Appendix H.6

Sonoma Technology, ***Research and Development of Planned Burning Emission Inventories for the Central States Regional Air Planning Association*** **(July 30, 2004)**

Sonoma Technology, Inc.

1360 Redwood Way, Suite C
Petaluma, CA 94954-1169
707/665-9900
FAX 707/665-9800
www.sonomatech.com

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

FINAL REPORT
STI-902514-2516-FR

By:
Stephen B. Reid
Steven G. Brown
Dana Coe Sullivan
Heather L. Arkinson
Tami H. Funk
Patricia S. Stiefer
Sonoma Technology, Inc.
1360 Redwood Way, Suite C
Petaluma, CA 94954-1169

Prepared for:
The Central States Air Resource Agencies and
The Central Regional Air Planning Association
10005 South Pennsylvania Avenue, Suite C
Oklahoma City, Oklahoma 73159

July 30, 2004

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
Project QA Officer

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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.

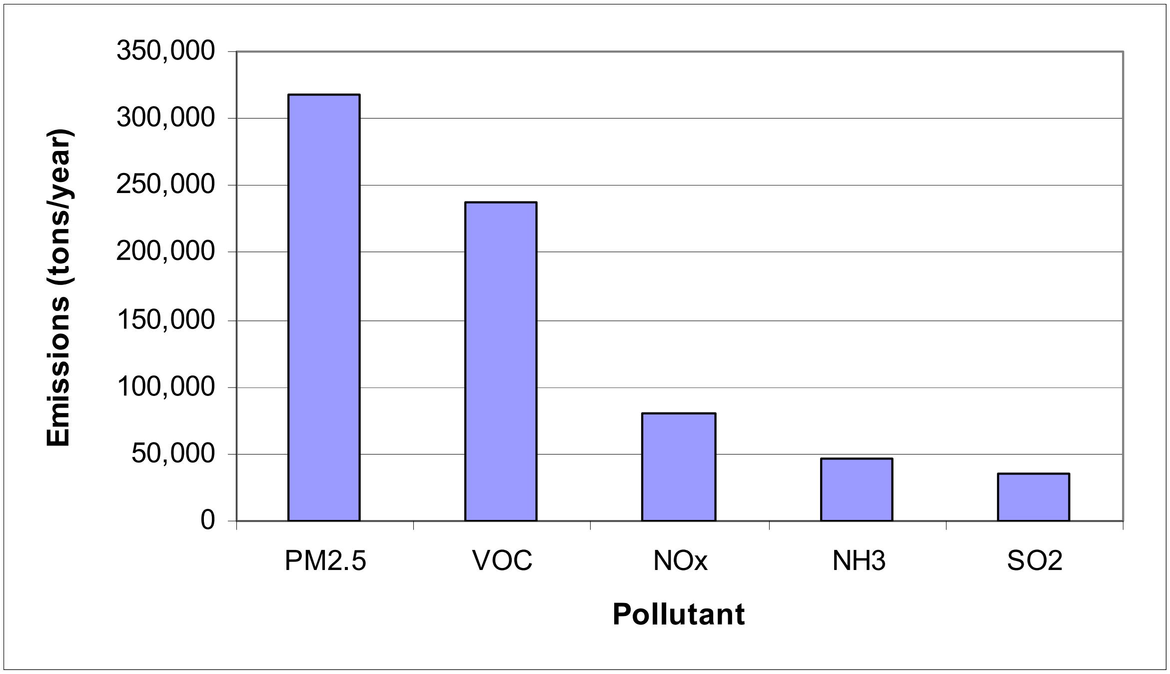

Figure ES-1. CENRAP annual planned burning emissions by pollutant.

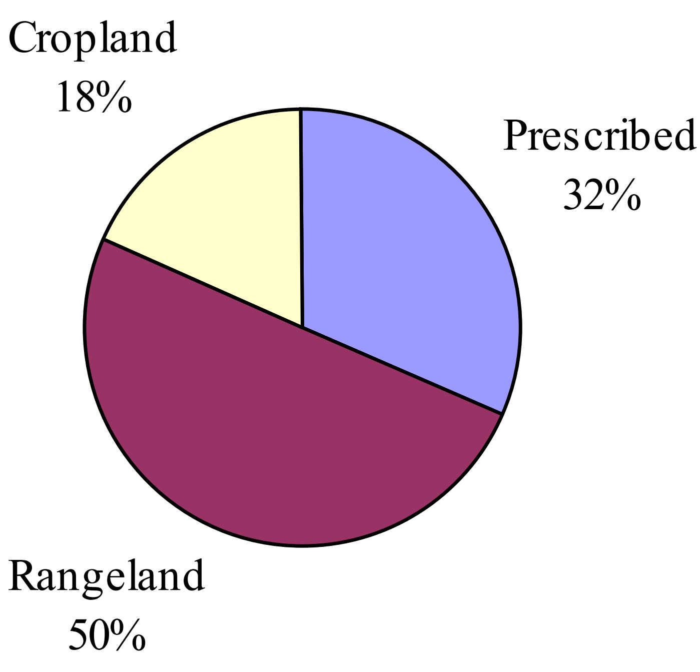

Figure ES-2. CENRAP annual planned burning $PM_{2.5}$ emissions by source category.

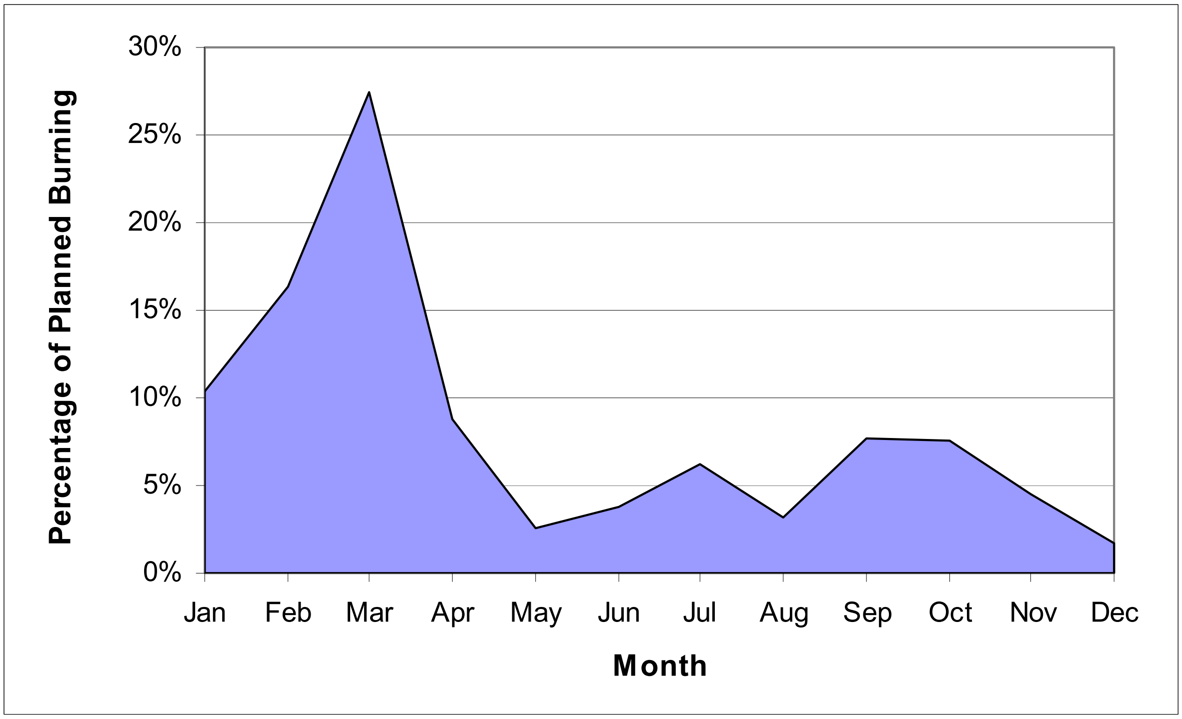

Figure ES-3. Monthly variability in total emissions for the CENRAP region.

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.

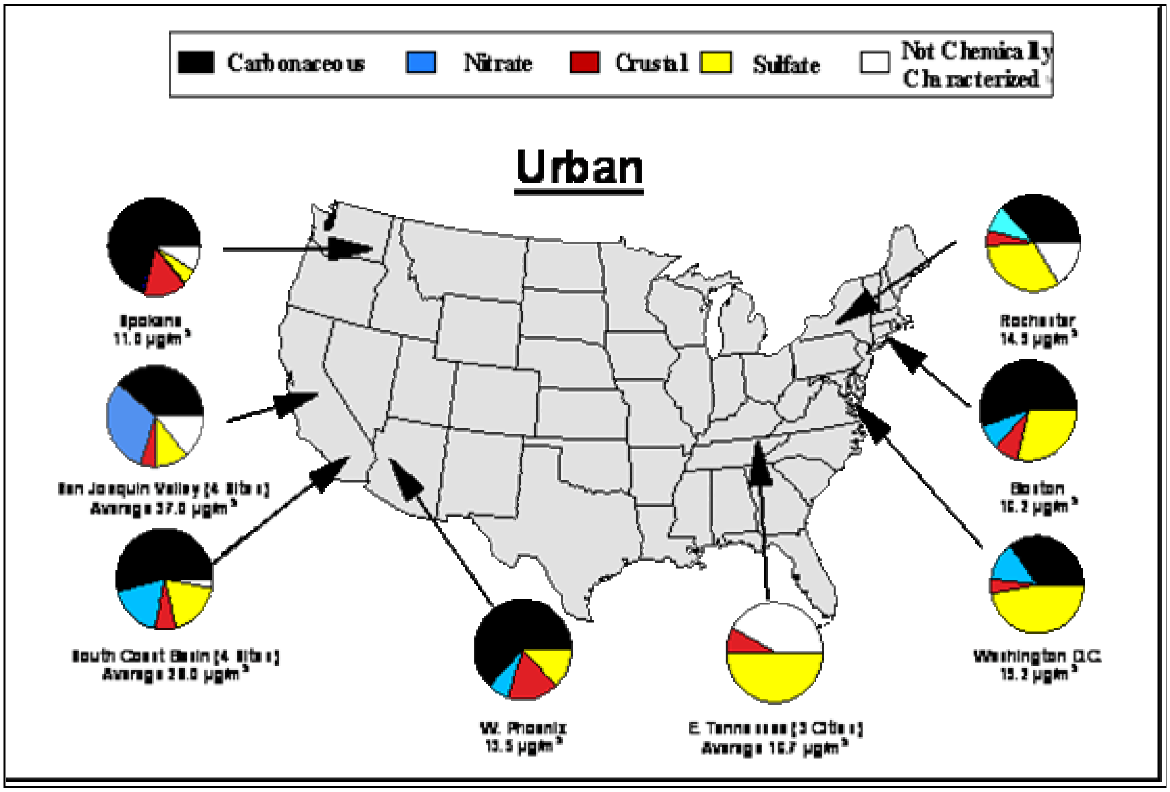

Figure 1-1. Compositions of annual average concentrations of $PM_{2.5}$ observations in urban locations (U.S. Environmental Protection Agency, 1998).

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).

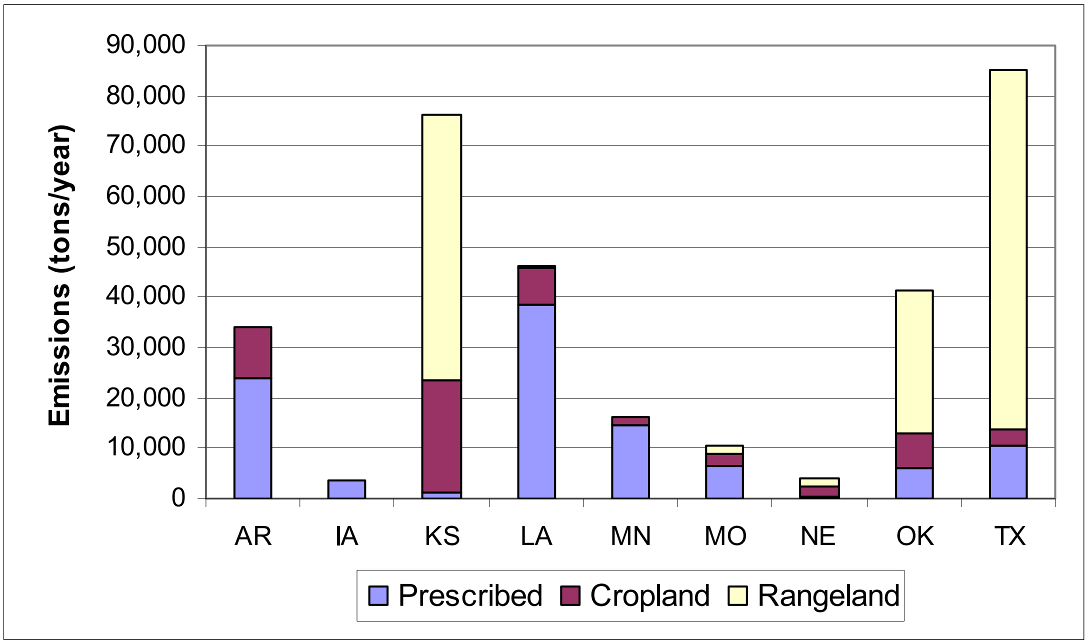

Figure 1-2. Total annual $PM_{2.5}$ emissions by type of planned burning for each state in the CENRAP region.

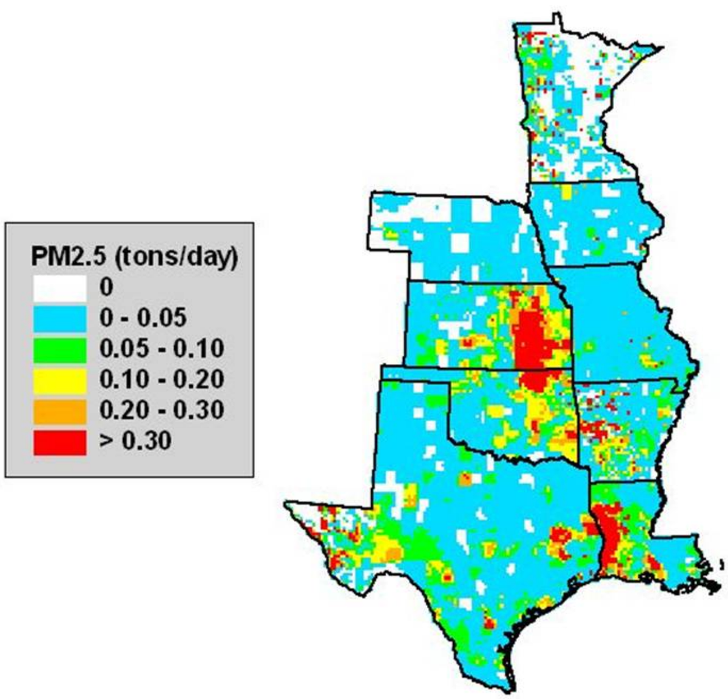

Figure 1-3. Example map of daily emission densities for the CENRAP region (for April 10, 2002).

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

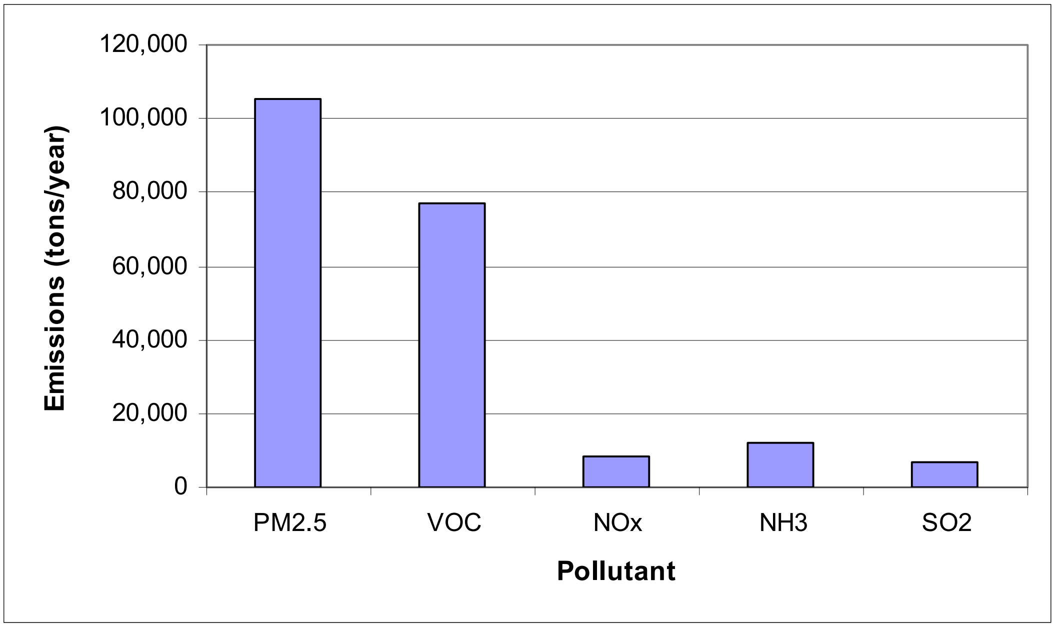

Figure 2-1. Annual prescribed burning emissions by pollutant.

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.

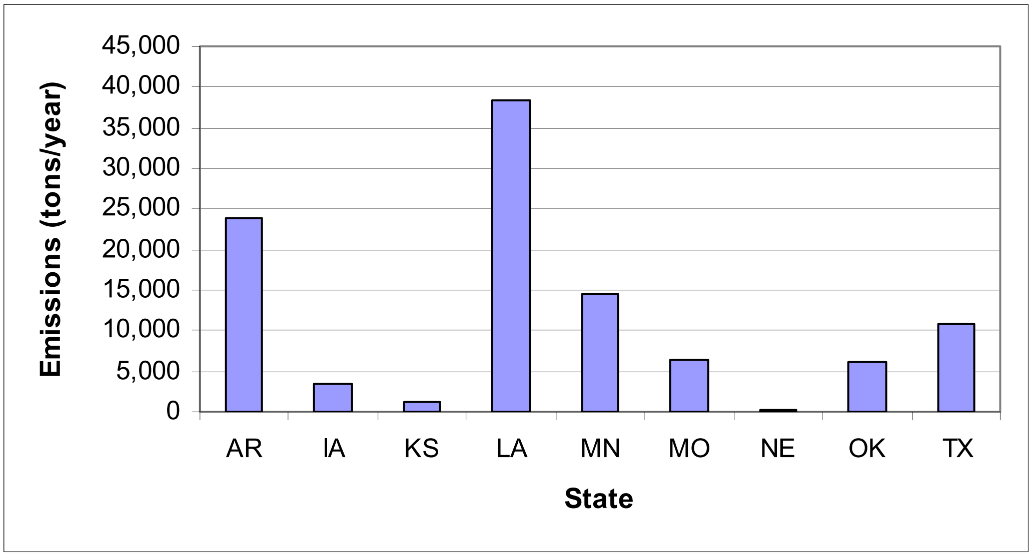

Figure 2-2. Annual prescribed burning $PM_{2.5}$ emissions by state.

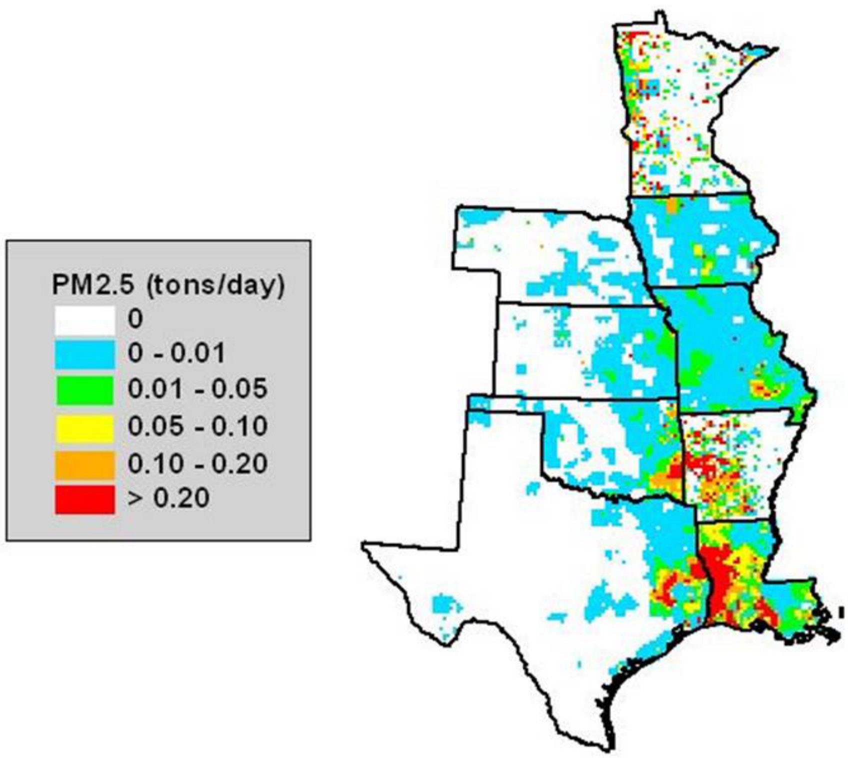

Figure 2-3. Example map of daily $PM_{2.5}$ emissions from prescribed burning (for April 10, 2002).

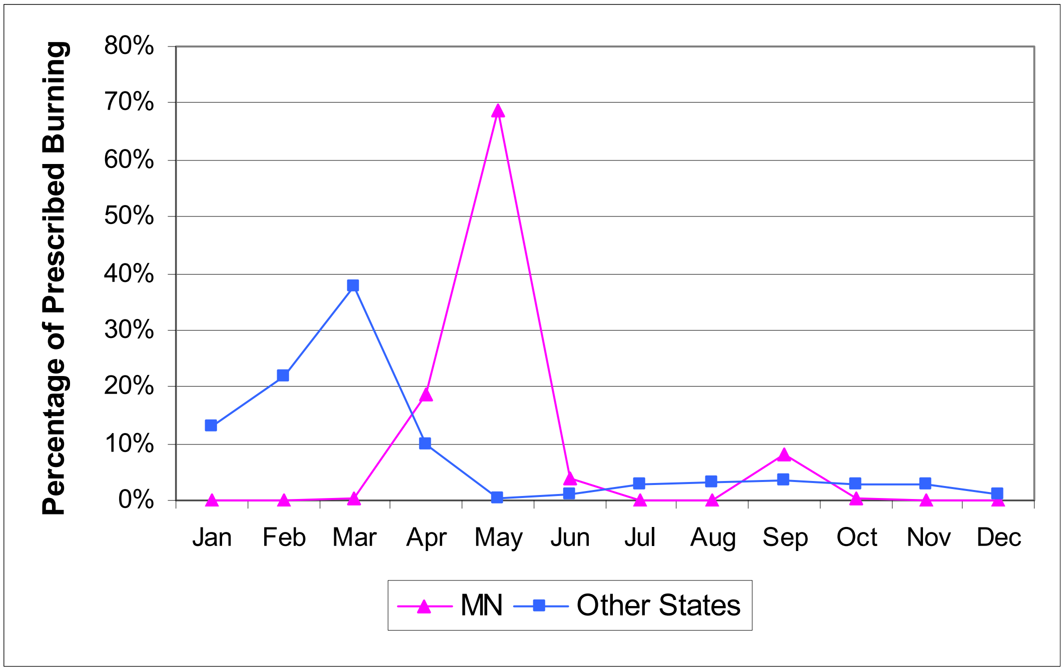

Figure 2-4. Monthly variation in emissions from prescribed burning.

