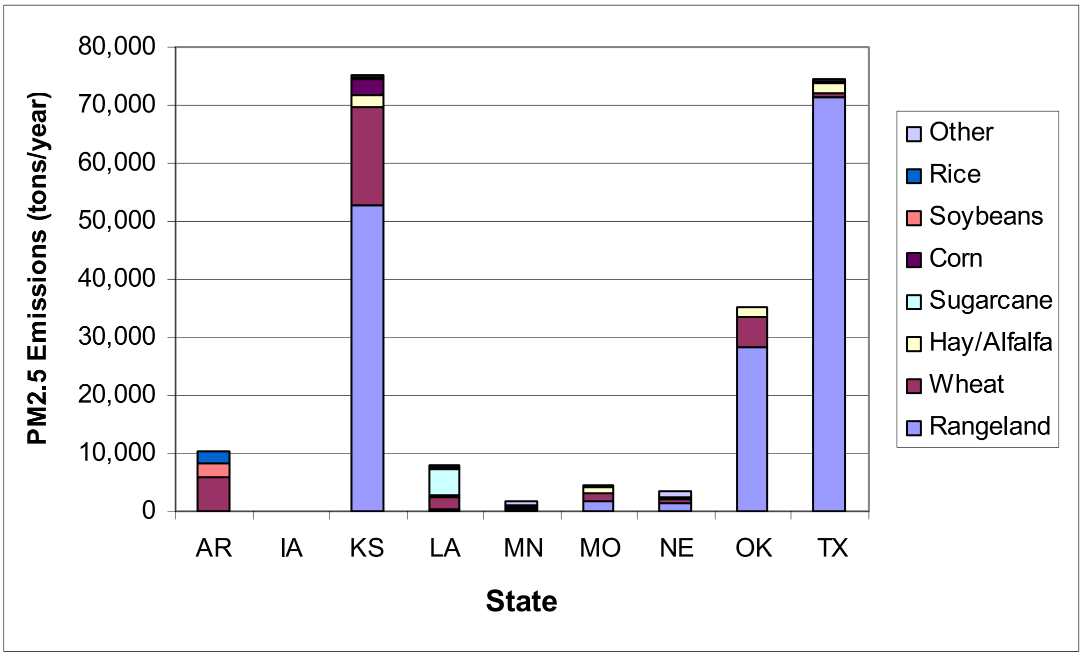

Figure 2-5. $PM_{2.5}$ emissions from agricultural burning by state.

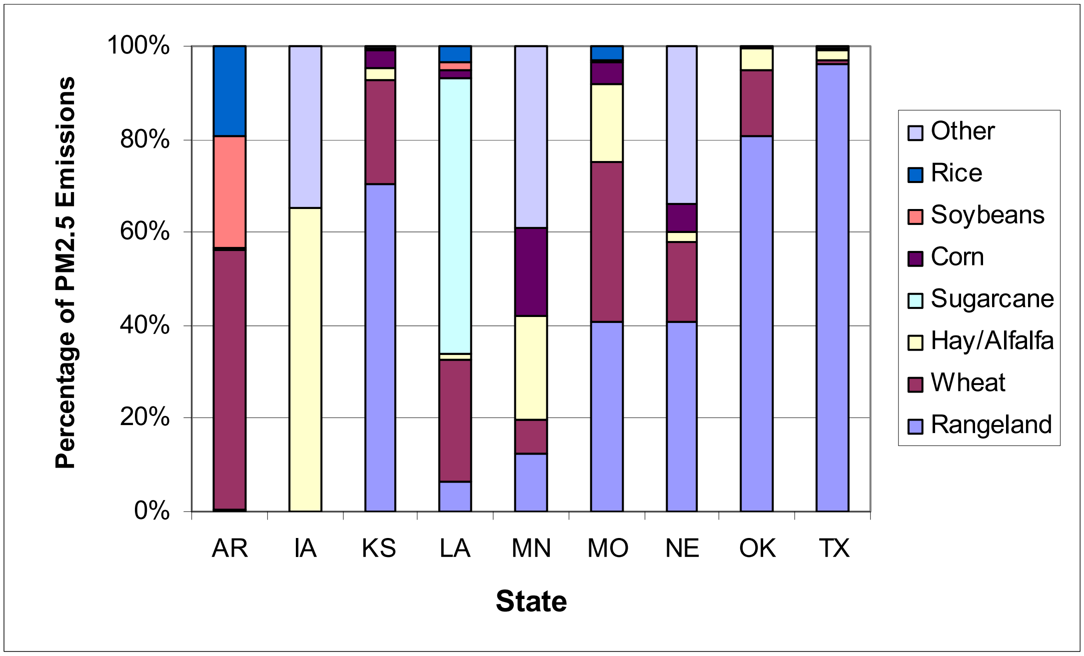

Figure 2-6. Percent contribution by crop type to state $PM_{2.5}$ emissions from agricultural burning.