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.

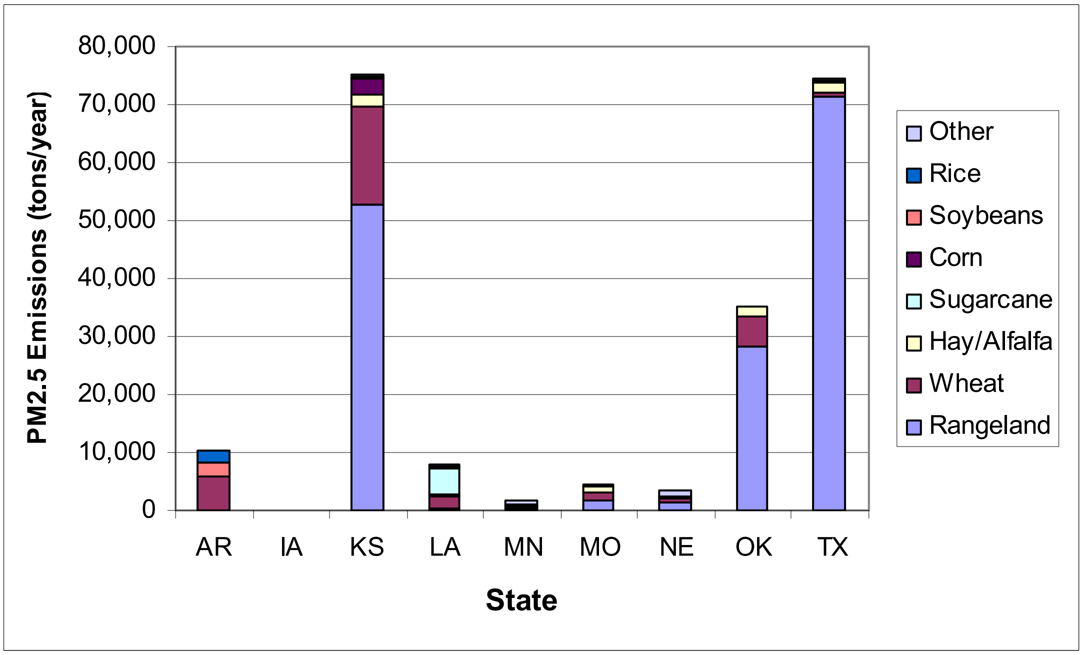

Figure 2-5. $PM_{2.5}$ emissions from agricultural burning by state.

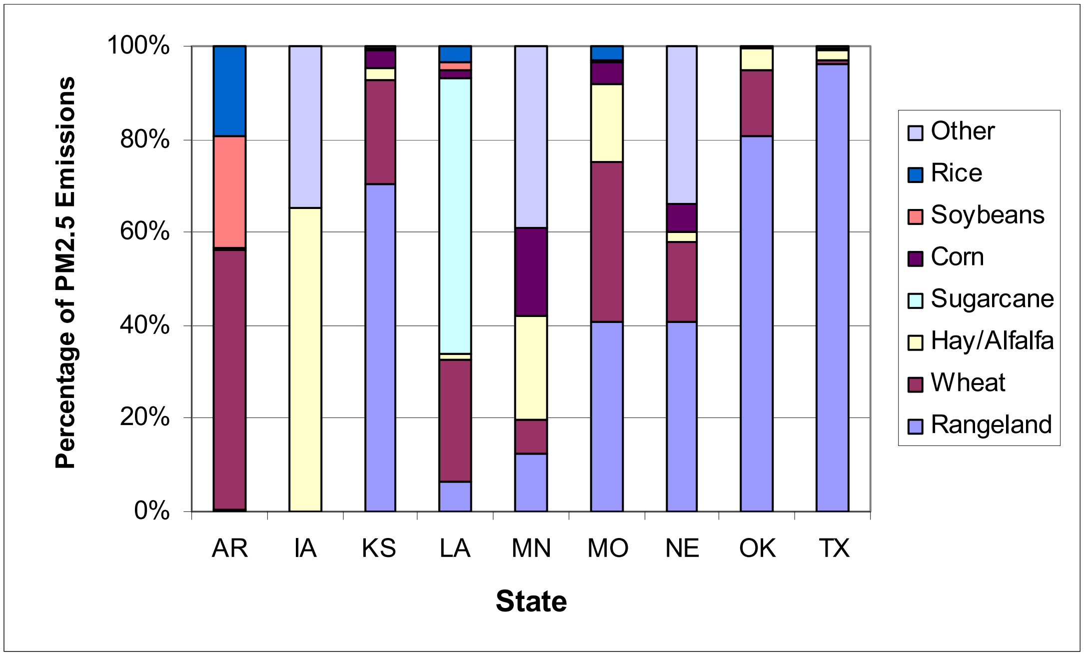

Figure 2-6. Percent contribution by crop type to state $PM_{2.5}$ emissions from agricultural burning.

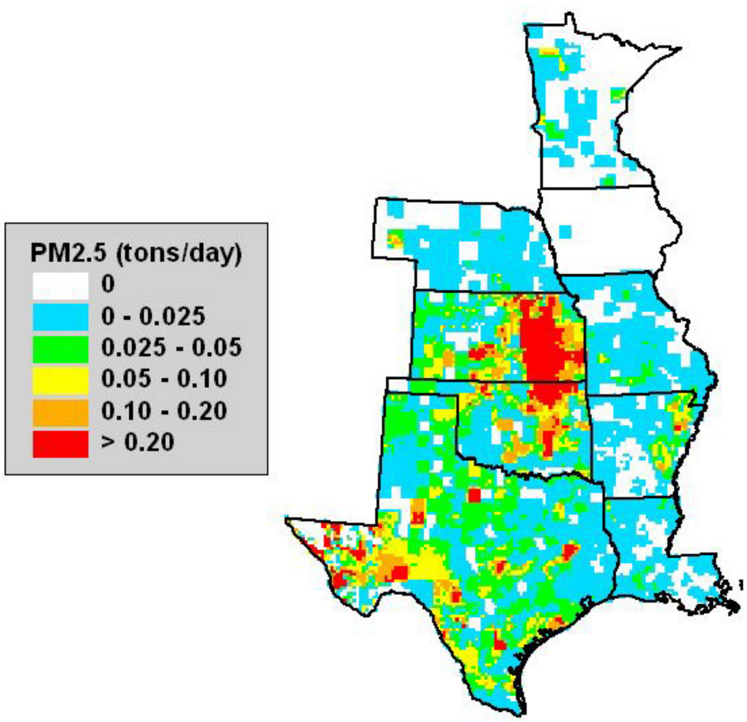

Figure 2-7. Example map of daily agricultural burning emissions (for April 10, 2002).

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.

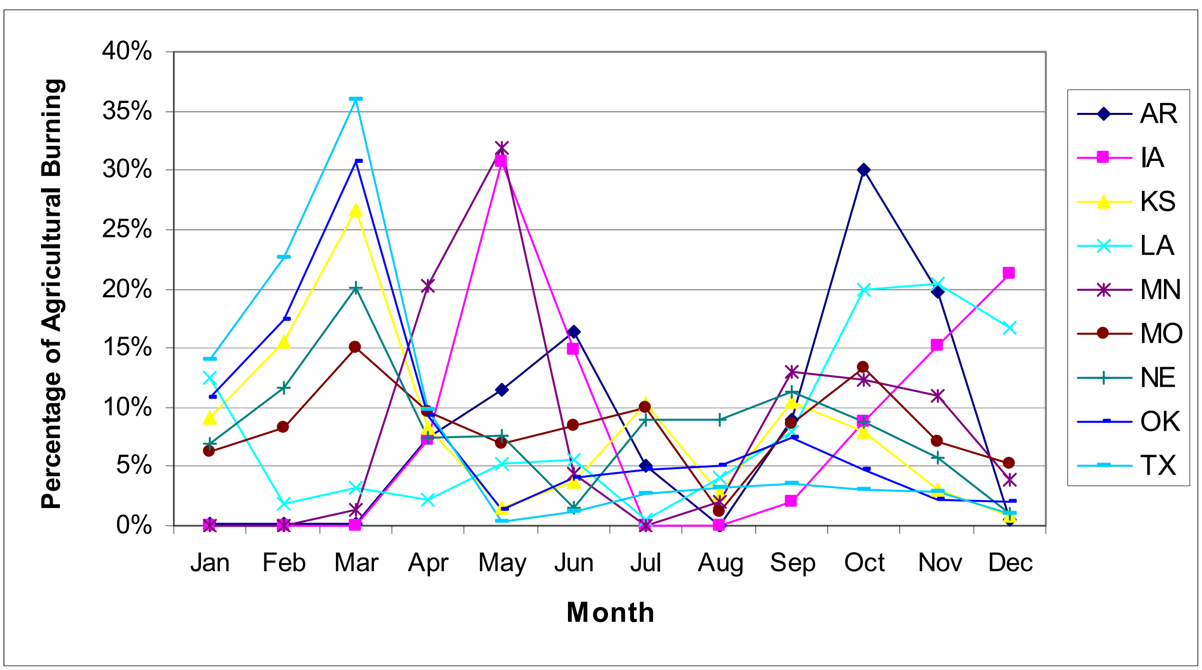

Figure 2-8. Monthly variation in emissions from agricultural burning by state.

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.

Slash and Site Preparation Burning

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.

<u>Pile Burning</u>

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:

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

[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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APPENDIX A

EMISSION ESTIMATION METHODS FOR THE CENRAP PLANNED BURNING EMISSION INVENTORIES

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Sonoma Technology, Inc.

1360 Redwood Way, Suite C
Petaluma, CA 94954-1169
707/665-9900
FAX 707/665-9800
www.sonomatech.com

EMISSION ESTIMATION METHODS FOR THE CENRAP PLANNED BURNING EMISSION INVENTORIES

Final Methods Document
STI-902512-2451-FMD2

By:
Stephen B. Reid
Tami H. Funk
Patricia S. Stiefer
Heather L. Arkinson
Dana L. Coe
Sonoma Technology, Inc.
1360 Redwood Way, Suite C
Petaluma, CA 94954-1169

Prepared for:
The Central States Air Resource Agencies and
The Central Regional Air Planning Association
10005 South Pennsylvania Avenue, Suite C
Oklahoma City, OK 73159

July 30, 2004

QUALITY ASSURANCE STATEMENT

This report was reviewed and approved by the project Quality Assurance (QA) Officer or his delegated representative, as provided in the project QA plan.

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Lyle R. Chinkin
Project QA Officer

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LIST OF TABLES

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. 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. It is recognized that 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) developed emission inventories of episodic combustion events for the CENRAP region. Consistent with the project goals presented in the Work Plan (Coe, 2003), the scope of the inventories will be limited to agricultural and prescribed burning. Wildfires, structural fires and waste burning (such as the "slash" burning of logging residue) were not considered in the development of these inventories.

1.1 SUMMARY OF RECOMMENDED METHODS

To develop emission inventories of planned burning activities for the CENRAP region, we employed existing models and information: the First-Order Fire Effects Model (FOFEM), emission factors gathered from published literature, and Geographic Information Systems (GIS) databases of land cover and vegetation. In addition, we gathered new information through telephone and mail surveys.

FOFEM, a computing tool developed through the Joint Fire Science Program (JFSP), can be used to predict a variety of effects from fires on forested lands and rangelands, including air pollutant emissions, fuel consumption, tree mortality, and soil heating (Reinhardt et al., 2003; Reinhardt et al., 1997). For this project, the FOFEM model was used to generate estimates of fuel loadings and emission rates for prescribed burns. This data was then used in conjunction with prescribed burning history information (detailing the location, land type, season, and size of burn incidents) to calculate emissions from this source. Fire history data for prescribed burning on wildlands, publicly managed lands, tribal lands, and private lands were gathered from federal and state agencies, as well as some private organizations.

For agricultural burning, emission factors and fuel-loading factors for a variety of crop types have been published in the EPA's guidance document, "Compilation of Air Pollutant Emission Factors (AP-42)" (U.S. Environmental Protection Agency, 2003) and by Jenkins et al. (1996). From these sources, we identified fuel loading factors and emission factors for a wide variety crop types. These factors were applied to county-specific agricultural burning activity data to generate emissions estimates. This activity data was obtained through systematic telephone and mail 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 the sources described above to produce county-level emission inventories of agricultural and prescribed burning. **Table 1-1** summarizes sources of emission factors, activity data, and land cover data.

Table 1-1. Summary of approaches to estimate planned-burning emissions.

	Prescribed Burning	Agricultural and Rangeland Burning
Emission factors	FOFEM Model	AP-42; (Jenkins et al., 1996)
Fire history data	Federal and state agencies; telephone contacts with tribes and private owners of large land tracts	Telephone and mail surveys of County Agricultural Extension Services
Land cover data	EPA's BELD3 database	EPA's BELD3 database

1.2 IMPORTANT ASSUMPTIONS

The methods that we selected for use were based on several important assumptions:

- Default fuel loading values by vegetation type contained in the FOFEM model are sufficiently representative of conditions in the CENRAP region[1].
- The land cover/vegetation types used by the FOFEM model and those in the BELD database are similar enough to allow a reasonable cross-walk to be established between the two data sets.
- The crop types in the BELD database are similar enough to crop varieties for which emission factors and fuel loadings are available to allow a reasonable cross-walk to be established between the two data sets.
- County AES will be capable of providing responses that reasonably represent agricultural and rangeland burning activities in the CENRAP region.

[1] Personnel at the U.S. Forest Service in Minnesota provided updated fuel loadings for 3,700 acres of grassland burns and "blowdown" burns (the burning of vegetation after storms to reduce fire hazard) occurring in the Superior National Forest in 2002. Default fuel loadings were used in all other cases.

2. AGRICULTURAL BURNING

2.1 OVERVIEW

Agricultural burning is primarily a means of clearing harvested lands. Because the CENRAP region is largely agricultural, such activity is likely to be a source of significant episodic combustion emissions in most counties. Allen and Dennis (Allen and Dennis, 2000; Dennis et al., 2002) recently completed a study of emissions from fires in Texas, which included agricultural and rangeland burning in 1996 and 1997. According to their assessments, these types of agricultural activities emitted over 66,000 tons of particulate matter of less than 2.5 μm aerodynamic diameter ($PM_{2.5}$) and accounted for 84% of over 3.3 million acres of vegetation burned in Texas during those two years.

2.2 AGRICULTURAL BURNING EMISSION FACTORS AND FUEL LOADINGS

Emissions from agricultural burning activities are dependent on the types of vegetation burned and the manner of combustion, and can be estimated using the following equation:

*Emissions (lb) = Fuel loading (ton/acre) * Emission factor (lb/ton) * Acres burned*

In its Compendium of Air Pollutant Emission Factors, (AP-42) (U.S. Environmental Protection Agency, 2003), the EPA provides fuel loadings and emission factors for particulate matter (PM), carbon monoxide (CO), methane (CH_4), and non-methane hydrocarbons (NMHC) for a variety of field and orchard crops. In some cases, AP-42 emission factors are provided for two different burning techniques: headfire burning (when a fire is started on the upwind side of a field) and backfire burning (when a fire is started downwind). In addition, a more recent study at the University of California at Davis derived emission factors for the combustion of barley straw, corn stover, rice straw, wheat straw, and almond tree prunings (Jenkins et al., 1996). In this study, emission factors for CO, total hydrocarbons (THC), nitrogen oxides (NO_x), sulfur dioxide (SO_2), and PM were based on measurements collected during wind tunnel tests.

Fuel loadings and emission factors are provided in **Table 2-1**. For barley, corn, rice, wheat, and almonds, emission factors were derived entirely from Jenkins' (1996) study using average emission rates and moisture contents from two wind tunnel configurations. An emission factor for volatile organic compounds (VOC) was derived from Jenkins' THC values by using the fraction of reactive gases equal to 0.5698 that was published in a California Air Resources Board (CARB) guidance document (Gaffney, 2000). For the remaining crops, emission factors for NO_x and SO_2 were set equal to Jenkins's average values for field or orchard crops, and emissions factors for VOC were calculated from the CH_4 and NMHC values reported in AP-42, again by using the CARB fraction of reactive gases. The emission factors for CO were taken directly from AP-42, and particulate matter of less than 10 μm aerodynamic diameter (PM_{10}) and $PM_{2.5}$ were calculated from the PM values in AP-42 by using fractions of 0.9835 for PM_{10} and 0.9379 for $PM_{2.5}$ for field crops and fractions of 0.9814 for PM_{10} and 0.9252 for $PM_{2.5}$ for orchard crops based on CARB's guidance (Gaffney, 2000). Fuel loadings were taken from AP-42 for all crop types. (For grasses and wild reeds, which were not reported in AP-42, the value for wild hay was used.)

Table 2-1. Fuel loadings and emission factors for agricultural burning.

(Page 1 of 2)

Crop Type	Fuel Loading (tons/acre)	Emission Factors (lbs/ton) PM_{10}	$PM_{2.5}$	CO	VOC	NO_x	SO_2
Field Crops							
Asparagus	1.5	39.3	37.5	150.0	49.0	4.5	0.6
Barley	1.7	14.3	13.8	183.7	15.0	5.1	0.1
Corn	4.2	11.4	10.9	70.9	6.6	3.3	0.4
Cotton	1.7	7.9	7.5	176.0	3.6	4.5	0.6
Grasses	1.0	15.7	15.0	101.0	11.1	4.5	0.6
Pineapple		7.9	7.5	112.0	4.6	4.5	0.6
Rice	3.0	6.3	5.9	57.4	4.7	5.2	1.1
Safflower	1.3	17.7	16.9	144.0	14.8	4.5	0.6
Sorghum	2.9	17.7	16.9	77.0	5.1	4.5	0.6
Sugar cane	4.0	8.3	7.9	81.0	9.0	4.5	0.6
Wheat	1.9	10.6	10.1	123.6	7.6	4.3	0.9
Unspecified	2.0	20.7	19.7	117.0	13.3	4.5	0.6
Alfalfa - Headfire	0.8	44.3	42.2	106.0	20.8	4.5	0.6
Alfalfa - Backfire	0.8	28.5	27.2	119.0	21.7	4.5	0.6
Bean (red) - Headfire	2.5	42.3	40.3	186.0	26.8	4.5	0.6
Bean (red) - Backfire	2.5	13.8	13.1	148.0	14.2	4.5	0.6
Hay (wild) - Headfire	1.0	31.5	30.0	139.0	12.5	4.5	0.6
Hay (wild) - Backfire	1.0	16.7	15.9	150.0	9.7	4.5	0.6
Oats - Headfire	1.6	43.3	41.3	137.0	19.3	4.5	0.6
Oats - Backfire	1.6	20.7	19.7	136.0	10.3	4.5	0.6
Pea - Headfire	2.5	30.5	29.1	147.0	21.7	4.5	0.6
Wheat - Headfire	1.9	21.6	20.6	128.0	9.7	4.5	0.6
Wheat - Backfire	1.9	12.8	12.2	108.0	6.6	4.5	0.6
Orchard Crops							
Almond	1.6	7.0	6.7	52.2	5.2	5.9	0.1
Apple	2.3	3.9	3.7	42.0	2.3	5.2	0.1
Apricot	1.8	5.9	5.6	49.0	4.6	5.2	0.1
Avocado	1.5	20.6	19.4	116.0	18.5	5.2	0.1
Cherry	1.0	7.9	7.4	44.0	6.0	5.2	0.1
Citrus (orange, lemon)	1.0	5.9	5.6	81.0	6.8	5.2	0.1
Date palm	1.0	9.8	9.3	56.0	3.8	5.2	0.1
Fig	2.2	6.9	6.5	57.0	6.0	5.2	0.1
Nectarine	2.0	3.9	3.7	33.0	2.3	5.2	0.1
Olive	1.2	11.8	11.1	114.0	10.3	5.2	0.1
Peach	2.5	5.9	5.6	42.0	3.0	5.2	0.1
Pear	2.6	8.8	8.3	57.0	5.1	5.2	0.1
Prune	1.2	2.9	2.8	47.0	4.6	5.2	0.1
Walnut	1.2	4.2	4.0	67.0	4.8	4.2	0.2
Unspecified	1.6	5.9	5.6	52.0	6.0	5.2	0.1

Table 2-1. Fuel loadings and emission factors for agricultural burning.

(Page 2 of 2)

Crop Type	Fuel Loading (tons/acre)	Emission Factors (lbs/ton) PM_{10}	$PM_{2.5}$	CO	VOC	NO_x	SO_2
Vine Crops							
Unspecified	2.5	4.9	4.7	51.0	3.8	5.2	0.1
Weeds							
Russian thistle, or tumbleweed	0.1	21.6	20.6	309.0	1.1	4.5	0.6
Tales, or wild reeds	1.0	4.9	4.7	34.0	15.7	4.5	0.6
Unspecified	3.2	14.8	14.1	85.0	6.8	4.5	0.6

2.3 AGRICULTURAL BURNING ACTIVITY DATA

To obtain activity data for agricultural burning events in the CENRAP region, STI's subcontractor, Population Research Systems (PRS), conducted systematic telephone and mail surveys of county AES offices. PRS attempted to contact each AES office in all 969 counties of the CENRAP region in order to recruit AES personnel to complete a telephone survey. This survey was designed to determine the fraction of each county's acreage typically burned each year by crop type, the timing of such burn events, and the burn methods employed. Data collected through the survey was then applied to National Agricultural Statistics Service (NASS) county-level estimates of acreages grown by crop type for 2002.

This data collection effort had a target response rate of 25% to 50%. Ultimately, 549 contacts were made, for a response rate of 56% (ranging from 36% to 93% from state to state). By including such large proportions of the available respondent pool and the total geographic area of the CENRAP region, the achievable representativeness of the study was maximized and the potential uncertainties minimized. Survey responses were used to generate profiles of agricultural burning practices by geographic region and crop type. In general, profiling was done on a statewide basis for each crop: a regional average burn profile was used to represent all counties for which no survey data are available. However, personnel at the Kansas Department of Health and Environment divided the state of Kansas into three subregions for wheat burning and four subregions for rangeland burning. Separate burn profiles for the burning of wheat and rangeland were produced for each of these subregions and applied to counties within those subregions for which no survey data were available.

The proposed survey questionnaire is provided in Appendix A, and maps displaying Kansas subregions for wheat and rangeland burning are provided in Appendix C.

2.4 SPATIAL ALLOCATION OF AGRICULTURAL BURNING

Agricultural burning was spatially allocated by using the BELD GIS database. The BELD database includes spatial distributions of crops (by crop type) at the county (and sub-county) level gridded to 1 km^2. Activity data obtained through the agricultural survey questionnaires about the types of crops burned at the county level was spatially allocated by matching the reported crop types from the questionnaire to the crop types in the BELD database by county. The fire activity data was applied to the area (acreage) of crops by county for the purposes of calculating countywide emissions. Gridded surrogate data, or spatial allocation factors, were developed by gridding the agricultural burn activity data and corresponding crop types to the 12-km × 12-km national Regional Planning Organization (RPO) grid domain.

2.5 TEMPORAL ALLOCATION OF AGRICULTURAL BURNING

Agricultural burning, like other agricultural activities, has a distinct seasonal pattern, although this pattern tends to vary by crop type and region. To identify such seasonal patterns in the CENRAP region, the survey of agricultural experts contained questions designed to identify times of the year when agricultural burning takes place for the various crops grown in each of the CENRAP states. Survey responses were used to design seasonal profiles that characterize agricultural burning activities by state and crop type.

The survey also contained questions related to weekly and diurnal variations in agricultural burning activities. These questions were designed to identify the fraction of agricultural burning that takes place on weekdays versus weekend days, as well as the fraction of burning that takes place during daylight hours versus nighttime hours.

2.6 CHEMICAL SPECIATION OF AGRICULTURAL BURNING

PM and VOC emissions were chemically speciated according to profiles published by the EPA and the CARB. **Table 2-2** summarizes the profile references and the individual compounds included in the profiles. Using these references, we created speciation profiles and cross-reference files according to SMOKE speciation schemes.

Table 2-2. Chemical speciation of agricultural burning: profile information.

Profile Name	Profile Number	Profile Source	Source Category SCC Code	SCC Description	Reference	Proposed Classification Schemes	Individual Compounds
PM							
Agricultural Burning – Field Crops	430	ARB	CARB SCC Code 67066202620000 (assumed to correspond to EPA SCC Code 2801500000)	Waste Burning – Agricultural Debris – Field Crops	(Jenkins et al., 1996)	Default SMOKE classification scheme and individual compounds	Aluminum, Ammonia, Antimony, Arsenic, Barium, Bromine, Cadmium, Calcium, Elemental Carbon, Organic Carbon, Chlorine, Chromium, Cobalt, Copper, Gallium, Gold, Indium, Iron, Lanthanum, Lead, Manganese, Mercury, Molybdenum, Nickel, Nitrates, Palladium, Phosphorous, Potassium, Rubidium, Selenium, Silicon, Silver, Sodium, Strontium, Sulfur, Thallium, Tin, Titanium, Uranium, Vanadium, Yttrium, Zinc, Zirconium, Unidentified
VOC							
Miscellaneous Burning – Forest Fires	0307	EPA	2801500000	Miscellaneous Area Sources – Agriculture Production – Crops – Agricultural Field Burning – Whole Field Set on Fire – Total, all crop types	(Sandberg et al., 1975)	Default SMOKE classification scheme (Carbon Bond IV) and individual compounds	Acetylene, 1,3-Butadiene, N-Butane, 1-Butene,Isomers of Butene, Ethane, Ethylene, Isobutane, 3-Methyl-1-Butene, Propyne, Isomers of Pentane, Propane, Propylene, Unidentified

3. PRESCRIBED BURNING

3.1 OVERVIEW

The purpose of prescribed burning is commonly believed to the clearing of undergrowth in timberlands or grasslands to prevent wildfires or make various types of land improvements. For example, planned burns are used for timber stand improvement (site preparation fires for reforestation projects; removal of diseased trees), range improvement and wildlife habitat improvement. The types and amounts of such burning vary regionally both due to local weather and to local forest/land types.

As with agricultural burning, emission rates are specific to materials burned and burn management practices. Some degree of reporting and record-keeping is required of wildfire prevention efforts by state, federal, and tribal agencies. However, access and interpretation of these records is difficult. Even less information is available for planned burning of undergrowth for private land improvement. As with agricultural burning, significant effort is necessary to develop activity data sets that can be used for regional-scale emissions assessments.

3.2 PRESCRIBED BURNING EMISSION FACTORS AND FUEL LOADINGS

For this project, the FOFEM model was used to generate estimates of fuel loadings and emission rates for prescribed fires which were then applied to estimates of acres burned acquired from fire history data. This model was developed based on research findings gathered from peer-reviewed literature sources, internal agency reports, and other “gray literature” sources. The accuracy and certainty of FOFEM results are consistent with the current status of scientific measurements of fuel consumptions and air emissions for prescribed burning and wildfires. Although measurement data are limited and uncertain, the FOFEM model generally represents a synthesis of the most up-to-date information available.

Required inputs to FOFEM 5.0 include the following:

- Vegetation land cover type
- Season of the year (spring, summer, fall, or winter)
- Moisture conditions (including the moisture content of various fuel types)
- Configuration of the burn (natural conditions, piled fuel, or slash fuel)
- Percent of the tree canopy crown expected to burn (0% for a well-executed prescribed burn)
- Percent of fallen logs that are rotten (default equals 10%)
- Size distribution of fallen logs of 3 in. or greater diameter
  - Even distribution across the size range, from 3 in. to 20+ in.
  - A distribution that tends toward the larger logs
  - A distribution that tends toward the smaller logs
  - A distribution that tends toward the center of the size range
  - A distribution that tends toward the endpoints of the size range.

FOFEM calculates emission factors for PM_{10}, $PM_{2.5}$, CH_4, carbon dioxide (CO_2), CO, NO_x, and SO_2. For ammonia (NH_3) and NMHC, we applied the approximations that were employed by Allen and Dennis (2000), which assumed NMHC and NH_3 emission factors that vary as follows:

$$EF_{NH_3} = EF_{NO_x} \times 14 \times \left(1 - \frac{EF_{CO_2}}{EF_{CO_2} + EF_{CO}}\right) \qquad \textbf{(3-1)}$$

$$EF_{NMHC} = 1.52 + (EF_{CH_4} \times 1.232) \qquad \textbf{(3-2)}$$

Before FOFEM could be applied to the CENRAP region, it was necessary to determine which of the model's vegetation types are found in the region, and what the moisture contents of various fuel types were at the times and places in which prescribed burning events occurred. (For the remaining FOFEM inputs, such as burn configuration, log-size distributions, and the percentage of fallen logs that are rotten, default settings were used).

FOFEM allows users to choose between two main vegetation cover classifications: the National Vegetation Classification System (NVCS) and the Society of American Foresters/Society for Range Management (SAF/SRM) cover types. (A third option, the Fuel Characteristic Classification [FCC], does not yet cover all regions of the country.) The NVCS uses a classification hierarchy which emphasizes differences in both vegetation structure and floristics[2], and the system is periodically updated to include new information on natural community classifications developed at the state level. Such natural communities are based on all species of vegetation. SAF forest cover types, on the other hand, are based primarily on dominant tree species. While trees can be indicators of their environments, some trees are so broadly adapted that their presence indicates little about the conditions of the surrounding natural community. Thus, SAF cover types are less useful than those found in the NVCS (New Hampshire Division of Forests and Lands, 2002). To determine which of the NVCS or SAF cover types are found in the CENRAP region, a cross-walk was developed between the FOFEM and BELD databases. In developing this cross-walk, BELD vegetation types were matched to NVCS coverage types wherever possible; SAF data was used only when clear matches could not be made to NVCS coverages. The cross-walks used are presented in Appendix B.

Fuel moisture content is the quantity of water in a fuel particle expressed as a percentage of the oven-dry weight of the fuel (National Weather Service, 1998). FOFEM requires settings for three fuel classifications[3]: 10-hour, 1000-hour, and duff[4]. Fuel moisture data are available

[2] Floristics is the study of the number, distribution, and relationships of plant species in one or more areas.
[3] The rate of change of the moisture content is dependent on the diameter of the woody fuel, various diameter ranges are classified according to their "time lag." Time lag refers to the length of time it takes a fuel to respond to changes in environmental moisture conditions: larger diameter fuels generally have longer time lags. The time lag categories typically used for fire behavior and fire danger rating are specified as 1-hr (0-¼"), 10-hr (¼"-1"), 100-hr (1"-3"), and 1000-hr (3" or greater).
[4] Duff is partially decomposed organic matter, leaf litter, or organic soils (such as humus or peat), which accumulates in layers on the forest floor.

from the Wildland Fire Assessment System (WFAS)—a database of the National Interagency Fire Center (NIFC) in Boise, Idaho. WFAS is based on daily weather observations taken at about 1500 fire weather stations throughout the United States and entered into the Weather Information Management System (WIMS). These weather observations are used to calculate fuel moisture levels for 1-hr, 10-hr, 100-hr, and 1000-hr fuel types. WIMS data for the CENRAP region was acquired and used to determine a range of 10-hr, 1000-hr and duff moisture levels for the CENRAP region for 2002. The 100-hr moisture values were used as a surrogate for duff moisture, following the approach of Harrington (2003).

Once vegetation types and fuel moisture levels present in the CENRAP region were determined, FOFEM was run for each unique combination of vegetation type-moisture level to generate emission rates in pounds per acre burned. Outputs from these FOFEM runs were used to produce a look-up table of emission factors by vegetation type and moisture condition. For each prescribed burning event, we were able to use WIMS data from the nearest fire weather station to determine fuel moisture contents for that event and BELD data to determine the type of vegetation burned. This information was used to select and apply an appropriate emission factor from the FOFEM look-up table.

3.3 PRESCRIBED BURNING ACTIVITY DATA

In summary, the prescribed burn activity data for state and private lands from the CENRAP states will consist of detailed data obtained from smoke management programs, state fire marshals, or state forest services; summary data obtained from state agencies and allocated by county; summary data estimated by applying federal surrogates to state lands and allocated by county; and county level data based on the results of the rangeland burning survey questions.

3.3.1 Activity Data for Federal Lands

The National Interagency Fire Management Integrated Database (NIFMID) was the source of data used for prescribed fires occurring on Department of the Interior (DOI) lands (U.S. Fish and Wildlife Service, National Park Service, and Bureau of Indian Affairs [http://famweb.nwcg.gov/weatherfirecd/]). This database contains fire type (prescribed, wildfire, etc.), start and end dates, extent (acres), and location (geographic coordinates and township/range/section).

The National Fire Plan Operations and Reporting System (NFPORS), contains year 2002 fire occurrence data for the U.S. Forest Service (USFS). NFPORS data were used to characterize prescribed fires on USFS lands in the six states with land managed by that agency: Arkansas, Louisiana, Minnesota, Missouri, Oklahoma, and Texas.

Additional prescribed burn data on federally managed lands were included in data acquired from state smoke management programs (this data was cross-checked against NIFMID and NFPORS data to prevent double-counting). For example, some DOI data was included among the state reports that did not appear in the NIFMID final report for 2002, and some USFS burns appeared in these reports as well.

3.3.2 Activity Data for State, Tribal, and Private Lands

Each of the CENRAP states has unique regulations regarding prescribed burning on state and private lands. Records of prescribed burns are compiled at different levels within each state. Consequently, several sources of information contributed to the prescribed burn activity data for state, private, and tribal lands.

In cases where we could not acquire good-quality information about prescribed burns on state lands, the percentage of federal lands that were burned within the state in the year 2002 was used as a surrogate for the percentage of state lands that were burned that year. The total acreage of burned state lands were allocated according to the proportion of state lands within each county. In addition, the temporal profile of the burns that occurred on federal lands within these states was applied to the burns that were estimated for their state lands.

Minnesota, Arkansas and Louisiana have voluntary or mandatory smoke management programs for which records of prescribed burns on state and private lands are kept. Records including the scheduled date, extent (acres), and location (geographic coordinates or township/range/section) of large scale prescribed burns that occurred during the year 2002 on state and private lands in Minnesota and Arkansas were obtained from the Minnesota Interagency Fire Center and the Arkansas Forestry Commission, respectively. Also, the Louisiana Forestry Division provided summary data describing the dates and acreages of prescribed burns that occurred on Louisiana's state and private lands during the year 2002. This summary data listed burns by district and had to be allocated to the county level using the acreage of forested land within each county.

A statewide permitting system exists for all other planned burns in Minnesota, including small scale residential or agricultural burns. The permits are issued by local fire wardens, and an estimated 60,000 burn permits were issued in the state in 2002. Records of these permitted burns are not compiled above a county level and are not in electronic format. Of the 60,000 permits, roughly 65% are estimated to be issued for "ditch burns" (fires set alongside roads or fencerows for weed abatement purposes) or "pile burns" (fires used to dispose of piles of waste material). Ditch burns are generally less than one quarter mile in length and were not considered in the inventory due to their small size and the lack of specific data. Also, since pile burns are used for waste management purposes, they fall beyond the scope this inventory. The remaining 35% of the permitted burns are performed on open land and range and are likely to be captured by the agricultural survey (Meadows, 2004).

In Oklahoma, a 15-county area in the eastern portion of the state has a controlled burn authorization system for open burning on private lands and lands managed by the state forest service. Records containing the date, type (grassland, woodland, brush pile, etc.), extent (acres), and location (address) of prescribed burns that occurred in that region of Oklahoma during 2002 were obtained from the Oklahoma Forestry Service[5]. Oklahoma's Department of Wildlife Conservation (DWC) estimated the total number of acres burned on lands managed by the DWC in 2002, which accounted for the remainder of the state lands in Oklahoma that undergo substantial prescribed burning.

[5] About one-third of these records was provided in hard-copy format and were not included in the final inventory.

The Kansas State Fire Marshal's office keeps a database of fire incidents in Kansas as reported by local fire departments (although prescribed burns in Kansas may or may not be reported to the local fire departments, depending on the specific regulations within each township). The dates and locations (counties) of the controlled burns that were reported to the local fire departments in Kansas during 2002 were obtained from the Kansas State Fire Marshal's database.

In Texas, virtually all of the burning on state lands is conducted by the Texas Parks and Wildlife Department (TPWD) in state parks and Wildlife Management Areas (WMA). TPWD was able to provide data on burns occurring in state parks, but WMA burns are not tracked in a central database. Attempts to gather data from individual WMA managers were not successful, so the number of WMA acres burned in 2002 was estimated from data published by Allen and Dennis (2000) for 1996 and 1997.

Missouri, Iowa, and Nebraska have neither smoke management programs nor prescribed burn records compiled above the county level. The Forestry Section of the Missouri Department of Conservation summarized the number of acres burned by The Nature Conservancy, the Missouri Department of Natural Resources, and the Missouri Department of Conservation on state and private lands in Missouri during the year 2002. In the state of Iowa, the Bureau of Wildlife performs a large portion of the state's prescribed burns on public grasslands. However, records of the prescribed burns that occur on Iowa's conservation lands are not compiled by the Bureau of Wildlife above the dispatch level. Therefore, the percentage of federal lands burned in the state of Iowa during 2002 was used as a surrogate in order to estimate the total number of acres burned on Iowa's state lands. In Nebraska, a statewide burn ban requires prescribed burns to be permitted, but records of prescribed burn permits are not compiled above the county level. Therefore, the percentage of federal lands burned in the state of Nebraska in 2002 was used as a surrogate to estimate the total number of acres burned on state lands. The estimated acreage of state lands burned in Missouri, Iowa, and Nebraska will be allocated by county using the percentage of state lands in each county within each state.

To ensure that burning on tribal lands was captured in the data sources listed above; contacts were made to tribes that collectively hold over 95% of the tribal lands in the CENRAP region. It was confirmed that these tribes report their burns to either the BIA or the Minnesota Interagency Fire Center.

For burning on private land, it was assumed that burns by individual parties would be related to agricultural practices (and, therefore, captured in the agricultural survey data) or the burning of waste (and, therefore, not considered under the scope of this project). Significant burns on private lands are most likely to be conducted by the forest industry, or by organizations such as the Nature Conservancy (TNC), The Prairie Plains Institute, or the Platte River Whooping Crane Maintenance Trust (Whitney, 2003). We did not obtain specific data from all the aforementioned organizations due to time constraints, though the TNC provided a database of all burns conducted by that agency in 2002.

Planned burns by private forestry companies in Louisiana and Arkansas are largely included in the data received from the Louisiana Forestry Division and the Arkansas Forestry

Commission. Forestry companies also perform planned burns in the Piney Woods region of east Texas. However, records of the planned burns that occurred during 2002 were not available from the Texas Forest Service. Traditionally, the Texas Forest Service reported planned burning information in the Harvest Trends Report; yet, after 1999, the Harvest Trends Report ceased to include information about planned burning because the practice of planned burning for forest management has diminished in recent years due to liability concerns (Xu, 2004). In the absence of other information, data reported by Allen & Dennis (2000) on acres burned by private timber companies in the Piney Woods region for 1996 and 1997 were averaged to produce an estimate of 20,000 acres burned per year. These acres were allocated to the county level based on the forested acreage in each county that makes up the Piney Woods region.

3.3.3 Activity Data for Rangelands

Rangeland burning occurs extensively on private lands throughout the CENRAP states, particularly in Kansas, Nebraska, Oklahoma, and central and west Texas. To obtain activity data for rangeland burning events in the CENRAP region, the agricultural burning survey given to county AES offices included rangeland burning questions designed to determine the fraction of rangeland acreage typically burned each year and the timing of such burn events. The survey results (discussed in Section 2) yielded activity data for private lands for all of the CENRAP states. We obtained additional prescribed burning information for private lands in some of the CENRAP states, as previously discussed in Section 3.3.2.

3.4 SPATIAL ALLOCATION OF PRESCRIBED BURNING

Fire occurrence locations for prescribed burns were typically provided as point coordinates (i.e., latitude and longitude values), township/range assignments, or county name. While the size of the fire was typically provided (in acres), the actual boundaries of the prescribed burns were not usually provided. To represent the location and approximate size of each burn, the reported location of each burn was assumed to be the centroid of the burn and was mapped as a point using the latitude/longitude coordinates. County-specific vegetation profiles from the BELD data were then matched to each fire location to determine the vegetation types associated with each fire. The vegetation data (used by the FOFEM model), fire size, occurrence date, and associated fuel moisture data were used to calculate emissions for each fire.

While many of the prescribed burns were large, there were no fires larger than the 12-km x 12-km grid cell resolution. Therefore, when the locations of prescribed burns were known, they were treated as point sources in the emission inventory. Approximately 40% of the prescribed burning inventory was allocated spatially and temporally as a point source inventory. (States that were able to provide “incident-level” databases of prescribed burn activity included Arkansas, Minnesota, and Oklahoma.) When the locations of fires were not reported, a spatial surrogate approach was used to develop gridded spatial allocation factors.

Spatial allocation factors were used to spatially distribute emissions at the sub-county level (by grid cell). To develop gridded surrogate data, a surrogate data source is used to represent the locations of fire activity. Prescribed burns were spatially distributed on rural grasslands and forested lands, while agricultural burns were spatially distributed on agricultural land by crop type based on data obtained from the agricultural burning surveys. The spatial allocation factors were developed for the 12-km × 12-km National RPO grid.

3.5 TEMPORAL ALLOCATION OF PRESCRIBED BURNING

Fire history data collected for prescribed burns on federal lands specifies the dates on which the burns began and ended. These data were used to generate state-specific temporal profiles to allocate emissions from prescribed burning to the proper months of the year and days of the week. Also, by examining the number of burns completed in one day versus those spanning multiple days (and therefore continuing through the night), it was possible to estimate the fraction of prescribed burning that takes place in daylight hours versus nighttime hours.

In the absence of date-specific information for prescribed burns on state lands, temporal profiles derived from federal prescribed burns were applied to burns on state lands.

3.6 CHEMICAL SPECIATION OF PRESCRIBED BURNING

PM and VOC emissions were chemically speciated according to profiles developed by the EPA and the CARB. **Tables 3-1 and 3-2** summarize the profile references and the individual compounds included in two profiles: (1) prescribed burning of grasslands and (2) prescribed burning of woodlands. Using these references, we created speciation profiles and cross-reference files according to SMOKE speciation schemes.

Table 3-1. Chemical speciation of prescribed burns: profile information for grasslands.

Profile Name	Profile Number	Profile Source	Source Category SCC Code	SCC Description	Reference	Proposed Classification Schemes	Individual Compounds
				PM			
Range Improvement Burning	441	ARB	CARB SCC Code 67066402000000 (assumed to correspond to EPA SCC Code 2810020000)	Waste Burning – Range Management – Range Improvement	(Jenkins et al., 1996)	Default SMOKE classification scheme and individual compounds	Aluminum, Ammonia, Antimony, Arsenic, Barium, Bromine, Cadmium, Calcium, Elemental Carbon, Organic Carbon, Chlorine, Chromium, Cobalt, Copper, Gallium, Gold, Indium, Iron, Lanthanum, Lead, Manganese, Mercury, Molybdenum, Nickel, Nitrates, Palladium, Phosphorous, Potassium, Rubidium, Selenium, Silicon, Silver, Sodium, Strontium, Sulfur, Thallium, Tin, Titanium, Uranium, Vanadium, Yttrium, Zinc, Zirconium, Unidentified
				NMHC			
Miscellaneous Burning – Forest Fires	0307	EPA	2810020000	Miscellaneous Area Sources – Other Combustion – Prescribed Burning of Rangeland – Total	(Sandberg et al., 1975)	Default SMOKE classification scheme (Carbon Bond IV) and individual compounds	Acetylene, 1,3-Butadiene, N-Butane, 1-Butene,Isomers of Butene, Ethane, Ethylene, Isobutane, 3-Methyl-1-Butene, Propyne, Isomers of Pentane, Propane, Propylene, Unidentified

Table 3-2. Chemical speciation of prescribed burns: profile information for forestlands.