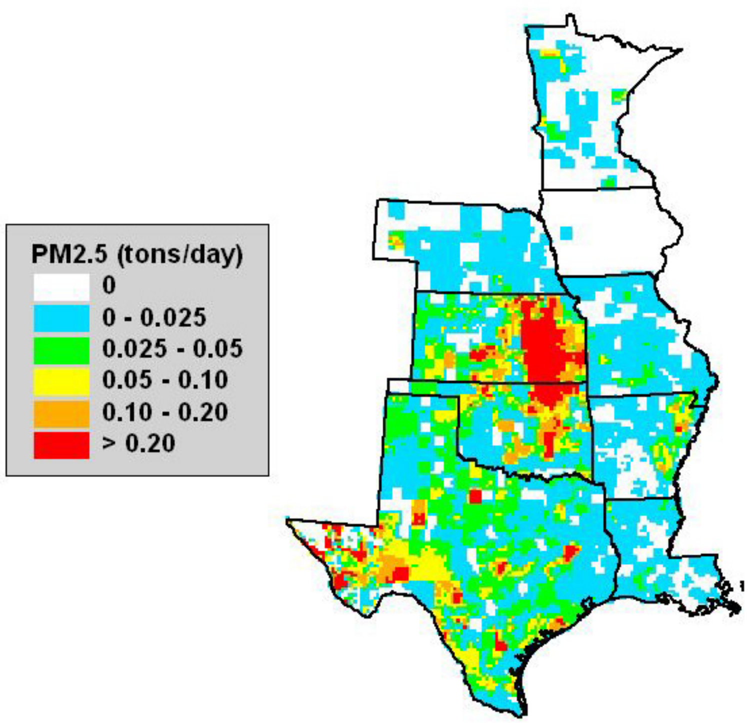

Figure 2-7. Example map of daily agricultural burning emissions (for April 10, 2002).

Emissions from agricultural burning tend to follow a bimodal pattern of seasonal variability, with large peaks in the spring and smaller peaks in the fall (see **Figure 2-8**). For most states, the month with the highest emissions from agricultural burning is March, although northern states like Minnesota and Iowa show a spring peak in May. For Arkansas and Louisiana, the highest emissions occur in September and October, respectively, which is due to the large acreages of winter wheat (Arkansas) and sugarcane (Louisiana) burned in those states.

2.2.2 Assessment of Emissions from Agricultural Burning

The "bottom up" survey data gathered for the agricultural burning portion of this inventory made it possible to generate emissions estimates that take into account county-level burn practices for each CENRAP state, including information on the timing of burns and the techniques used to burn individual crops.

This study indicates that agricultural burning practices vary widely from state to state and even county to county. For example, 54 of the 56 counties surveyed in Iowa reported no agricultural burning, as did 50 of the 77 counties surveyed in Minnesota. Among states that do burn extensively, practices vary by crop type. The survey indicates that burning is widely used to destroy wheat stubble in Arkansas, as over 40% of that crop is burned each year. By contrast, no other state that grows significant amounts of wheat burns more than 15% of the crop annually.