Profile Name	Profile Number	Profile Source	Source Category SCC Code	SCC Description	Reference	Proposed Classification Schemes	Individual Compounds
PM							
Forest Management Burning	463	ARB	CARB SCC Code 67066602000000 (assumed to correspond to EPA SCC Code 2810015000)	Waste Burning – Forest Management – Forest Management	(Jenkins et al., 1996)	Default SMOKE classification scheme and individual compounds	Aluminum, Ammonia, Antimony, Arsenic, Barium, Bromine, Cadmium, Calcium, Elemental Carbon, Organic Carbon, Chlorine, Chromium, Cobalt, Copper, Gallium, Gold, Indium, Iron, Lanthanum, Lead, Manganese, Mercury, Molybdenum, Nickel, Nitrates, Palladium, Phosphorous, Potassium, Rubidium, Selenium, Silicon, Silver, Sodium, Strontium, Sulfur, Thallium, Tin, Titanium, Uranium, Vanadium, Yttrium, Zinc, Zirconium, Unidentified
NMHC							
Miscellaneous Burning – Forest Fires	0307	EPA	2810015000	Miscellaneous Area Sources – Other Combustion – Prescribed Burning for Forest Management – Total	(Sandberg et al., 1975)	Default SMOKE classification scheme (Carbon Bond IV) and individual compounds	Acetylene, 1,3-Butadiene, N-Butane, 1-Butene,Isomers of Butene, Ethane, Ethylene, Isobutane, 3-Methyl-1-Butene, Propyne, Isomers of Pentane, Propane, Propylene, Unidentified

4. AIR QUALITY DATA ANALYSIS

The objective of data analysis for this project was to preliminarily assess whether planned burning appears to contribute to impaired visibility events in Class I areas. We used existing ambient pollutant data from Class I areas in conjunction with the planned burn emission inventories developed through this project. To meet this objective, we performed the following steps:

- Summarized 2002 air quality data available for Class I areas in the CENRAP region (e.g., IMPROVE[f] speciated $PM_{2.5}$ data). Smoke components that contribute to visibility impairment include organic carbon (OC) and elemental carbon (EC).
- Identified where and when planned, prescribed, and/or agricultural burns occurred near and/or upwind of Class I areas in 2002 by using the Task 1 emission inventory.
- Characterized the ambient data for the 20% best and 20% worst visibility days at the Class I areas, including the average composition of the $PM_{2.5}$ and the average contribution of pollutants to light extinction. Determined whether any of these days coincide with burns included in the inventory.
- Investigated the ambient data for days with high concentrations of or contributions from EC and non-soil potassium (associated with biomass burning). Investigated seasonal patterns and whether any of these days coincide with burns listed in the inventory.
- Analyzed days of interest in more detail by performing trajectory analyses, inspecting satellite photos, and investigating existing hourly pollutant data (e.g., whether nephelometer measurements indicate the impact of air parcels with increased $PM_{2.5}$ concentrations).

The deliverable for this task is a technical memorandum describing the analyses and summarizing analysis results. A discussion of the analysis and results is also included in the project Final Report.

[f] IMPROVE = Interagency Monitoring of Protected Visual Environments

5. PREPARATION OF DIGITAL EMISSION INVENTORY FILE SYSTEMS

The following files will be delivered by STI upon completion of the planned burning emission inventory with accompanying documentation:

- Emission data files in latest NIF format
- Emission data files converted to IDA format and ready for input to SMOKE 1.5
- Temporal profile and cross-reference files for use by SMOKE
- Spatial surrogate and cross-reference files for use by SMOKE
- Chemical speciation profiles and cross-reference files for use by SMOKE

6. REFERENCES

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APPENDIX A

PROPOSED SURVEY QUESTIONNAIRE

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Central States Regional Air Planning Association (CENRAP)
Telephone Interview
Project #1002

INTRO1: Hello, my name is __________. I'm calling on behalf of the Central States Regional Air Planning Association or CENRAP. CENRAP is an organization of states, tribes, federal agencies, and other interested parties that studies and addresses regional haze and visibility issues. Your state is participating in CENRAP and as such, your county has been randomly selected to participate in an important air quality study.

Q1a. Our records show that this is a cooperative agricultural extension office in _________ county in the state of ________. Is that correct?

[1] Yes	(Go to Qa2)
[2] No	(Go to Q1b)
[8] DON'T KNOW	(Terminate)
[9] REFUSED	(Terminate)

Q1b. What office have I called? ____ (Go to Q2a)

Q2a. I would like to speak with the person who would be most knowledgeable about your county's tilling practices and agricultural burning practices.

[1] I am that person	(Go to INTRO3a)
[2] I am that person, but I only know tilling	(Go to INTRO3a)
[3] I am that person, but I only know about burning	(Go to Q3a)
[4] I'll get him/her	(Go to INTRO2)
[5] No one is available now	(Go to CALLBACK)
[6] No such person	(Terminate)
[8] DON'T KNOW	(Terminate)
[9] REFUSED	(Terminate)

INTRO2: Hello, my name is __________. I'm calling on behalf of the Central States Regional Air Planning Association or CENRAP. CENRAP is an organization of states, tribes, federal agencies, and other interested parties that studies and addresses regional haze and visibility issues. Your state is participating in CENRAP and as such, your county has been randomly selected to participate in an important air quality study (Go to Q2b).

Q2b. Are you the person who is most knowledgeable about your county's tilling practices and agricultural burning practices.

[1] I am that person	(Go to INTRO3a)
[2] I am that person, but I only know tilling	(Go to INTRO3a)
[3] I am that person, but I only know about burning	(Go to Q3a)
[8] DON'T KNOW	(Terminate)
[9] REFUSED	(Terminate)

INTRO3a: The interview will take about 10 minutes. Your responses will be kept confidential and will not be connected to your name. Can I begin the interview? <Go to Q3a1>

Q3a. What agency or agencies would have information about tilling practices in your county? (Probe: Is that a state or county agency?) Can I get their telephone number as well?

1. ____
2. ____

777 = NOT APPLICABLE
888 = DON'T KNOW
999 = REFUSED

<Go to INTRO3b>

INTRO3b: The interview will take about 10 minutes. Your responses will be kept confidential and will not be connected to your name. Can I begin the interview? <Go to Q3a1>

CALLBACK: When would be a good time for us to call back to talk with someone about agricultural burning in your county? Who should we ask for? <Interviewer Note: If told you have reached the incorrect agency, ask for correct agency name and telephone number>

TERMINATE: Thank you for your time. Goodbye.

<If Q1a Eq 2, go to Q3a2. If Q1a Eq 1, go to Q3a1>

Q3a1. What is the name of this office? _________________________

88888 = DON'T KNOW
9999 = REFUSED

Q3a2. What is your name? _________________________

8888 = DON'T KNOW
9999 = REFUSED

Q3a3. What is your telephone number beginning with the area code? ( ) __________

8888888 = DON'T KNOW
9999999 = REFUSED

Q3b. I’m now going to read you a list of crops and I’d like you to tell me whether these crops are grown in your county? (Programmer note: 1 data output column only; Yes=1, No=2)

1. Corn _____
2. Wheat _____
3. Sorghum _____
4. Rice _____
5. Other cereal crops _____
6. Soybeans _____
7. Sugarcane _____
8. Hay or alfalfa _____
9. Cotton _____
10. Other crops not previously mentioned _____
11. Grazed rangelands _____

8 = DON’T KNOW
9 = REFUSED

<If Q2a or Q2b Eq 1 or 2, go to Q4. If Q2a or Q2b Eq 3, go to Q14>

Agricultural Dust Questions

<Note: Show selected crop names from Q3b for Questions #4 through #12 with the exception of showing Q3b11. Only show Q3b11 for questions #14 through #19>

Q4. How many plantings of each crop type are normally completed during a year? Let’s start with (name of 1st crop). Typically, how many plantings per year are made for (name of 1st crop)? How about for (name of 2nd crop)? For (name of 3rd crop)? Read list of remaining selected crops.

a. Corn _____
b. Wheat _____
c. Sorghum _____
d. Rice _____
e. Other cereal crops _____
f. Soybeans _____
g. Sugarcane _____
h. Hay or alfalfa _____
i. Cotton _____
j. Other crops not previously mentioned _____

88 = DON’T KNOW
99 = REFUSED

Q5. In your county, are tilling passes typically made on each crop before planting and after harvesting or are harvesting and planting completed in one pass? Let's start with (name of 1st crop). Typically, when are tilling passes made for (name of 1st crop)? Is it before planting and after harvesting or is tilling completed in one pass? How about for (name of 2nd crop)? Read list of remaining selected crops.

1 = Yes, passes are made before planting and after harvesting
2 = Tilling passes are completed at the same time
88 = DON'T KNOW
99 = REFUSED

	Passes
a. Corn	_____
b. Wheat	_____
c. Sorghum	_____
d. Rice	_____
e. Other cereal crops	_____
f. Soybeans	_____
g. Sugarcane	_____
h. Hay or alfalfa	_____
i. Cotton	_____
j. Other crops not previously mentioned	_____

<If Q5a through Q5j Eq 2, 8, or 9, go to Q6. If Q5a through Q5j Eq 1, go to Q7>

Q6. How many tilling passes are typically made on each crop in your county? Let's start with (name of 1st crop). Typically, how many tilling passes are made for (name of 1st crop)? How about for (name of 2nd crop)? Read list of remaining selected crops.

	Passes
a. Corn	_____
b. Wheat	_____
c. Sorghum	_____
d. Rice	_____
e. Other cereal crops	_____
f. Soybeans	_____
g. Sugarcane	_____
h. Hay or alfalfa	_____
i. Cotton	_____
j. Other crops not previously mentioned	_____

88 = DON'T KNOW
99 = REFUSED

<Go to Q8>

Q7. How many tilling passes are typically made on each crop before planting and after harvesting in your county? Let's start with (name of 1st crop). Typically, how many passes are made for (name of 1st crop) before planting? How about for (name of 2nd crop)? Read list of remaining selected crops.

Let's now turn to harvesting. Typically, how many passes are made for (name of 1st crop) after harvesting? For (name of 2rd crop)? Read list of remaining selected crops.

	1. Planting	2. Harvesting
a. Corn	_____	_____
b. Wheat	_____	_____
c. Sorghum	_____	_____
d. Rice	_____	_____
e. Other cereal crops	_____	_____
f. Soybeans	_____	_____
g. Sugarcane	_____	_____
h. Hay or alfalfa	_____	_____
i. Cotton	_____	_____
j. Other crops not previously mentioned	_____	_____

88 = DON'T KNOW
99 = REFUSED

Q8. Do farmers use any special tilling practices such a no-till, low-till, ridge-till, or mulch-till farming in your county? Let's start with (name of 1st crop), are no-till, low-till, ridge-till, or mulch-till tilling practices typically used for this crop?

What about for (name of 2nd crop)? Are no-till, low-till, ridge-till, or mulch-till practices typically used for this crop? Read list of remaining selected crops.

(Yes=1, No=2)

	1. No-till	2. Low-till	3. Ridge-till	4. Mulch-till
a. Corn	_____	_____	_____	_____
b. Wheat	_____	_____	_____	_____
c. Sorghum	_____	_____	_____	_____
d. Rice	_____	_____	_____	_____
e. Other cereal crops	_____	_____	_____	_____
f. Soybeans	_____	_____	_____	_____
g. Sugarcane	_____	_____	_____	_____
h. Hay or alfalfa	_____	_____	_____	_____
i. Cotton	_____	_____	_____	_____
j. Other types of crop not previously mentioned	_____	_____	_____	_____

8 = DON'T KNOW
9 = REFUSED

<If Q5a through Q5j Eq 2, 8, or 9, go to Q10. If Q5a through Q5j Eq 1, go to Q9>

Q9. For each crop, please tell me how many days before planting and after harvesting does tilling typically occur in your county. Let's start with (name of 1st crop). Typically, how many days before planting does tilling occur for (name of 1st crop)? How about for (name of 2nd crop)? Read list of remaining selected crops.

Let's now turn to harvesting. Typically, how many days after harvesting does tilling occur for (name of 1st crop)? For (name of 2rd crop)? Read list of remaining selected crops.

	1. Before Planting	2. After Harvesting
a. Corn	_____	_____
b. Wheat	_____	_____
c. Sorghum	_____	_____
d. Rice	_____	_____
e. Other cereal crops	_____	_____
f. Soybeans	_____	_____
g. Sugarcane	_____	_____
h. Hay or alfalfa	_____	_____
i. Cotton	_____	_____
j. Other crops not previously mentioned	_____	_____

888 = DON'T KNOW
999 = REFUSED

Q10. For each crop, please tell me whether tilling usually occurs on weekdays, weekends, or both weekdays and weekends? (Programmer note: 1 data output column only; Weekdays=1, Weekends=2, Both=3)

a. Corn	_____
b. Wheat	_____
c. Sorghum	_____
d. Rice	_____
e. Other cereal crops	_____
f. Soybeans	_____
g. Sugarcane	_____
h. Hay or alfalfa	_____
i. Cotton	_____
j. Other crops not previously mentioned	_____

8 = DON'T KNOW
9 = REFUSED

Q11. For each crop, please tell me whether tilling usually occurs during daytime, nightime, or both daytime and nighttime hours? (Programmer note: 1 data output column only; Daytime=1, Nightime=2, Both=3)

a. Corn	_____
b. Wheat	_____
c. Sorghum	_____
d. Rice	_____
e. Other cereal crops	_____
f. Soybeans	_____
g. Sugarcane	_____
h. Hay or alfalfa	_____
i. Cotton	_____
j. Other crops not previously mentioned	_____

8 = DON'T KNOW
9 = REFUSED

<If Q11a through Q11j Eq 3 go to Q12. If Q11a through Q11j Eq 1, 2, 8, or, 9 go to Q13>

Q12. For each crop, please tell me what percent of tilling occurs during daytime and nighttime hours? Let's start with (name of first crop). What percent of tilling for this crop occurs in the daytime and what percent occurs in the nighttime?

	1. % Daytime	2. % Nighttime
a. Corn	_____	_____
b. Wheat	_____	_____
c. Sorghum	_____	_____
d. Rice	_____	_____
e. Other cereal crops	_____	_____
f. Soybeans	_____	_____
g. Sugarcane	_____	_____
h. Hay or alfalfa	_____	_____
i. Cotton	_____	_____
j. Other crops not previously mentioned	_____	_____

888 = DON'T KNOW
999 = REFUSED

<NOTE: For Q12a1 through Q12j2, daytime % and nighttime % must add to 100% or question must be re-asked>

<If Q2a or Q2b Eq 2, go to Q13>
<If Q2a or Q2b Eq 1, go to Q14>

Q13. What agency should I contact concerning agricultural burning in your county? (Probe: Is that a state or county agency?) Can I get the telephone number as well?

a. ____

b. ____

888 = DON'T KNOW
999 = REFUSED

<Go to THANK YOU>

Agricultural Burning Questions

<Note: Show selected crop names from Q3b for Questions #14 through #19>

Q14. For each crop, what percent of the total acreage is typically burned each year in your county? Let's start with (name of 1st crop). What percent of (name of 1st crop) is burned each year? Read list of remaining selected crops.

a.	Corn	_____ %
b.	Wheat	_____ %
c.	Sorghum	_____ %
d.	Rice	_____ %
e.	Other cereal crops	_____ %
f.	Soybeans	_____ %
g.	Sugarcane	_____ %
h.	Hay or alfalfa	_____ %
i.	Cotton	_____ %
j.	Other crops not previously mentioned	_____ %
k.	Grazed rangelands	_____ %

888 = DON'T KNOW
999 = REFUSED

Q15. For each crop, please tell me how many days before planting and after harvesting does agricultural burning typically occur in your county. Let's start with (name of 1st crop). Typically, how many days before planting does agricultural burning occur for (name of 1st crop)? How about for (name of 2nd crop)? Read list of remaining selected crops.

Let's now turn to harvesting. Typically, how many days after harvesting does agricultural burning occur for (name of 1st crop)? For (name of 2rd crop)? Read list of remaining selected crops.

		1. Before Planting	2. After Harvesting
a.	Corn	_____	_____
b.	Wheat	_____	_____
c.	Sorghum	_____	_____
d.	Rice	_____	_____
e.	Other cereal crops	_____	_____
f.	Soybeans	_____	_____
g.	Sugarcane	_____	_____
h.	Hay or alfalfa	_____	_____
i.	Cotton	_____	_____
j.	Other crops not previously mentioned	_____	_____
k.	Grazed rangelands	_____	_____

888 = DON'T KNOW
999 = REFUSED

Q16. For each crop, please tell me whether agricultural burning usually occurs during weekdays, weekends, or both weekdays and weekends? (Programmer note: 1 data output column only; Weekdays=1, Weekends=2, Both=3)

a. Corn	_____
b. Wheat	_____
c. Sorghum	_____
d. Rice	_____
e. Other cereal crops	_____
f. Soybeans	_____
g. Sugarcane	_____
h. Hay or alfalfa	_____
i. Cotton	_____
j. Other crops not previously mentioned	_____
k. Grazed rangelands	_____

8 = DON'T KNOW
9 = REFUSED

Q17. For each crop, please tell me whether crop residue is typically burned in your county during daytime, nightime, or both daytime and nighttime hours? (Programmer note: 1 data output column only; Daytime=1, Nightime=2, Both=3)

a. Corn	_____
b. Wheat	_____
c. Sorghum	_____
d. Rice	_____
e. Other cereal crops	_____
f. Soybeans	_____
g. Sugarcane	_____
h. Hay or alfalfa	_____
i. Cotton	_____
j. Other crops not previously mentioned	_____
k. Grazed rangelands	_____

8 = DON'T KNOW
9 = REFUSED

<If Q17 Eq 3, go to Q18. If Q17 Eq 1, 2, 8, or 9, go to Q19>

Q18. For each crop, please tell me what percent of crop residue is burned during daytime and nighttime hours? Let's start with (name of first crop). What percent of crop residue burning for this crop occurs in the daytime and what percent occurs in the nighttime?

	1. % Daytime	2. % Nighttime
a. Corn	_____	_____
b. Wheat	_____	_____
c. Sorghum	_____	_____
d. Rice	_____	_____
e. Other cereal crops	_____	_____
f. Soybeans	_____	_____
g. Sugarcane	_____	_____
h. Hay or alfalfa	_____	_____
i. Cotton	_____	_____
j. Other crops not previously mentioned	_____	_____
k. Grazed rangelands	_____	_____

888 = DON'T KNOW
999 = REFUSED

<NOTE: For Q18a1 through Q18k2, daytime % and nighttime % must add to 100% or question must be re-asked>

Q19. For the following crops, please tell me whether headfires, backfires, or both types of fires are used. Headfires are burning in the direction of the wind and backfires are burning in a direction opposite to the wind. (Programmer note: 1 data output column only; Headfire=1, Backfire=2, Both=3)

a. Hay or alfalfa _____
b. Soybeans _____
c. Wheat _____

8 = DON'T KNOW
9 = REFUSED

Q20. What agency or agencies regulate agricultural burning in your county? (Probe: Is that a state or county agency?) Can I get the telephone number as well?

a. ____

b. ____

888 = DON'T KNOW
999 = REFUSED

<Go to THANK YOU>

<u>THANK YOU</u>: Those are all the questions. Thank you for your time. Goodbye.

APPENDIX B

VEGETATION CROSS-WALKS

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List of Crops included in the BELD Database for each CENRAP State

STATE	ST_NAME	INDEX	GENUS
05	ARKANSAS	24	CORN
05	ARKANSAS	25	COTTON
05	ARKANSAS	27	HAY
05	ARKANSAS	28	MISC_CROP
05	ARKANSAS	29	OATS
05	ARKANSAS	31	PEANUTS
05	ARKANSAS	32	POTATOES
05	ARKANSAS	33	RICE
05	ARKANSAS	35	SORGHUM
05	ARKANSAS	36	SOYBEANS
05	ARKANSAS	38	WHEAT
19	IOWA	23	BARLEY
19	IOWA	24	CORN
19	IOWA	27	HAY
19	IOWA	28	MISC_CROP
19	IOWA	29	OATS
19	IOWA	32	POTATOES
19	IOWA	34	RYE
19	IOWA	35	SORGHUM
19	IOWA	36	SOYBEANS
19	IOWA	38	WHEAT
20	KANSAS	22	ALFALFA
20	KANSAS	23	BARLEY
20	KANSAS	24	CORN
20	KANSAS	27	HAY
20	KANSAS	28	MISC_CROP
20	KANSAS	29	OATS
20	KANSAS	34	RYE
20	KANSAS	35	SORGHUM
20	KANSAS	36	SOYBEANS
20	KANSAS	37	TOBACCO
20	KANSAS	38	WHEAT
22	LOUISIANA	24	CORN
22	LOUISIANA	25	COTTON
22	LOUISIANA	27	HAY
22	LOUISIANA	28	MISC_CROP
22	LOUISIANA	29	OATS
22	LOUISIANA	31	PEANUTS
22	LOUISIANA	32	POTATOES
22	LOUISIANA	33	RICE
22	LOUISIANA	35	SORGHUM
22	LOUISIANA	36	SOYBEANS
22	LOUISIANA	38	WHEAT
27	MINNESOTA	22	ALFALFA
27	MINNESOTA	23	BARLEY
27	MINNESOTA	24	CORN
27	MINNESOTA	27	HAY
27	MINNESOTA	28	MISC_CROP
27	MINNESOTA	29	OATS
27	MINNESOTA	32	POTATOES
27	MINNESOTA	33	RICE
27	MINNESOTA	34	RYE
27	MINNESOTA	36	SOYBEANS
27	MINNESOTA	38	WHEAT

Unique Crops
ALFALFA
BARLEY
CORN
COTTON
HAY
MISC_CROP
OATS
PEANUTS
POTATOES
RICE
RYE
SORGHUM
SOYBEANS
TOBACCO
WHEAT

List of Crops included in the BELD Database for each CENRAP State

STATE	ST_NAME	INDEX	GENUS
29	MISSOURI	23	BARLEY
29	MISSOURI	24	CORN
29	MISSOURI	25	COTTON
29	MISSOURI	27	HAY
29	MISSOURI	28	MISC_CROP
29	MISSOURI	29	OATS
29	MISSOURI	31	PEANUTS
29	MISSOURI	32	POTATOES
29	MISSOURI	33	RICE
29	MISSOURI	34	RYE
29	MISSOURI	35	SORGHUM
29	MISSOURI	36	SOYBEANS
29	MISSOURI	37	TOBACCO
29	MISSOURI	38	WHEAT
31	NEBRASKA	22	ALFALFA
31	NEBRASKA	23	BARLEY
31	NEBRASKA	24	CORN
31	NEBRASKA	27	HAY
31	NEBRASKA	28	MISC_CROP
31	NEBRASKA	29	OATS
31	NEBRASKA	32	POTATOES
31	NEBRASKA	34	RYE
31	NEBRASKA	35	SORGHUM
31	NEBRASKA	36	SOYBEANS
31	NEBRASKA	38	WHEAT
40	OKLAHOMA	22	ALFALFA
40	OKLAHOMA	23	BARLEY
40	OKLAHOMA	24	CORN
40	OKLAHOMA	25	COTTON
40	OKLAHOMA	27	HAY
40	OKLAHOMA	28	MISC_CROP
40	OKLAHOMA	29	OATS
40	OKLAHOMA	31	PEANUTS
40	OKLAHOMA	32	POTATOES
40	OKLAHOMA	34	RYE
40	OKLAHOMA	35	SORGHUM
40	OKLAHOMA	36	SOYBEANS
40	OKLAHOMA	38	WHEAT
48	TEXAS	22	ALFALFA
48	TEXAS	23	BARLEY
48	TEXAS	24	CORN
48	TEXAS	25	COTTON
48	TEXAS	27	HAY
48	TEXAS	28	MISC_CROP
48	TEXAS	29	OATS
48	TEXAS	31	PEANUTS
48	TEXAS	32	POTATOES
48	TEXAS	33	RICE
48	TEXAS	34	RYE
48	TEXAS	35	SORGHUM
48	TEXAS	36	SOYBEANS
48	TEXAS	38	WHEAT

Unique Crops

Cross-walk of BELD Vegetation Types to FOFEM Forest Classification Types

BELD	Genus	Species	FOFEM ID	FOFEM Cover Description
26	GRASSLAND	----	SRM 215	Valley Grassland (Annual Grassland)
30	RANGELAND	----	SRM 215	Valley Grassland (Annual Grassland)
39	ACACIA	----	SAF 70	Longleaf Pine - rough age 3
40	AILANTHUS	ALTISSIMA	SAF 70	Longleaf Pine - rough age 3
41	ALNUS	RUBRA	NVCS 1371	Alnus rubra Forest
42	MALUS	----	SAF 70	Longleaf Pine - rough age 3
43	FRAXINUS	AMERICANA	NVCS 2030	Acer saccharinum - Fraxinus americana - Tilia americana Forest
44	TILIA	AMERICANA	NVCS 1360	Acer saccharum - Tilia americana - (Quercus rubra) Forest
45	FAGUS	GRANDIFOLIA	NVCS 1420	Fagus grandifolia - Acer saccharum - (Liriodendron tulipifera) Forest
46	BETULA	NIGRA	SAF 70	Longleaf Pine - rough age 3
47	BUMELIA	LANUGINOSA	SAF 70	Longleaf Pine - rough age 3
48	MELALEUCA	QUINQUENERVIA	SAF 70	Longleaf Pine - rough age 3
49	UMBELLULARIA	CALIFORNICA	SAF 70	Longleaf Pine - rough age 3
51	CASTANEA	DENTATA	SAF 70	Longleaf Pine - rough age 3
52	CATALPA	----	SAF 70	Longleaf Pine - rough age 3
53	CHAMAECYPARIS	NOOTKATENSIS	NVCS 660	Chamaecyparis nootkatensis Forest
54	THUJA	OCCIDENTALIS	SAF 83	Longleaf Pine - Slash Pine - rough age 3
55	AESCULUS	OCTANDRA	SAF 70	Longleaf Pine - rough age 3
56	MELIA	AZEDARACH	SAF 70	Longleaf Pine - rough age 3
58	TAXODIUM	MUCRONATUM	SAF 70	Longleaf Pine - rough age 3
59	CORNUS	FLORIDA	SAF 70	Longleaf Pine - rough age 3
60	PSEUSOTSUGA	MENZIESII	SAF 70	Longleaf Pine - rough age 3
61	OSTRYA	VIRGINIANA	NVCS 5370	Juniperus virginiana - (Fraxinus americana, ostrya virginiana) Woodland
63	ULMUS	AMERICANA	NVCS 2310	Quercus texana,Celtis laevigata,Ulmus(americana,crassifolia),Gleditsia tricanthos)
64	EUCALYPTUS	----	SAF 70	Longleaf Pine - rough age 3
65	ABIES	BALSAMEA	SAF 51	White Pine - Chestnut Oak
66	ABIES	MAGNIFICA	NVCS 631	Abies magnifica Forest
67	ABIES	LASIOCARPA	NVCS 881	Abies lasiocarpa Forest
69	ABIES	GRANDIS	NVCS 621	Abies grandis Forest
70	ABIES	PROCERA	SAF 70	Longleaf Pine - rough age 3
71	ABIES	AMABILIS	NVCS 570	Abies amabilis - Abies concolor Forest
73	ABIES	MAGNIFICA SHASTENSIS	SAF 70	Longleaf Pine - rough age 3
74	ABIES	----	SAF 70	Longleaf Pine - rough age 3
75	ABIES	LASIOCARPA ARIZONICA	SAF 70	Longleaf Pine - rough age 3
76	ABIES	CONCOLOR	NVCS 570	Abies amabilis - Abies concolor Forest
77	GLEDITSIA	TRIACANTHOS	SAF 70	Longleaf Pine - rough age 3
78	CELTIS	OCCIDENTALIS	SRM 604	Bluestem - Grama Prairie
79	CRATAEGUS	----	SAF 70	Longleaf Pine - rough age 3

BELD	Genus	Species	FOFEM ID	FOFEM Cover Description
80	TSUGA	----	SAF 70	Longleaf Pine - rough age 3
81	CARYA	OVATA	NVCS 1380	Carya (glabra, ovata) - Fraxinus americana - Quercus (alba, rubra) Forest
82	ILEX	OPACO	SAF 70	Longleaf Pine - rough age 3
83	CARPINUS	CAROLINIANA	SAF 70	Longleaf Pine - rough age 3
84	CALOCEDRUS	DECURRENS	NVCS 650	Calocedrus decurrens - Pseudotsuga menziesii Forest
85	JUNIPERUS	VIRGINIANA	NVCS 5370	Juniperus virginiana - (Fraxinus americana, ostrya virginiana) Woodland
86	GYMNOCLADUS	DIOICUS	SAF 70	Longleaf Pine - rough age 3
87	LARIX	LARICINA	SAF 98	Pond Pine
88	GORDONIA	LASIANTHUS	SAF 70	Longleaf Pine - rough age 3
89	ARBUTUS	MENZIESII	NVCS 790	Pseudotsuga menziesii - Arbutus menziesii Forest
90	MAGNOLIA	GRANDIFLORA	SRM 910	Hairgrass
91	CERCOCARPUS	LEDIFOLIUS	NVCS 6461	Cercocarpus ledifolius Shrubland
92	ACER	GRANDIDENTATUM	NVCS 1301	Acer grandidentatum Lowland Forest
93	ACER	MACROPHYLLUM	NVCS 3350	Pseudotsuga menziesii - Acer macrophyllum Forest
94	ACER	NIGRUM	SAF 27	Sugar Maple
95	ACER	NEGUNDO	SRM 404	Threetip Sagebrush
96	ACER	BARBATUM	SAF 70	Longleaf Pine - rough age 3
97	ACER	SPICATUM	SAF 70	Longleaf Pine - rough age 3
98	ACER	PLATANOIDES	SAF 70	Longleaf Pine - rough age 3
99	ACER	RUBRUM	NVCS 5270	Acer rubrum Saturated Woodland
100	ACER	GLABRUM	SAF 70	Longleaf Pine - rough age 3
101	ACER	SACCHARINUM	NVCS 2030	Acer saccharinum - Fraxinus americana - Tilia americana Forest
103	ACER	PENSYLVANICUM	SAF 70	Longleaf Pine - rough age 3
104	ACER	SACCHARUM	NVCS 1320	Acer saccharum - Betula alleghaniensis - (Fagus grandifolia) Forest
105	PROSOPIS	----	SAF 70	Longleaf Pine - rough age 3
106	MISCELLANEOUS	HD SPP	SAF 70	Longleaf Pine - rough age 3
108	SORBUS	AMERICANA	SAF 70	Longleaf Pine - rough age 3
109	MORUS	RUBRA	SAF 70	Longleaf Pine - rough age 3
110	NYSSA	SYLVATICA	SAF 70	Longleaf Pine - rough age 3
111	QUERCUS	ARIZONICA	SAF 70	Longleaf Pine - rough age 3
112	QUERCUS	ILICIFOLIA	NVCS 7200	Quercus ilicifolia Shrubland
113	QUERCUS	VELUTINA	NVCS 3320	Pinus virginiana - Quercus (alba, stellata, falcata, velutina) Forest
114	QUERCUS	MARILANDICA	NVCS 3000	Juniperus virginiana - Quercus (stellata, velutina, marilandica) Forest
115	QUERCUS	DOUGLASII	SAF 70	Longleaf Pine - rough age 3
116	QUERCUS	INCANA	NVCS 5320	Quercus hemisphaerica - Quercus margarettiae - Quercus incana Woodland
117	QUERCUS	MACROCARPA	NVCS 11951	Quercus macrocarpa - (Quercus alba) Wooded Herbland
118	QUERCUS	KELLOGGII	NVCS 5130	Quercus kelloggii Temporarily Flooded Woodland
119	QUERCUS	AGRIFOLIA	SAF 70	Longleaf Pine - rough age 3

BELD	Genus	Species	FOFEM ID	FOFEM Cover Description
120	QUERCUS	LOBATA	NVCS 4940	Quercus lobata Woodland
121	QUERCUS	CHRYSOLEPIS	SAF 59	Yellow Poplar - White Oak - Northern Red Oak
122	QUERCUS	PRINUS	NVCS 3330	Pinus virginiana - Quercus (coccinea, prinus) Forest
123	QUERCUS	MUEHLENBERGII	NVCS 2990	Juniperus virginiana - Quercus (muehlenbergii, stellata) Forest
124	QUERCUS	STELLATA	NVCS 2990	Juniperus virginiana - Quercus (muehlenbergii, stellata) Forest
125	QUERCUS	DURANDII	SAF 70	Longleaf Pine - rough age 3
126	QUERCUS	EMORYI	SAF 70	Longleaf Pine - rough age 3
127	QUERCUS	ENGELMANNII	SAF 70	Longleaf Pine - rough age 3
128	QUERCUS	----	SAF 70	Longleaf Pine - rough age 3
129	QUERCUS	GAMBELII	NVCS 7181	Quercus gambelii Shrubland
130	QUERCUS	WISLIZENNI	SAF 70	Longleaf Pine - rough age 3
131	QUERCUS	LAURIFOLIA	NVCS 3460	Pinus taeda - Quercus (phellos, nigra, laurifolia)
132	QUERCUS	VIRGINIANA	SAF 22	White Pine - Hemlock
133	QUERCUS	OBLONGIFOLIA	SAF 70	Longleaf Pine - rough age 3
134	QUERCUS	ELLIPSOIDALIS	NVCS 11960	Quercus velutina - (Quercus ellipsoidalis) Wooded Herbland
135	QUERCUS	RUBRA	NVCS 1360	Acer saccharum - Tilia americana - (Quercus rubra) Forest
136	QUERCUS	NUTTALLII	SAF 70	Longleaf Pine - rough age 3
137	QUERCUS	GARRYANA	NVCS 5510	Pseudotsuga menziesii - Quercus garryana Woodland
138	QUERCUS	LYRATA	NVCS 2550	Quercus lyrata - (Carya aquatica) Seasonally Flooded Forest
139	QUERCUS	PALUSTRIS	NVCS 2560	Quercus palustris - (Quercus bicolor) Seasonally Flooded Forest
140	QUERCUS	STELLATA	NVCS 1570	Quercus alba - Quercus (falcata, stellata) Forest
141	QUERCUS	COCCINEA	NVCS 1590	Quercus coccinea - Quercus falcata Forest
142	QUERCUS	----	SAF 70	Longleaf Pine - rough age 3
143	QUERCUS	IMBRICARIA	SAF 70	Longleaf Pine - rough age 3
144	QUERCUS	SHUMARDII	NVCS 3450	Pinus taeda - Quercus (pagoda, michauxii, shumardii)
145	QUERCUS	HYPOLEUCOIDES	SAF 70	Longleaf Pine - rough age 3
146	QUERCUS	FALCATA	NVCS 3280	Pinus taeda - Quercus (alba, falcata, stellata) Forest
147	QUERCUS	----	SAF 70	Longleaf Pine - rough age 3
148	QUERCUS	MICHAUXII	NVCS 2760	Quercus michauxii - Quercus pagoda Saturated Forest
149	QUERCUS	FALCATA	NVCS 3200	Pinus palustris,Pinus(echinata,taeda),Quercus(incana,margarettiae,falcata,laevis
150	QUERCUS	BICOLOR	NVCS 2260	Quercus macrocarpa - Quercus bicolor - (Carya laciniosa)
151	QUERCUS	LAEVIS	NVCS 1610	Quercus laevis Forest
152	QUERCUS	NIGRA	NVCS 3460	Pinus taeda - Quercus (phellos, nigra, laurifolia)
153	QUERCUS	ALBA	NVCS 1540	Quercus alba - (Quercus nigra) Forest
154	QUERCUS	PHELLOS	NVCS 2300	Quercus phellos - Ulmus crassifolia
155	MACLURA	POMIFERA	SAF 70	Longleaf Pine - rough age 3
156	PAULOWNIA	TOMENTOSA	SAF 70	Longleaf Pine - rough age 3
157	ASIMINA	TRILOBA	SAF 70	Longleaf Pine - rough age 3

BELD	Genus	Species	FOFEM ID	FOFEM Cover Description
158	DIASPYROS	VIRGINIANA	SAF 70	Longleaf Pine - rough age 3
162	PINUS	MURICATA	SAF 70	Longleaf Pine - rough age 3
164	PINUS	ARISTATA	NVCS 3931	Pinus aristata Woodland
165	PINUS	LEIOPHYLLA	SAF 70	Longleaf Pine - rough age 3
166	PINUS	COULTERI	SAF 70	Longleaf Pine - rough age 3
167	PINUS	SABINIANA	SAF 70	Longleaf Pine - rough age 3
168	PINUS	STROBUS	NVCS 530	Pinus strobus Forest
169	PINUS	BALFOURIANA	SAF 70	Longleaf Pine - rough age 3
170	PINUS	BANKSIANA	NVCS 390	Pinus banksiana Forest
171	PINUS	JEFFERYI	SAF 70	Longleaf Pine - rough age 3
172	PINUS	ATTENUATA	NVCS 3940	Pinus attenuata Woodland
173	PINUS	FLEXILIS	NVCS 4051	Pinus flexilis Woodland
174	PINUS	TAEDA	NVCS 550	Pinus taeda Forest
175	PINUS	CONTORTA	NVCS 411	Pinus contorta Forest
176	PINUS	PALUSTRIS	NVCS 3200	Pinus palustris,Pinus(echinata,taeda),Quercus(incana,margarettiae,falcata,laevis
177	PINUS	RADIATA	SAF 84	Slash Pine - rough age 3
178	PINUS	MONOPHYLLA	NVCS 4091	Pinus monophylla Woodland
179	PINUS	DISCOLOR	NVCS 4011	Pinus discolor Woodland
180	PINUS	EDULIS	NVCS 431	Pinus edulis Forest
181	PINUS	RIGIDA	NVCS 4230	Pinus virginiana - Pinus rigida Woodland
182	PINUS	SEROTINA	NVCS 4620	Pinus palustris - Pinus serotina Saturated Woodland
183	PINUS	PONDEROSA	NVCS 481	Pinus ponderosa - Pseudotsuga menziesii Forest
184	PINUS	RESINOSA	NVCS 510	Pinus resinosa Forest
185	PINUS	CLAUSA	NVCS 400	Pinus clausa Forest
186	PINUS	SYLVESTRIS	SAF 70	Longleaf Pine - rough age 3
187	PINUS	ECHINATA	NVCS 420	Pinus echinata Forest
188	PINUS	ELLIOTTII	NVCS 250	Pinus elliottii Tropical Forest
189	PINUS	GLABRA	SAF 70	Longleaf Pine - rough age 3
190	PINUS	LAMBERTIANA	SAF 70	Longleaf Pine - rough age 3
191	PINUS	STROBIFORMIS	SAF 70	Longleaf Pine - rough age 3
192	PINUS	PUNGENS	SAF 70	Longleaf Pine - rough age 3
193	PINUS	VIRGINIANA	NVCS 3310	Pinus virginiana - Liquidambar styraciflua - Liriodendron tulipifera Forest
195	PINUS	ALBICAULIS	NVCS 381	Pinus albicaulis Forest
196	PINUS	MONTICOLA	NVCS 451	Pinus monticola Forest
198	POPULUS	GRANDIDENTATA	SAF 70	Longleaf Pine - rough age 3
199	PRUNUS	----	SAF 70	Longleaf Pine - rough age 3
200	CERCIS	CANADENSIS	SAF 70	Longleaf Pine - rough age 3
201	ROBINIA	PSEUDOACACIA	SAF 70	Longleaf Pine - rough age 3

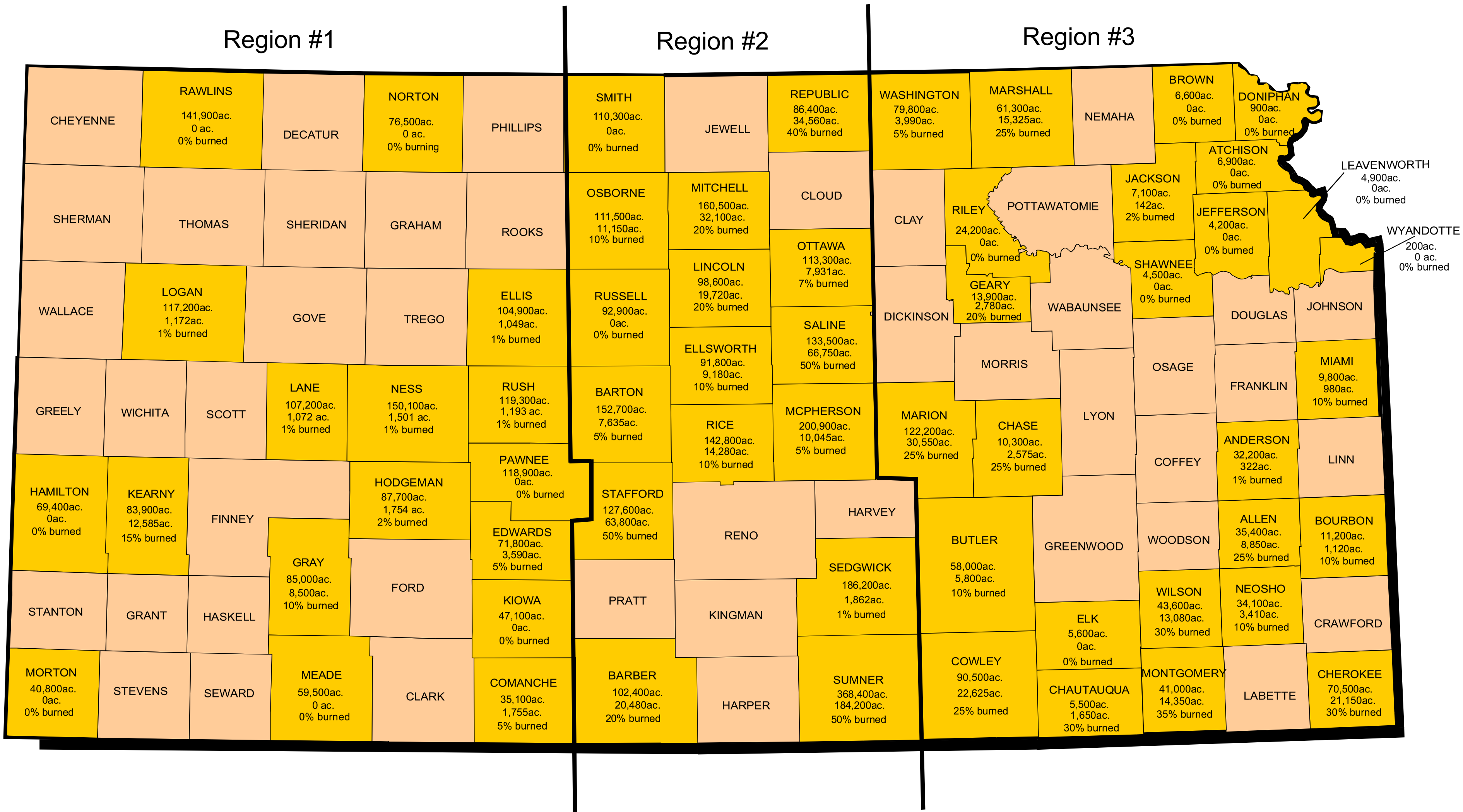
BELD	Genus	Species	FOFEM ID	FOFEM Cover Description
202	SASSAFRAS	ALBIDUM	SAF 70	Longleaf Pine - rough age 3
203	SEQUOIA	SEMPERVIRENS	NVCS 310	Sequoia sempervirens - Tsuga heterophylla Forest
204	AMELANCHIER	ARBOREA	SAF 70	Longleaf Pine - rough age 3
205	HALESIA	----	SAF 70	Longleaf Pine - rough age 3
206	COTINUS	OBOVATUS	SAF 70	Longleaf Pine - rough age 3
207	SAPINDUS	DRUMMONDII	SAF 70	Longleaf Pine - rough age 3
208	OXYDENDRUM	ARBORETUM	SAF 70	Longleaf Pine - rough age 3
209	VACCINIUM	ARBOREUM	SAF 70	Longleaf Pine - rough age 3
210	PICEA	MARIANNA	SAF 70	Longleaf Pine - rough age 3
211	PICEA	PUNGENS	NVCS 731	Picea pungens Forest
212	PICEA	BREWERIANA	SAF 70	Longleaf Pine - rough age 3
213	PICEA	ENGELMANNII	NVCS 691	Picea engelmannii Forest
214	PICEA	ABIES	SAF 70	Longleaf Pine - rough age 3
215	PICEA	RUBENS	SAF 84	Slash Pine - rough age 3
216	PICEA	SITCHENSIS	NVCS 760	Picea sitchensis Forest
217	PICEA	----	SAF 70	Longleaf Pine - rough age 3
218	PICEA	GLAUCA	NVCS 711	Picea glauca Forest
219	LIQUIDAMBAR	STYRACIFLUA	NVCS 3270	Pinus taeda - (Liquidambar styraciflua - Liriodendron tulipifera) Forest
220	PLATANUS	OCCIDENTALIS	NVCS 3440	Pinus taeda - Platanus occidentalis - Acer negundo Temporarily Flooded Forest
221	SAPIUM	SEBIFERUM	SAF 70	Longleaf Pine - rough age 3
222	TAMARIX	CHINENSIS	SAF 70	Longleaf Pine - rough age 3
223	LITHOCARPUS	DENSIFLORUS	SAF 70	Longleaf Pine - rough age 3
224	TORREYA	CALIFORNICA	SAF 70	Longleaf Pine - rough age 3
225	ALEURITES	FORDII	SAF 70	Longleaf Pine - rough age 3
226	UNKNOWN	----	SAF 70	Longleaf Pine - rough age 3
227	JUGLANS	NIGRA	SAF 70	Longleaf Pine - rough age 3
228	PLANERA	AQUATICA	SRM 723	Sea Oats
229	SALIX	NIGRA	SAF 104	Sweetbay - Swamp Tupelo - Redbay
230	LIRIODENDRON	TULIPIFERA	NVCS 1420	Tamarack
231	CLADRASTIS	LUTEA	SAF 70	Longleaf Pine - rough age 3