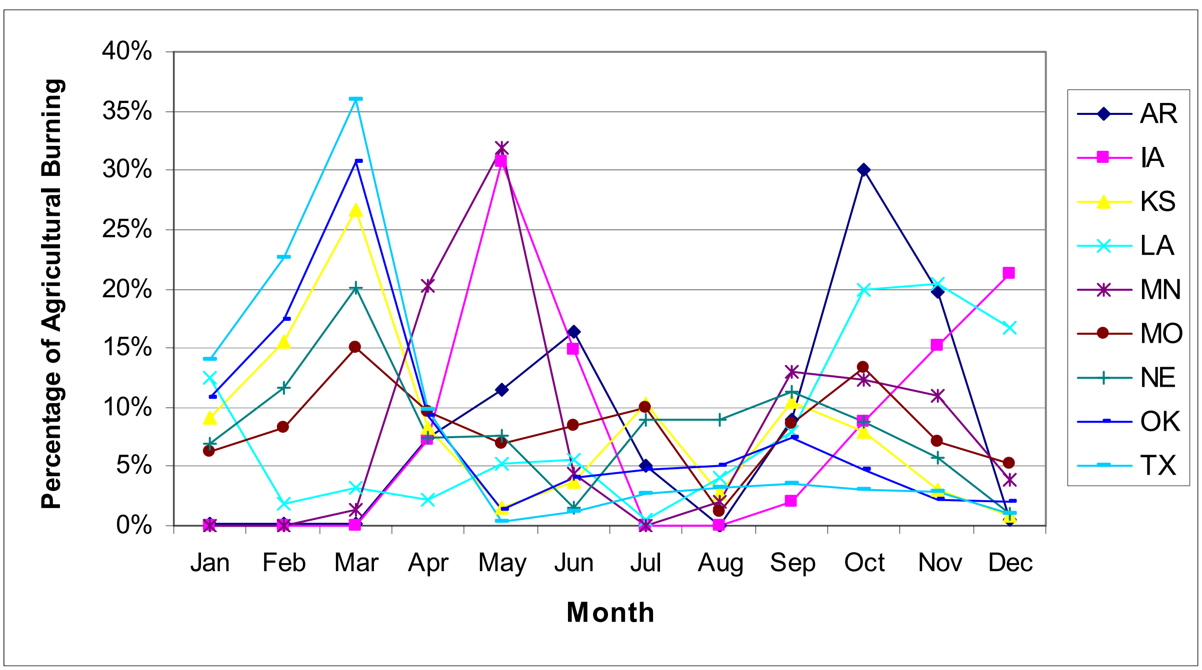

Figure 2-8. Monthly variation in emissions from agricultural burning by state.

It is also important to note that while agricultural burning accounts for about 70% of the annual $PM_{2.5}$ emissions from planned burning activity for the CENRAP region as a whole, almost 90% of the agricultural burning emissions occur in three states: Texas, Oklahoma, and Kansas. Moreover, about 70% of all agricultural burning emissions in the CENRAP states result from the burning of rangeland in these three states.

Uncertainties related to agricultural burning emissions result largely from an incomplete understanding of local regulations pertaining to such burning. For example, several states with a significant number of counties including Iowa, Minnesota, Nebraska, and Missouri reported no agricultural burning. These reports of no burning may be due to local restrictions on agricultural burning or other factors. Also, survey responses for each state were extrapolated to generate a statewide burn profile by crop type, and these profiles were used to represent all counties for which no survey data were available. However, further investigation is necessary to determine if burn practices vary within individual states enough to warrant subdividing certain states into regions.[4]

2.3 MISCELLANEOUS BURNING SOURCE CATEGORIES

Several subcategories of miscellaneous prescribed burning occur within the CENRAP region. Most of these burn types relate to the disposal of waste materials and, therefore, were not included in the final emissions inventory. However, some information on these burns was gathered during the course of the project and is summarized below.

<u>Slash and Site Preparation Burning</u>

Slash burning is typically used to dispose of logging residue produced by the harvesting or trees and, as such, is most often practiced by private timber companies. Based on employment estimates for the logging industry (U.S. Census Bureau, 2003), states in the CENRAP domain that produce significant amounts of timber are Arkansas, Louisiana, Minnesota, and Texas (see **Table 2-3**).

Table 2-3. 2001 logging industry employment by state.

State	Number of employees
Arkansas	2,914
Iowa	175
Kansas	65
Louisiana	3,325
Minnesota	1,019
Missouri	378
Nebraska	65
Oklahoma	281
Texas	2,227

[4] A subregional approach was used for wheat and rangeland burning in the state of Kansas, and such an approach may be applicable to other states/crop types.

To illustrate the relative significance of slash burning, Allen & Dennis (2000) report 55,000 acres of logging-related slash burning in Texas during 1997, about 3% of the total planned burning acreage for that year. In the fire history data obtained by STI (which mostly pertains to burning on publicly-managed lands), very few burns were identified as slash burns—amounting to 400 acres in Minnesota and less than 5 acres in Oklahoma and Iowa (no other states identified burns as slash).