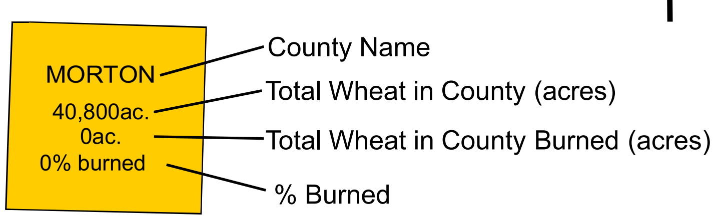
APPENDIX C

MAPS OF KANSAS AGRICULTURAL SUBREGIONS

KANSAS

Acres of Wheat Burned/Year



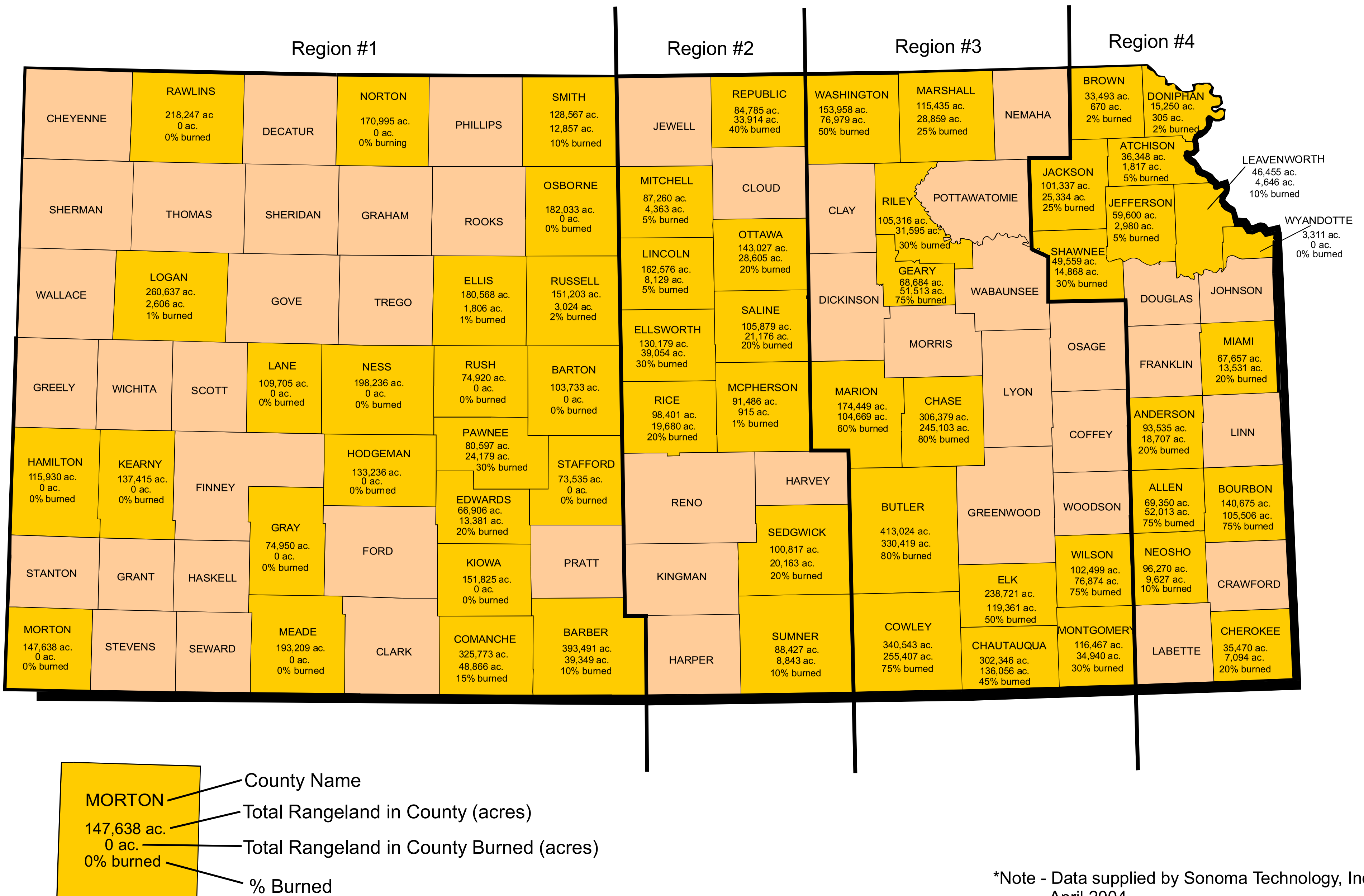


*Note - Data supplied by Sonoma Technology, Inc. April 2004

*Note - Wheat regions verified by Bill Hargrove at Kansas State University Agriculture Extension Office

KANSAS

Acres of Rangeland Burned/Year



*Note - Data supplied by Sonoma Technology, Inc
April 2004
Appendix A of Final Report (STI-902514-2516-FR)

APPENDIX B

TABULATION OF EMISSIONS ESTIMATES FOR THE CENRAP REGION

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Table B-1. Annual emissions by state and source category.

State	Burn Type	Acres Burned	Emissions (tons/year)						
			PM_{10}	$PM_{2.5}$	CO	NO_x	SO_2	NH_3	VOC
Arkansas	Prescribed Burning	244,146	28,130	23,838	302,219	1,961	1,577	2,910	17,444
	Rangeland Burning	3,061	62	52	307	44	15	7	29
	Cropland Burning	652,246	10,709	10,175	74,223	3,648	622	2,094	6,225
	Wheat	*354,209*	*5,968*	*5,691*	*40,116*	*1,514*	*202*	*1,077*	*2,798*
	Hay/Alfalfa	*8,050*	*73*	*70*	*599*	*18*	*2*	*13*	*40*
	Sugarcane	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
	Corn	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
	Soybeans	*67,398*	*2,564*	*2,445*	*14,342*	*379*	*51*	*270*	*1,818*
	Rice	*222,589*	*2,104*	*1,970*	*19,165*	*1,736*	*367*	*735*	*1,569*
	Other	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
	Total	899,453	38,901	34,065	376,749	5,653	2,214	5,011	23,698
Iowa	Prescribed Burning	21,449	4,072	3,457	44,542	166	195	257	2,547
	Rangeland Burning	0	0	0	0	0	0	0	0
	Cropland Burning	2,247	44	42	145	5	1	4	20
	Wheat	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
	Hay/Alfalfa	*1,660*	*29*	*27*	*81*	*3*	*0*	*2*	*13*
	Sugarcane		*0*	*0*	*0*	*0*	*0*	*0*	*0*
	Corn		*0*	*0*	*0*	*0*	*0*	*0*	*0*
	Soybeans		*0*	*0*	*0*	*0*	*0*	*0*	*0*
	Rice		*0*	*0*	*0*	*0*	*0*	*0*	*0*
	Other	*587*	*15*	*14*	*64*	*2*	*0*	*2*	*7*
	Total	23,696	4,116	3,498	44,688	171	195	261	2,567
Kansas	Prescribed Burning	38,106	1,450	1,226	14,424	228	114	143	881
	Rangeland Burning	3,625,270	75,943	52,901	652,250	23,185	10,160	7,487	43,483
	Cropland Burning	1,390,520	23,227	22,156	153,313	5,909	777	3,950	11,401
	Wheat	*1,058,014*	*17,420*	*16,610*	*118,902*	*4,523*	*603*	*3,216*	*8,194*
	Hay/Alfalfa	*189,085*	*2,252*	*2,148*	*12,701*	*408*	*54*	*290*	*1,143*
	Sugarcane	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
	Corn	*126,956*	*3,039*	*2,906*	*18,902*	*880*	*107*	*373*	*1,760*
	Soybeans	*9,996*	*210*	*200*	*1,252*	*34*	*5*	*24*	*154*
	Rice	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
	Other	*6,469*	*306*	*292*	*1,557*	*65*	*9*	*46*	*150*
	Total	5,053,896	100,620	76,283	819,987	29,322	11,052	11,579	55,765
Louisiana	Prescribed Burning	350,353	45,288	38,376	486,668	3,125	2,531	4,671	28,060
	Rangeland Burning	29,540	613	491	3,597	372	128	65	305
	Cropland Burning	456,901	7,771	7,397	66,203	3,474	482	2,388	6,762
	Wheat	*114,661*	*2,189*	*2,087*	*13,570*	*490*	*65*	*349*	*998*
	Hay/Alfalfa	*5,763*	*90*	*85*	*401*	*13*	*2*	*9*	*36*
	Sugarcane	*296,994*	*4,930*	*4,693*	*48,113*	*2,673*	*356*	*1,901*	*5,346*
	Corn	*5,817*	*139*	*133*	*866*	*40*	*5*	*17*	*81*

Table B-1. Annual emissions by state and source category.

State	Burn Type	Acres Burned	PM10	PM2.5	CO	NO_x	SO2	NH3	VOC
	Soybeans	*2,418*	*128*	*122*	*562*	*14*	*2*	*10*	*81*
	Rice	*31,248*	*295*	*277*	*2,691*	*244*	*52*	*103*	*220*
	Other	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
	Total	836,794	53,672	46,264	556,468	6,970	3,140	7,124	35,126
Minnesota	Prescribed Burning	86,642	17,222	14,609	187,853	742	836	1,150	10,740
	Rangeland Burning	17,314	358	216	3,904	16	25	33	228
	Cropland Burning	84,611	1,587	1,513	8,621	341	44	215	928
	Wheat	*7,962*	*132*	*126*	*897*	*34*	*5*	*24*	*62*
	Hay/Alfalfa	*28,503*	*402*	*383*	*1,565*	*56*	*8*	*40*	*211*
	Sugarcane	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
	Corn	*14,223*	*341*	*326*	*2,118*	*99*	*12*	*42*	*197*
	Soybeans	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
	Rice	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
	Other	*33,923*	*712*	*678*	*4,041*	*153*	*20*	*109*	*458*
	Total	188,567	19,167	16,338	200,378	1,100	905	1,398	11,895
Missouri	Prescribed Burning	64,781	7,460	6,338	80,019	536	417	756	4,633
	Rangeland Burning	109,160	2,281	1,763	15,244	1,182	415	228	1,182
	Cropland Burning	181,818	2,677	2,551	17,845	725	105	465	1,317
	Wheat	*94,279*	*1,546*	*1,474*	*10,581*	*403*	*54*	*287*	*728*
	Hay/Alfalfa	*63,545*	*767*	*732*	*4,590*	*143*	*19*	*102*	*353*
	Sugarcane	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
	Corn	*8,837*	*212*	*202*	*1,316*	*61*	*7*	*26*	*123*
	Soybeans	*458*	*13*	*12*	*92*	*3*	*0*	*2*	*10*
	Rice	*14,673*	*139*	*130*	*1,263*	*114*	*24*	*48*	*103*
	Other	*26*	*1*	*1*	*3*	*0*	*0*	*0*	*0*
	Total	355,759	12,419	10,652	113,107	2,443	937	1,448	7,132
Nebraska	Prescribed Burning	6,127	410	347	4,316	36	24	27	254
	Rangeland Burning	114,807	2,403	1,468	25,863	152	179	223	1,520
	Cropland Burning	100,719	2,244	2,140	14,439	491	65	330	1,430
	Wheat	*47,336*	*656*	*625*	*5,039*	*202*	*27*	*144*	*324*
	Hay/Alfalfa	*5,430*	*72*	*68*	*323*	*11*	*1*	*8*	*38*
	Sugarcane	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
	Corn	*9,430*	*226*	*216*	*1,404*	*65*	*8*	*28*	*131*
	Soybeans	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
	Rice	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
	Other	38,523	1,291	1,231	7,673	212	28	151	938
	Total	221,653	5,057	3,956	44,619	679	268	580	3,205
Oklahoma	Prescribed Burning	104,749	7,322	6,196	76,615	750	479	769	4,507
	Rangeland Burning	1,830,017	38,117	28,443	280,780	16,885	6,419	3,890	20,578

Emissions (tons/year): PM10 through VOC columns.

Table B-1. Annual emissions by state and source category.

State	Burn Type	Acres Burned	PM10	PM2.5	CO	NO_x	SO2	NH3	VOC
	Cropland Burning	473,342	7,114	6,785	47,157	1,760	234	1,234	3,414
	Wheat	*325,838*	*5,197*	*4,955*	*36,238*	*1,393*	*186*	*991*	*2,465*
	Hay/Alfalfa	*137,707*	*1,690*	*1,612*	*9,464*	*302*	*40*	*214*	*815*
	Sugarcane	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
	Corn	*8,879*	*213*	*203*	*1,322*	*62*	*7*	*26*	*123*
	Soybeans	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
	Rice	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
	Other	*918*	*15*	*14*	*133*	*4*	*0*	*3*	*11*
	Total	2,408,108	52,552	41,424	404,551	19,395	7,131	5,893	28,499
Texas	Prescribed Burning	137,310	12,669	10,732	134,423	1,071	757	1,427	7,824
	Rangeland Burning	3,576,810	101,580	71,407	1,033,500	12,979	8,637	12,114	61,961
	Cropland Burning	221,771	3,129	2,986	18,929	668	89	459	1,435
	Wheat	*39,472*	*729*	*695*	*4,615*	*169*	*22*	*120*	*334*
	Hay/Alfalfa	*161,566*	*1,895*	*1,808*	*11,711*	*364*	*49*	*258*	*887*
	Sugarcane	*501*	*8*	*8*	*81*	*5*	*1*	*3*	*9*
	Corn	*7,481*	*179*	*171*	*1,114*	*52*	*6*	*22*	*104*
	Soybeans	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
	Rice	*640*	*6*	*6*	*55*	*5*	*1*	*2*	*5*
	Other	*12,111*	*312*	*298*	*1,352*	*75*	*10*	*53*	*97*
	Total	3,935,891	117,378	85,125	1,186,851	14,718	9,482	14,000	71,220
All States	Prescribed Burning	1,053,663	124,023	105,119	1,331,080	8,615	6,929	12,111	76,889
	Rangeland Burning	9,305,979	221,357	156,742	2,015,445	54,815	25,977	24,046	129,287
	Cropland Burning	3,564,175	58,501	55,744	400,874	17,021	2,418	11,139	32,931
	Wheat	*2,041,771*	*33,836*	*32,263*	*229,956*	*8,729*	*1,164*	*6,207*	*15,903*
	Hay/Alfalfa	*601,309*	*7,269*	*6,934*	*41,436*	*1,318*	*176*	*937*	*3,535*
	Sugarcane	*297,495*	*4,938*	*4,700*	*48,194*	*2,678*	*357*	*1,904*	*5,355*
	Corn	*181,623*	*4,348*	*4,157*	*27,041*	*1,259*	*152*	*534*	*2,517*
	Soybeans	*80,270*	*2,915*	*2,779*	*16,248*	*429*	*57*	*305*	*2,062*
	Rice	*269,150*	*2,544*	*2,382*	*23,174*	*2,099*	*444*	*888*	*1,898*
	Other	*92,557*	*2,652*	*2,528*	*14,824*	*510*	*67*	*364*	*1,661*
	Total	13,923,817	403,882	317,605	3,747,399	80,451	35,324	47,295	239,107

Emissions columns (PM10 through VOC) are in tons/year.

APPENDIX C

ASSESSMENT OF INFLUENCE FROM PRESCRIBED BURNING ON CLASS I SITES USING AMBIENT SPECIATED $PM_{2.5}$ DATA

C.1 OBJECTIVE AND APPROACH

The objective of this task was to use ambient speciated $PM_{2.5}$ data from Class I areas (from the 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 The following approach was employed:

- Assess the seasonal chemical compositions of $PM_{2.5}$ mass and aerosol light extinction in order 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 nearby a monitoring site in order to assess whether wood smoke influences are seen in the ambient measurements and significantly impacts visibility.
- Analyze emissions data on days when elevated OC, EC and K concentrations occurred at IMPROVE sites in order 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

C.2 AMBIENT MONITORING DATA

We analyzed ambient monitoring data from IMPROVE stations in order to assess the potential effect of prescribed burning emissions on visibility in the CENRAP region. We used ambient data from two IMPROVE stations located in Arkansas, Caney Creek (CACR1) and Upper Buffalo Wilderness (UPBU1). At the time of analysis, these sites were located in the area with the highest resolved fire histories, which would allow the best chance of showing direct influence between prescribed burning and ambient Class 1 data. **Figure C-1** shows the locations of IMPROVE stations in the CENRAP region, along with the point locations of prescribed burns that were available from the 2002 emissions inventory.

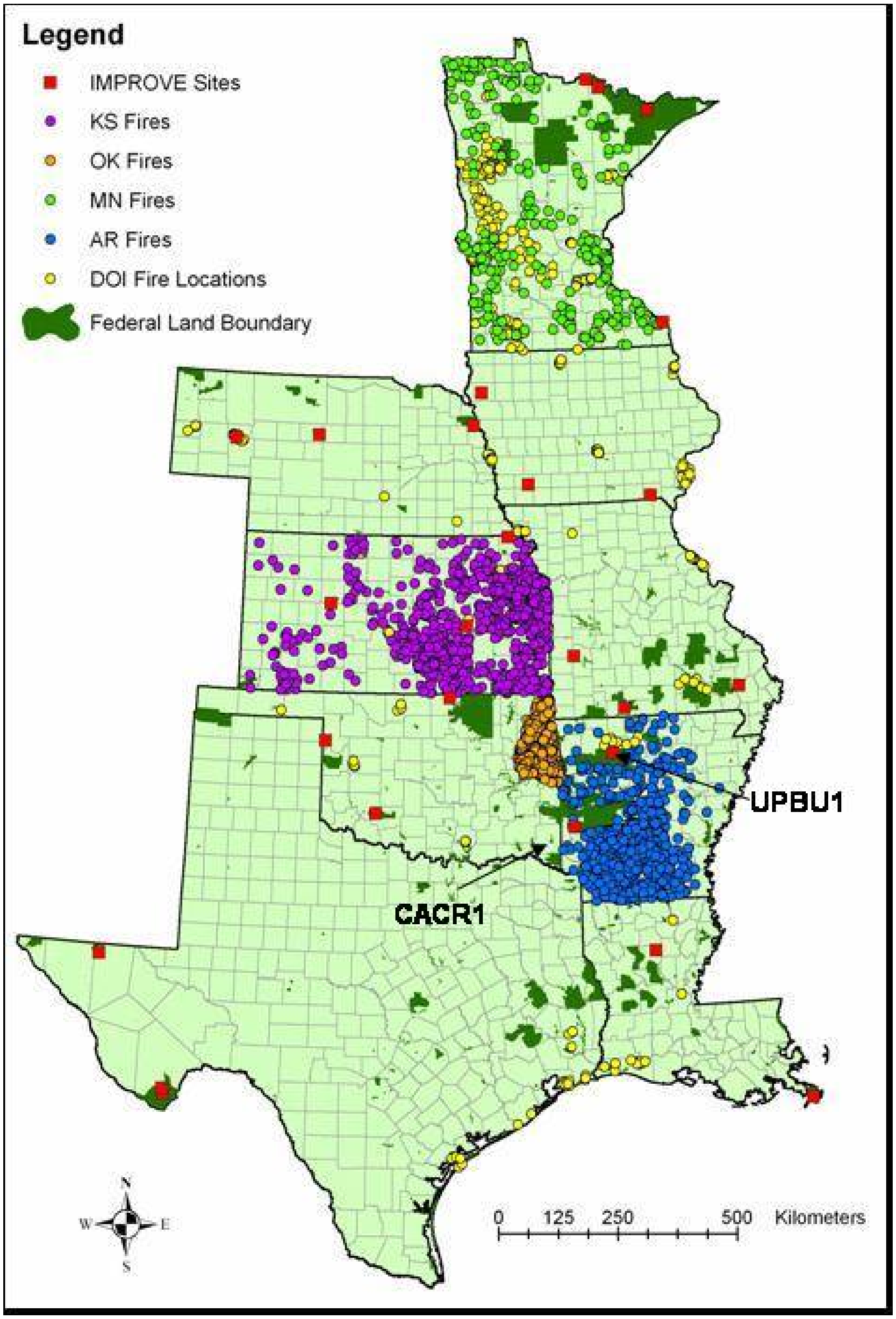


Figure C-1. IMPROVE station and fire locations.

We acquired data from the two ambient monitoring stations from the online IMPROVE database (http://vista.cira.colostate.edu/improve/). Specifically, we obtained values of all available parameters for the years 2000, 2001, and 2002, during which years the IMPROVE network collected 24-hr samples once every three days. Although the emissions inventory included fires only from 2002, IMPROVE data from all three years were used to ensure a robust statistical analysis of seasonal and annual aerosol compositions and species ratios. **Table C-1** summarizes the number of complete samples that we obtained from the IMPROVE database for 2000 through 2002 and for 2002 alone. The complete samples were cases in which all key species in our analysis were available: elemental carbon (EC), organic carbon (OC), potassium (K), ammonium nitrate (NH_4NO_3), and ammonium sulfate ($(NH_4)_2SO_4$).

Table C-1. Number of complete samples available from 2000–2002 and from 2002 at Caney Creek and Upper Buffalo Wilderness.

Site	N samples (2000 – 2002)	N samples (2002)
Caney Creek	254	110
Upper Buffalo Wilderness	318	117

In analyzing the ambient monitoring data with respect to fire activity data, we focused on species that generally characterize fine particulate aerosols and species that derive from wood smoke: elemental carbon (EC), organic carbon mass (OCM), ammonium nitrate (NH_4NO_3), ammonium sulfate ($(NH_4)_2SO_4$), potassium (K), non-soil potassium (KNS), and a composite of species that derive from soils (GEO). Several of the parameters were calculated from measured values according to IMPROVE protocol, as summarized in **Table C-2**.

Table C-2. IMPROVE algorithms for mass concentrations of fine aerosol species.

Species	Abbreviation	IMPROVE Calculation
Organic Carbon Mass	OCM	1.4*[organic carbon]
Ammonium Nitrate	NH_4NO_3	1.29*[nitrate]
Ammonium Sulfate	$(NH_4)_2SO_4$	4.125*[sulfur]
Non-soil Potassium	KNS	[potassium]-0.6*[iron]
Soil Elements	Soil	2.20*[aluminum]+2.49*[silicon]+1.63*[calcium] +2.42*[iron]+1.94*[titanium]

The IMPROVE algorithm for OCM adjusts the measured OC value for other elements associated with carbon molecules, such as oxygen and hydrogen, and it relies on the assumption that the average organic molecule contains 70% carbon. The ammonium nitrate and ammonium sulfate algorithms assume that nitrate and sulfate ions are fully neutralized by NH_4^+. The ammonium sulfate algorithm also assumes that all elemental sulfur is in the form of sulfate, and it converts the mass of elemental sulfur to ammonium sulfate using 4.125, which is the ratio of the molecular weight of ammonium sulfate (132 g/mol) to the molecular weight of elemental sulfur (32 g/mol). Similarly, the ammonium nitrate algorithm multiplies the nitrate concentration by the ratio (1.29) of the molecular weight of ammonium nitrate (80 g/mol) to the molecular weight of nitrate (62 g/mol). The non-soil potassium (KNS) algorithm results from the observed ratio (0.6) of potassium to iron in soils. The residual, non-soil potassium (KNS) is assumed to derive from smoke. Lastly, the soil algorithm includes the sum of soil-derived elements, adjusted by coefficients that account for their normal oxides.

The IMPROVE network utilizes the measured mass concentrations of OCM, EC, $(NH_4)_2SO_4$, NH_4NO_3, and soil components to estimate the light extinction resulting from each species. Light extinction values associated with the individual species are summed to reconstruct an overall aerosol extinction parameter (b_{ext}). The IMPROVE extinction calculations account for scattering, absorption, and the effects of relative humidity, as illustrated by equations listed in **Table C-3**. The coefficients represent the dry scattering efficiencies of the compounds, except the coefficient for the EC algorithm, which represents the light absorbing efficiency of EC. F_T(RH) equals an empirically determined relative humidity correction factor that accounts for the hygroscopic nature of the ionic aerosol species.

Table C-3. IMPROVE algorithms for light extinctions of fine aerosol species.

Species	Abbreviation	IMPROVE Calculation
Organic Carbon Mass	OCM Extinction	4*[organic carbon]
Ammonium Nitrate	NH_4NO_3 Extinction	3*F_T(RH)*[nitrate]
Ammonium Sulfate	$(NH_4)_2SO_4$ Extinction	3*F_T(RH)*[sulfur]
Elemental Carbon	EC Extinction	10*[elemental carbon]
Soil Elements	Soil Extinction	1*[Soil]

C.3 DATA VALIDATION

Data validation helps to prevent serious errors in data analysis and modeling results by identifying erroneous individual data values. The $PM_{2.5}$ Data Analysis Workbook contains the guidelines that we employ for PM data validation (Main and Roberts, 2001). The validation incorporates internal consistency checks of ambient monitoring data, such as the comparison of species concentrations using scatter plots, the calculation of reconstructed particulate mass, and the preparation of material balances. Scatter plots that illustrate the relationships between well characterized species enable data analysts to quickly inspect data and identify any suspect points that may require further attention. Scatter plots also provide a general overview of a data set and preliminary data analysis. Plots that compare species from common sources, such as soil, or from different analytical techniques, such as ion chromatography (IC) or x-ray fluorescence (XRF), can target outlying data points that may indicate an unusual event or an equipment problem. Plots between reconstructed mass and measured mass or between cations and anions help the analyst to visually assess data completeness and to validate data resulting from different measurement techniques. We generated a number of scatter plots using SYSTAT statistical software in an effort to validate the IMPROVE data before performing the comparative analysis. **Table C-4** summarizes the species we inspected using scatter plots, along with their expected relationships and typical sources.

The data quality was good, as IMPROVE data is quality controlled prior to being incorporated into the database; thus, minimal effort was required. The data validation plots explored include 2000 through 2002 data for both Caney Creek and Upper Buffalo Wilderness. The data from both sites exhibit similar relationships between measured species. **Figure C-2** illustrates the comparison between sulfur (S) and sulfate (SO_4^{-2}) for the data set from Upper Buffalo Wilderness. A relatively tight correlation and a slope of roughly three indicate a good

Table C-4. Scatter plot species and expected relationships.

Species	Species	Expected Relationship	Source or Reason
S	SO_4^{-2}	$3*S \sim SO_4^{-2}$	IC vs. XRF
Cl ion	Cl	~ 1:1	IC vs. XRF
Na ion	Na	~ 1:1	IC vs. XRF
K ion	K	~ 1:1	IC vs. XRF
Na	Cl	Correlation	Sea salt
Ca	Si	Correlation	Soil
Al	Si	Correlation	Soil
Fe	Si	Correlation	Soil
Fe	K	Correlation	Soil
OC	Total Carbon (TC)	Correlation	OC large part of TC
EC	TC	Some Correlation	EC part of TC
Se	SO_4^{-2}	Some Correlation	Coal Emissions
Fe	Zn	Some Correlation	Smelter Emissions
Ni	V	Some Correlation	Oil Combustion
K	EC	Some Correlation	Wood Smoke
b_{abs}	EC	Correlation	EC absorbs most light
Cations	Anions	Near 1:1	Neutralized Aerosol
$PM_{2.5}$	Reconstructed Mass	Good Correlation	Should be equal

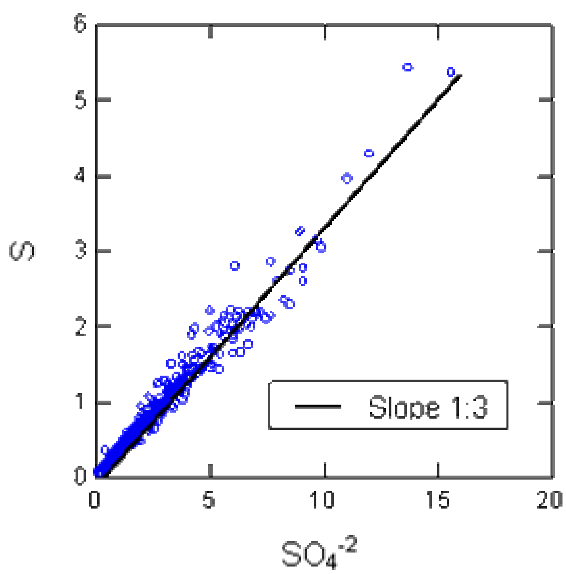
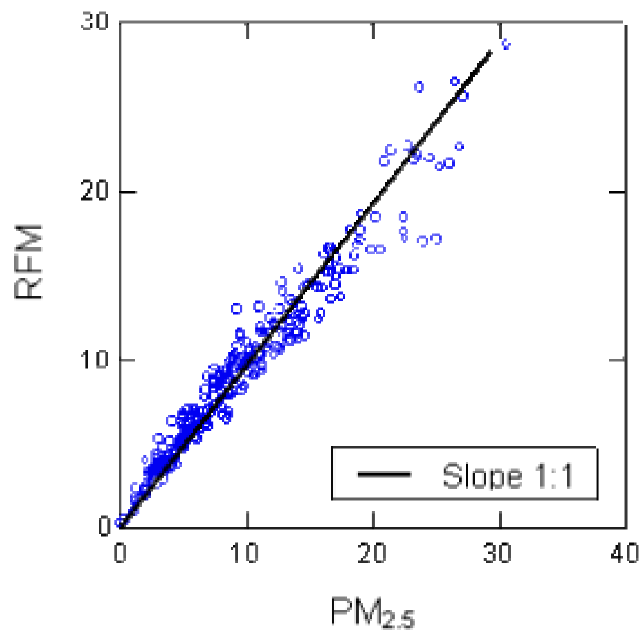


Figure C-2. Concentrations of XRF sulfur (S) versus IC sulfate (SO_4^{-2}) from the Upper Buffalo Wilderness IMPROVE station ($\mu g/m^3$). The line has a slope of one third, representing the expected 1:3 ratio between sulfur and sulfate.

comparison between the data obtained from the XRF and IC analyses. The slope equals 3 because the molecular mass of sulfate (96 g/mol) is three times the molecular mass of sulfur (32 g/mol). **Figure C-3** highlights the good correlation between the measured fine particulate mass ($PM_{2.5}$) and the reconstructed fine particulate mass (RFM). According to IMPROVE protocol, RFM equals the sum of SO_4^{-2}, NO_3^-, EC, OCM, and soil components. The good correlation between $PM_{2.5}$ and RFM indicates the overall reliability of the data sets and measurement techniques. The correlation exhibited between iron (Fe) and potassium (K) in **Figure C-4** is confounded by several data points of high K and low Fe, which suggests an additional source of K, possibly wood smoke, since both species commonly derive from soils. Overall this indicates that most K is from soil, which suggests influence from the non-soil sources is infrequent and contributes only a small amount of the



K.

Figure C-3. Concentrations of reconstructed fine mass (RFM) versus fine particulate mass ($PM_{2.5}$) from the Caney Creek IMPROVE station (μg/m^3). The line has a slope of one, representing a one to one ratio between RFM and $PM_{2.5}$.

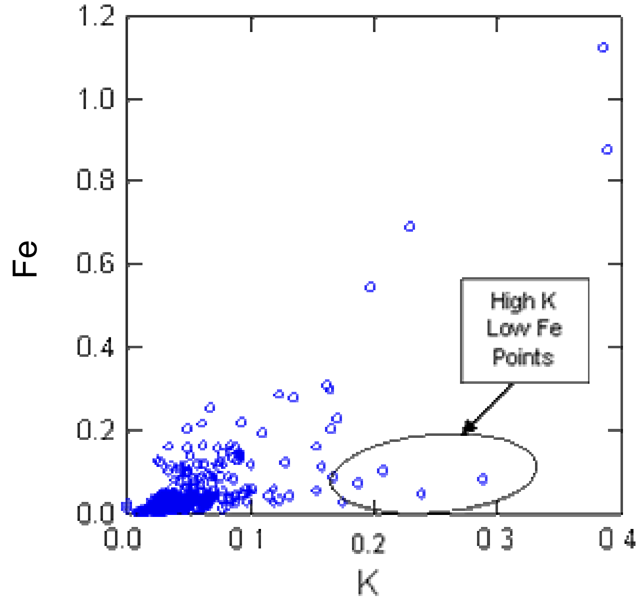


Figure C-4. Concentrations of iron (Fe) versus potassium (K) from the Upper Buffalo Wilderness IMPROVE station (µg/m^3). Points that exhibit higher than normal K to Fe ratios are highlighted.

C.4 CHARACTERIZING $PM_{2.5}$ DATA

It is important to first characterize the typical seasonal concentrations of and ratios between species to understand what comprises the "normal" composition of $PM_{2.5}$ before identifying whether specific source influences such as prescribed burning can be determined. **Figure C-5** depicts seasonal proportions of the median mass concentrations of OCM, EC, NH_4NO_3, $(NH_4)_2SO_4$, and soil influences for Caney Creek; Upper Buffalo Wilderness showed similar results. Summary statistics are given in Appendix A. At both sites, $(NH_4)_2SO_4$ and OCM comprise the dominant fractions of $PM_{2.5}$ in all seasons except winter, when NH_4NO_3 also contributes a significant fraction. The larger fraction of NH_4NO_3 in winter is consistent with nitrate formation mechanisms which favor cold, wet conditions, and the dominant fractions of $(NH_4)_2SO_4$ are consistent with observations made at other eastern IMPROVE sites (Malm, 1999). EC is a small component of the mass in all seasons.

Figure C-6 illustrates the proportions of light extinction attributed to OCM, EC, NH_4NO_3, $(NH_4)_2SO_4$, and soil for each season at Caney Creek; Upper Buffalo Wilderness showed similar results. Summary statistics are given in Appendix A. The dominant portion of light extinction derives from $(NH_4)_2SO_4$ in all seasons except winter, when NH_4NO_3 also contributes significantly. This is consistent with other analyses of $PM_{2.5}$ aerosol in the Midwest and CENRAP region (http://www2.nature.nps.gov/air/studies/bravo/bravo2003factsheet.htm)

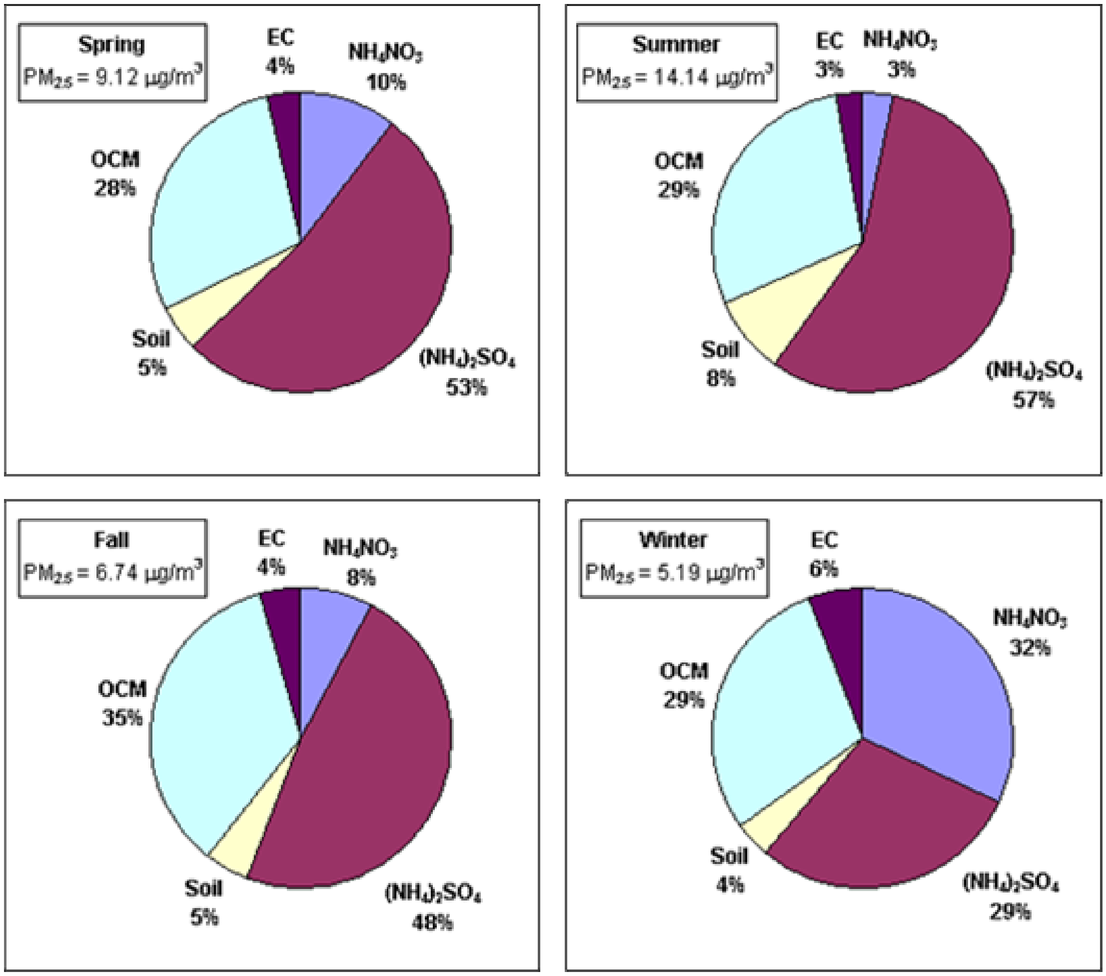


Figure C-5. Median mass and composition of $PM_{2.5}$ by season (spring is March to May, summer is June to August, fall is September to November, and winter is December to February) at Caney Creek for 2000 through 2002.

(Coutant et al., 2003; Coutant et al., 2002; Georgoulias and Dattner, 2002; Sisler and Malm, 2000; Malm, 1999). $PM_{2.5}$ composition at other Class 1 areas in the CENRAP region will likely be similar. The light extinction proportions resemble the mass concentration proportions, because the extinction calculations directly depend on mass concentrations. $(NH_4)_2SO_4$ has a large effect on visibility due to its extremely hygroscopic nature and large contribution to the overall mass. The effect of EC on visibility is most pronounced during the winter months when the effect of $(NH_4)_2SO_4$ is at a minimum, though it only accounts for about 5% of the total extinction.

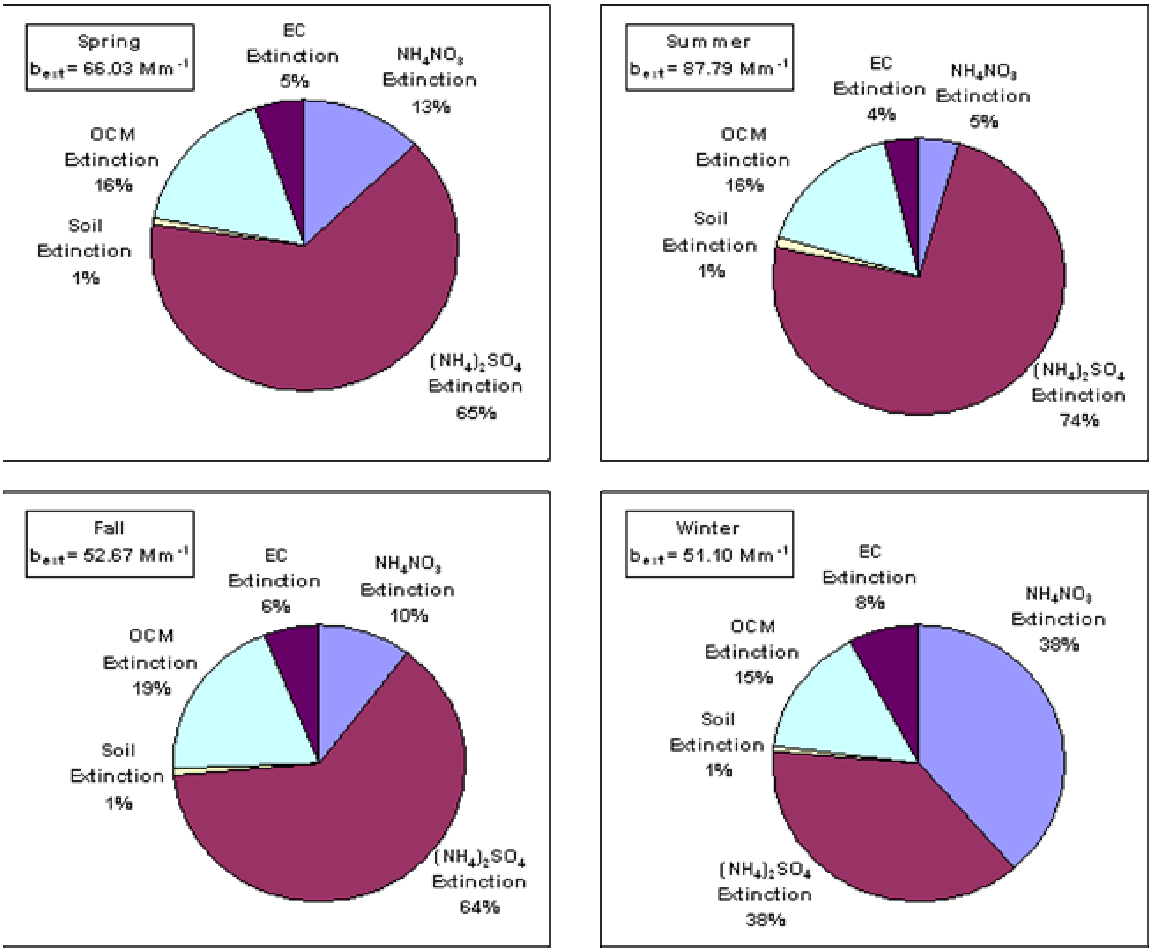
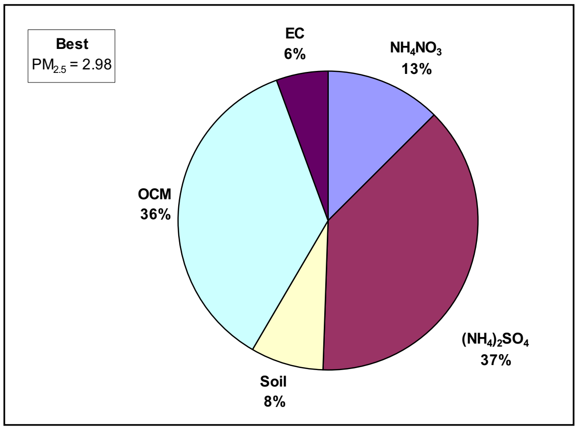
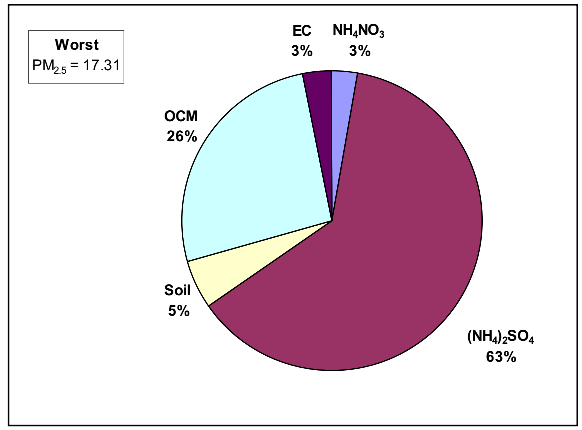


Figure C-6. Median extinction and composition of extinction by season (spring is March to May, summer is June to August, fall is September to November, and winter is December to February) at Caney Creek for 2000 through 2002.