Additionally, the state of Arkansas reports 50,000 acres of "site preparation burning," which are burns largely conducted by the timber industry to prepare lands for reforestation. It is likely that some of these burns involve slash fuels, though fuel model information was not tracked in the Arkansas database. Similarly, significant numbers of site preparation burns were included in the data we received from the state of Minnesota, though these burns were not identified as such (Miedtke, 2004).[5] Note for both Arkansas and Minnesota, these burns were included in the inventory but not assigned the higher fuel loadings that would be associated with slash fuels.

Pile Burning

As the name suggests, "pile" burning involves disposing of waste material by gathering the material into piles and burning it. Types of waste material include leaves and yard waste, logging residue, and brush or trees cleared from land for development purposes. With the exception of the state of Oklahoma, very few pile burns were included in the data provided to STI. For Oklahoma, a 15-county region in the northeastern part of the state that requires burn permits reported 180 incidents of leaf burning and 570 incidents of brush pile burning for 2002 (750 total). However, no data were provided on the sizes of these burns. The state of Minnesota also requires permits for private burns, and approximately 60,000 such permits were issued in 2002. It was estimated that 65% (39,000) of these permits would correspond to either pile burns or ditch/fencerow burns (covered in the next section), with the remaining 35% largely represented by burns on open land and rangeland that would be captured by the agricultural survey (Meadows, 2004).

To roughly estimate the possible emissions resulting from pile burns in Oklahoma and Minnesota, a fuel loading for a sizeable[6] pile burn published by the California Air Resources Board (2003) and emission factors published by the U.S. Environmental Protection Agency (2003) were applied to the number of pile burns in those states. (It was assumed that half of the 39,000 permits referenced above were for pile burns, and the 750 pile burns in Oklahoma were multiplied by 5 to extrapolate from 15 counties to all 77 counties in the state). $PM_{2.5}$ emissions were estimated as follows:

$$\text{OK: } PM_{2.5} = (750 \times 5) \text{ piles} \times \frac{1.36 \text{ tons}}{\text{pile}} \times \frac{14 \text{ lbs - } PM_{2.5}}{\text{ton}} \times \frac{\text{ton}}{2000 \text{ lbs}} = 36 \text{ tons}$$

[5] Personnel at the Minnesota Dispatch of the National Interagency Fire Center estimated that 75% of the site preparation burning in Minnesota was included in the data provided to STI. Site preparation burns not included in the data set would be those conducted by private landowners or companies.
[6] Fuel loadings for a burn 12 feet in diameter and 8 feet high were used.

$$\text{MN: } PM_{2.5} = (39{,}000\ /\ 2)\text{ piles x } \frac{1.36\text{ tons}}{\text{pile}} \text{ x } \frac{14\text{ lbs - }PM_{2.5}}{\text{ton}} \text{ x } \frac{\text{ton}}{2000\text{ lbs}} = 186\text{ tons}$$

For Oklahoma and Minnesota, these pile burns represent only 0.1% and 1.1%, respectively, of the $PM_{2.5}$ emissions already included in the planned burning inventory for these states. Pile burns in other states cannot be characterized with the data currently available.

Ditch and Fencerow Burning

Fires are sometimes used for weed abatement purposes along roadsides and fencerows. In the data obtained by STI, no individual fires were identified as ditch or fencerow burns, and because such fires are generally small in scale and practiced by private parties, it is likely that few such burns are included.

The only state where some assessment of these burns appears to be possible is Minnesota. As previously stated, approximately 39,000 of the 60,000 burn permits issued in that state each year are for pile burns and ditch/fencerow burns. To provide a rough estimate of emissions from this source, it was assumed that half these 39,000 burns were ditch burns, and that each burn covered 0.25 acres (Meadows, 2004). Using emission factors published by the U.S. Environmental Protection Agency (2003), $PM_{2.5}$ emissions were estimated as follows:

$$PM_{2.5} = (39{,}000\ /\ 2)\text{ burns x } \frac{0.25\text{ acres}}{\text{burn}} \text{ x } \frac{1\text{ ton}}{\text{acre}} \text{ x } \frac{15\text{ lbs - }PM_{2.5}}{\text{ton}} \text{ x } \frac{\text{ton}}{2000\text{ lbs}} = 37\text{ tons}$$

This estimate amounts to only 0.2% of the 16,000 tons of $PM_{2.5}$ already included in the planned burning inventory for Minnesota. Ditch and fencerow burns in other states cannot be characterized with the data currently available.

3. SUMMARY AND ASSESSMENT OF THE AIR QUALITY DATA ANALYSIS

3.1 OBJECTIVE AND APPROACH

The objective of this analysis was to use ambient speciated $PM_{2.5}$ data from Class I areas (from the Interagency Monitoring of Protected Visual Environments [IMPROVE] network) in the CENRAP states along with the planned burning emissions estimated in this study to assess whether ambient data can be used to identify planned burning contributions to visibility events in Class I areas, and to perform a preliminary assessment of the impact of planned burns on $PM_{2.5}$ and visibility at a few monitoring sites. The following approach was employed:

- Assess the seasonal chemical compositions of $PM_{2.5}$ mass and aerosol light extinction to determine what individual species are important to the mass and visibility extinction in the area.
- Determine seasonal concentrations of and ratios between selected species, such as OC, EC, and K, to establish a “baseline” average seasonal composition for comparison to days of poor visibility and days potentially influenced by prescribed burning.
- Assess chemical compositions of $PM_{2.5}$ and aerosol light extinction on the 20% best and 20% worst visibility days to determine what species have a large impact on visibility (i.e., are species from burning typically important in visibility reduction?).
- Analyze IMPROVE data, specifically OC, EC, and K concentrations, on dates when extensive burning occurred near a monitoring site in order to assess whether wood smoke influences are seen in the ambient measurements and significantly impact visibility.
- Analyze emissions data on days when elevated OC, EC, and K concentrations occurred at IMPROVE sites to determine whether days of elevated concentrations corresponded to known burns in the emission inventory data.
- Analyze air mass trajectories on selected days to determine whether meteorology (i.e., transport) explains the observed effects and to determine the extent to which meteorology affects haze.

3.2 SUMMARY OF FINDINGS

Details on data, methodology, and results from this analysis are provided in Appendix C. This work yielded the following findings:

- Speciated $PM_{2.5}$ data can be used to determine influence from planned burns when the meteorology is conducive to transport from the burn area to a Class I site.
- Smoke constituents, specifically EC and K, were not a significant fraction of the $PM_{2.5}$ mass and light extinction, even on days when there was evidence of planned burning influence, at the sites examined in this preliminary study.
- Ammonium sulfate, which is not generated from burning, is the dominant constituent of the $PM_{2.5}$ mass and light extinction, especially on the 20% worst visibility days. This

finding is consistent with other work in the Midwest and CENRAP regions including studies of Big Bend National Park and Seney Wildlife Refuge.

- On some days, influences from known prescribed burns were seen, though they were generally less than 10% of the $PM_{2.5}$ mass and light extinction. Improved spatially and temporally resolved emission inventories and additional case studies may show different results.
- The specific influence of smoke on $PM_{2.5}$ mass and light extinction could be better quantified using additional analyses, including source apportionment.

4. RECOMMENDATIONS FOR FURTHER RESEARCH

This study provided an improved and updated emission inventory for planned burning in the CENRAP states for year 2002. Preliminary examination of ambient measurements along with the inventory generated in this study suggests that planned burning may contribute to visibility impairment at Class I sites in the CENRAP states. As noted in previous sections of this report, we identified the following significant sources of uncertainty (roughly in order of importance): (1) the extent of fires performed by the USFS on publicly managed lands, (2) the extent of prescribed burning on privately held lands performed by the forestry industry and organizations such as TNC, (3) a need to better understand county-level open burning regulations, and (4) the fuel loadings and emission factors used for planned burning emissions estimates—particularly for prescribed burning in the state of Minnesota. In this section, we provide recommendations for improving each of these aspects of the inventory and describe additional analyses that could be conducted to better quantify the influence of planned burning on visibility impairment.

4.1 RECOMMENDATIONS FOR IMPROVING PRESCRIBED BURNING ACTIVITY DATA

As discussed in Section 2.1.2, significant differences exist in the way fire activity data is tracked and reported in each state; some states (such as Arkansas and Minnesota) capture a fire's exact date and location coordinates, and other states track fires only by region and month. Encouraging individual states to maintain "incident level" databases of fire activity would allow all prescribed fires to be treated as discrete point sources and improve the geographic and temporal resolution of the inventory.

Also, differences from state to state are even more pronounced for burns performed on privately held lands by individuals, private companies, and organizations such as TNC and the Audubon Society. However, permitting or reporting requirements are not consistent among the nine CENRAP states, and few states were able to provide us with reliable data on these burns.[7] Persistent attempts were made to contact private companies and organizations, but only TNC was able to provide burn data within the time limits of this project. It is recommended that further efforts be made to survey private parties regarding their burn activities, especially in the Piney Woods region of eastern Texas, where private timber companies have conducted significant amounts of prescribed burning in past years (Allen & Dennis, 2000)[8].

It should be noted, though, that most burns on private lands are likely to be related to agriculture or waste management (such as the burning of logging residue by forestry companies

[7] Exceptions include the state of Arkansas, which was able to provide a database of virtually all burns in the state larger than 5 acres,--including those occurring on private lands. The same was true for a 15-county region of Oklahoma that requires burn permits. The state of Minnesota also requires permits for all prescribed burning activities (including private burns), but does not keep centralized records of these burns.

[8] For purposes of this inventory, acres burned in 1996 and 1997 by private timber companies in the Piney Woods region were averaged to produce an estimate of 20,000 acres per year.

or pile burns by land developers) (Altman, 2004; Miedtke, 2004). The former burns are covered by the agricultural survey, and the latter burns are not included in the scope of this project.

Finally, alternative and newly emerging data sources such as satellite data and related products recently developed by the National Oceanic and Atmospheric Administration (NOAA) should be explored to help characterize fire locations and day-specific activity levels.

4.2 RECOMMENDATIONS FOR IMPROVING AGRICULTURAL BURNING ACTIVITY DATA

As stated in Section 2.2.2 of this report, uncertainties related to agricultural burning emissions result largely from an incomplete understanding of local regulations pertaining to such burning. Several states, including Iowa, Minnesota, Nebraska, and Missouri, had significant numbers of counties that reported no agricultural burning. It is recommended that further investigation be undertaken to gain a fuller understanding of county-level open burning restrictions, as well as an estimate of how such restrictions are enforced. Further discussions with county AES, as well as with individual farmers, could be used to acquire this information.

Also, survey responses for each state were extrapolated to generate a statewide burn profile by crop type, and these profiles were used to represent all counties for which no survey data were available. For the state of Kansas, however, subregional burn profiles were developed for wheat and rangeland burning, and further investigation is needed to determine if burn practices across other states vary enough to warrant subdividing these states into regions for certain crop types.

4.3 RECOMMENDATIONS FOR IMPROVED FUEL LOADINGS AND EMISSION FACTORS

Emission factors are often a subject of research, and it is recommended that efforts be made to identify and incorporate improved emission factors related to prescribed and agricultural burning that are published in the future. Also, although the default fuel loading values by vegetation type contained in the FOFEM model were judged to be sufficiently representative of conditions in the CENRAP region, some effort should be made to study these fuel loadings further. During the course of this project, personnel at the USFS in Minnesota indicated that the default fuel loadings in FOFEM are regularly updated during the analysis of burns in that state. STI was provided with adjusted fuel loadings for several vegetation and fuel types, most of which were related to “blowdown” burns (the burning of vegetation after storms to reduce fire hazard). These altered fuel loadings resulted in $PM_{2.5}$ emission factors up to 70% higher than those calculated with FOFEM default loadings. When these adjusted emission factors were applied to 3700 acres of burns identified by USFS personnel as blowdown, the prescribed burning portion of the $PM_{2.5}$ inventory for Minnesota increased by about 5%.

4.4 RECOMMENDATIONS FOR ADDITIONAL AMBIENT DATA ANALYSIS

In addition to improvements to the emission inventory, additional analyses could be conducted to better quantify the influence of burns on visibility impairment:

- Apply similar analyses to additional IMPROVE sites, such as these in Kansas or Minnesota, to investigate whether results of this task are indicative of the influence of burns throughout the CENRAP region.
- Utilize continuous $PM_{2.5}$ in conjunction with meteorological data to determine what meteorological conditions may be responsible for changes in $PM_{2.5}$ concentrations.
- Apply source apportionment tools such as UNMIX or Positive Matrix Factorization (PMF) to quantify influence of specific source types at a site using 24-hr (i.e., IMPROVE, Speciated Trends Network [STN], etc.) or continuous speciated data (such as at Bondville or St. Louis). These tools can be used to identify individual sources such as diesel, wood burning, etc.

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