C.5 CHARACTERIZATION OF VISIBILITY

In order to determine which species are most responsible for poor visibility, we isolated the top and bottom 20% visibility days in 2000 through 2002 by aerosol extinction at each site. Summary statistics of the best visibility data, worst visibility data, and overall data for Caney Creek and Upper Buffalo Wilderness were calculated. The median mass compositions for the best and worst visibility days, as well as the annual median from Caney Creek are depicted in **Figure C-7**; results for Upper Buffalo Wilderness are similar to those for Caney Creek. At both sites, days with poor visibility are dominated by $(NH_4)_2SO_4$ and show a decrease in the fractions of the other species, especially OCM and NH_4NO_3. The fractions of EC and Soil components vary to a lesser extent between the good visibility and poor visibility days and are minor contributors to mass and extinction.





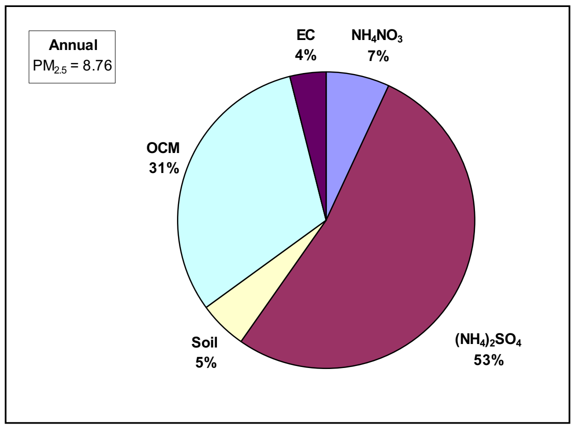


Figure C-7. Median $PM_{2.5}$ composition for the 20% best and worst aerosol extinction days and the median annual composition at Caney Creek from 2000 to 2002.

C.6 FIRE HISTORY DATA

In order to evaluate the effect of prescribed fires on visibility, we analyzed fire history data with the 2002 IMPROVE data for Caney Creek and Upper Buffalo Wilderness. We isolated the dates with IMPROVE data that corresponded to the day of or the day after prescribed burning occurred within a specific radius (i.e., range of influence) of each site. The range of influence around each site was established by using data from nearby meteorological stations: the radius around each site was calculated as the sum of the 24 hourly averaged wind speeds for each date, which represented an estimate of the distance that a parcel of air could have traveled on a given day. Theoretically, emissions from fires located within the range of influence could have been detected by the IMPROVE station if transport conditions were conducive. We then analyzed dates when the most extensive burning (with respect to acreage) occurred.

Due to the proximity of the two IMPROVE sites, several of the dates selected for each site overlap. The OCM, EC, K and KNS mass concentrations from overlapping dates that correspond to the day of or the day after extensive burning within the vicinity of both sites are compared to the springtime and annual mean concentrations from 2000 to 2002 for each site in **Figures C-8** and **C-9**. Error bars representing the 95% confidence limits for the mean concentrations of EC and KNS for the springtime and annual data sets are also plotted. In

Appendix A, mass concentrations of EC, KNS and the other key species for the selected dates and whether the EC and KNS concentrations significantly exceed the springtime are presented.

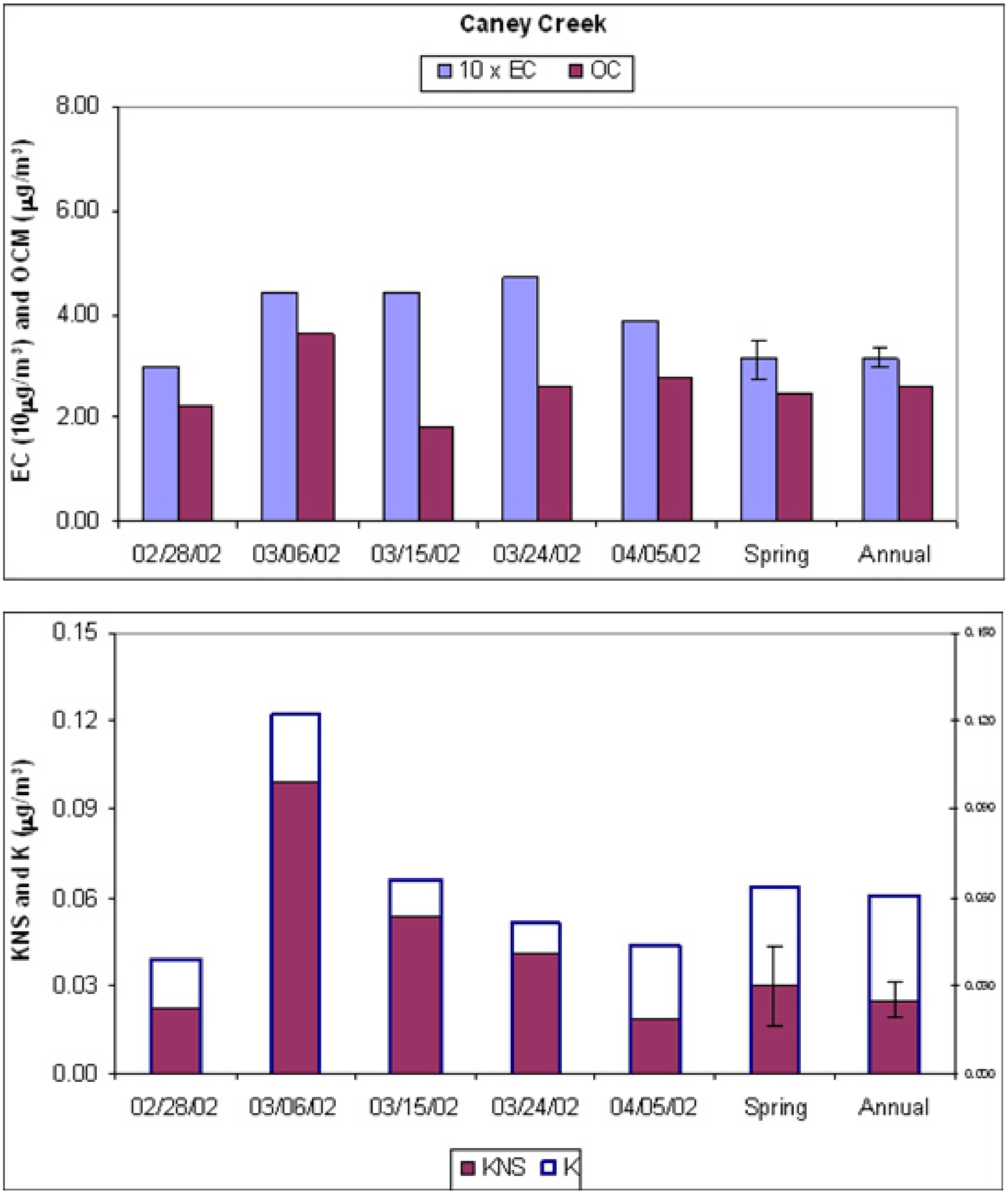


Figure C-8. EC, OCM, K and KNS mass concentrations (µg/m^3) for select dates compared to the spring and annual means for Caney Creek.

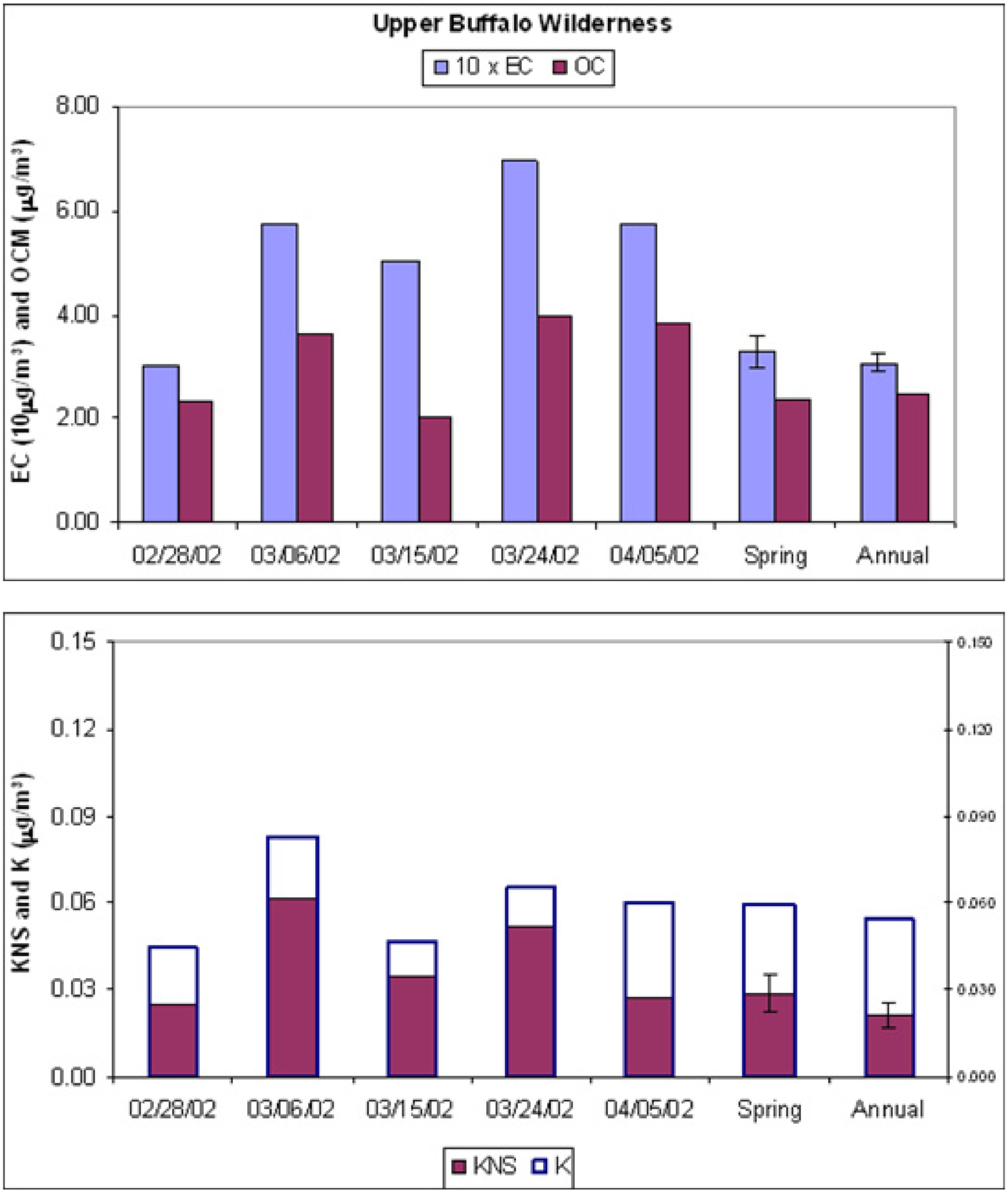


Figure C-9. EC and KNS mass concentrations (μg/m^3) for select dates compared to the spring and annual means for Upper Buffalo Wilderness.

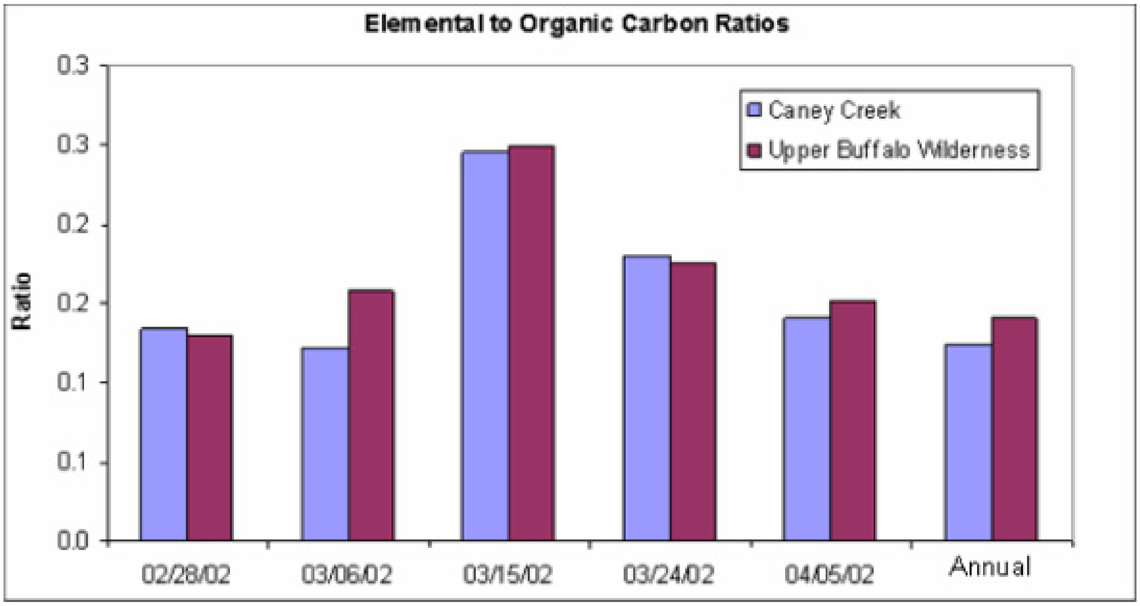
Extensive burns occurred on the days before March 6, 15, 24, and April 5. On these dates, the measured EC significantly (at a 95% confidence level) exceeds the springtime and annual means for both sites. On March 15 and 24, the contributions of EC in relation to OC are significantly higher than the springtime and annual average EC contributions for both sites. The elevated EC emissions observed on March 6, 15, 24, and April 5 could derive from the extensive burning that occurred on the previous days, if transport conditions were correct. Extensive burning occurred on February 28, but the EC measurements fell below the springtime and annual means at both sites, although not statistically significant at a 95% confidence level. On March 6, 15, and 24, the KNS mass concentrations exceeded the mean springtime and annual KNS concentrations for both sites, and the relative contribution of KNS in comparison to K is also higher on these dates. The elevated KNS also suggests influence from wood burning on these days. Air mass trajectories were run to further investigate the potential influence of prescribed burns on ambient measurements, as discussed in Section C.9.

Figure C-10 compares the mass concentration ratios of EC to OCM and of KNS to K for the selected dates to the annual median ratios. The KNS to K ratios from March 6, 15, and 24 clearly exceed the annual ratio, indicating a relatively large contribution of KNS during these dates. Since KNS largely derives from wood smoke, emissions from nearby burns likely influenced the IMPROVE sites. The EC to OCM ratio from March 15 also clearly exceeds the annual ratio, further suggesting fire influence on this day.

C.7 DO HIGH CONCENTRATIONS OCCUR ON DAYS OF PRESCRIBED BURNS?

In addition to isolating the dates associated with extensive burning from the fire history data and analyzing corresponding ambient measurements, we also isolated the dates with high mass concentrations from the ambient measurements and analyzed corresponding fire history data. For each site, we ranked the 2002 IMPROVE data by the mass concentrations of EC, OCM, KNS, and K. We summarized the selected dates, ranks of each compound, whether a fire occurred, and the total acres burned within the sphere of influence of each site in **Tables C-5** and **C-6**.

At both sites, the dates of higher EC and OCM mass concentrations overlap more with each other than with the dates of higher K mass concentrations, as EC and OCM both commonly derive from combustion sources and K derives largely from soils. At Upper Buffalo Wilderness, three of the five highest EC mass concentrations were measured on the dates that we had isolated during the previous analysis of fire occurrence, namely March 6, 24, and April 5. Since EC partly derives from wood smoke and extensive burns occurred on the day of and the day before these dates, the elevated EC emissions could derive from nearby prescribed burns. We further analyze the potential connection between elevated emissions of key species and fire occurrence in the next section, utilizing air mass trajectories for select dates.



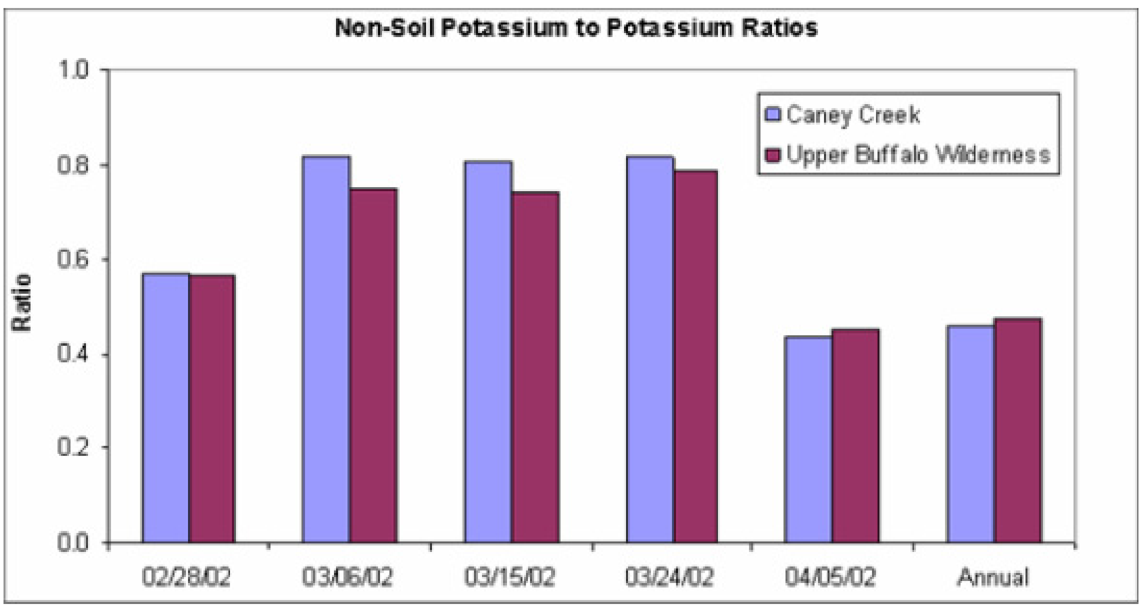


Figure C-10. EC to OCM and KNS to K mass concentration ratios for select dates compared to the annual median ratios for both sites

Table C-5. Dates with high measured EC, OCM, KNS and K mass concentrations and total acres burned within the sphere of influence of Caney Creek. The ranks order the days according to the five highest measured mass concentrations of each species.

Date	EC Rank	OCM Rank	KNS Rank	K Rank	Day of or before fires?	Total Acres
01/17/02	2				Of and Before	4,618
03/06/02			5		Of and Before	19,509
05/02/02			3		No Fires	0
05/08/02			2	4	Of and Before	N/A
06/22/02	5	5			Day Before	107
07/01/02				1	Day Of	41
07/04/02				5	No Fires	0
07/31/02				2	Of and Before	1,157
08/06/02		3			Of and Before	1,727
08/09/02	3	4			Of and Before	388
08/30/02	4				Of and Before	476
09/05/02		2	4		Of and Before	1,973
09/14/02	1	1	1	3	Of and Before	135

Table C-6. Dates with high measured EC, OCM, KNS, and K mass concentrations and total acres burned within the sphere of influence of Caney Creek. The ranks order the days according to the five highest measured mass concentrations of each species.

Date	EC Rank	OCM Rank	KNS Rank	K Rank	Day of or before fires?	Total Acres
03/06/02	5				Of and Before	20771
03/24/02	2				Of and Before	28567
04/05/02	4				Of and Before	8190
05/08/02			2	4	Of and Before	N/A
06/19/02	3	3	3		Of and Before	661
06/22/02	1	4	4		Day Before	356
07/01/02				1	Day Of	41
07/10/02		2			Of and Before	2114
07/31/02				3	Of and Before	927
08/03/02				5	Of and Before	189
08/06/02		5			Of and Before	1729
09/14/02		1	1	2	Of and Before	253
11/25/02			5		Of and Before	208

C.8 AIR MASS TRAJECTORIES

Back trajectories of air masses for the selected dates were created using the National Oceanic and Atmospheric Administration (NOAA) Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model. The NOAA HYSPLIT model is a three-dimensional air mass trajectory model based on weather model data and can be obtained from the NOAA web site at http://www.arl.noaa.gov/ready/hysplit4.html. The final (FNL) product of the Global Data Assimilation System (GDAS) that uses the Global Spectral Medium Range Forecast (MRF) model provides the weather data for the HYSPLIT model. The HYSPLIT model uses National Weather Service soundings and other diagnostic parameters such as temperature, relative humidity and radiative and momentum fluxes. It uses a 129 x 129 polar stereograph (three-dimensional) grid, with approximately 190 km resolution and 12 vertical layers, and is run at 6-hour increments. Back trajectories were run from 1800 CST with ending heights of 1000 and 500 meters in order to capture short-range transport in the lower boundary layer.

We ran trajectories for March 6, 15, and 24 and plotted them along with fires that occurred the day of and the day before the selected dates. **Figures C-11 through C-13** show the maps for March 6, 15, and 24. On these dates, the EC and KNS mass concentrations exceeded the annual means for each site, as summarized in Figure C-9.

Air mass trajectories demonstrated no influence from known burns at the Caney Creek site on March 6. However, the inventory does not include detailed fire history data for the southeastern corner of Oklahoma or for the eastern portion of Texas, over which the air mass advected before reaching the site. On approach to the Upper Buffalo Wilderness site, the air did pass directly over extensive fires that occurred on March 5. Therefore, the elevated EC and KNS emissions measured at Upper Buffalo Wilderness on March 6 could derive from wood smoke emissions from the previous day that influenced the site over a 24 hour period. Additionally, there were numerous nearby fires to Caney Creek on March 5 and 6 that would have affected the site via flow below 500 meters.

Similar to the situation on March 6, the air flowed directly over burns reported in the emissions inventory before reaching Upper Buffalo Wilderness on March 15, but the air did not flow over the reported burns when approaching Caney Creek. The elevated EC and KNS emissions measured at Upper Buffalo Wilderness on March 15 could be attributed to the wood smoke emissions from the extensive March 14 burns, and detailed fire history data from neighboring states would allow more definitive conclusions to be drawn about the measurements from Caney Creek. Also, the similarity in $PM_{2.5}$ composition at the two sites on this day indicates they were influenced from similar sources, again suggesting local low level flow advecting smoke to Caney Creek that is not shown by the trajectories.

Finally, on March 24, the air approaching Caney Creek circumvented the extensive fires reported by the inventory, while the air approaching Upper Buffalo Wilderness passed directly over them. Once again, the higher than average EC and KNS mass concentrations observed on March 24 at Upper Buffalo Wilderness could have originated from prescribed burning emissions, while more information would support definitive conclusions as to the Caney Creek emissions. Overall, the $PM_{2.5}$ composition and air mass trajectories show that fire influence from large-scale burns can be seen in the ambient data at Caney Creek and Upper Buffalo Wilderness. More extensive emission inventory data is needed to better assess the impact of prescribed burn emissions in the CENRAP region.

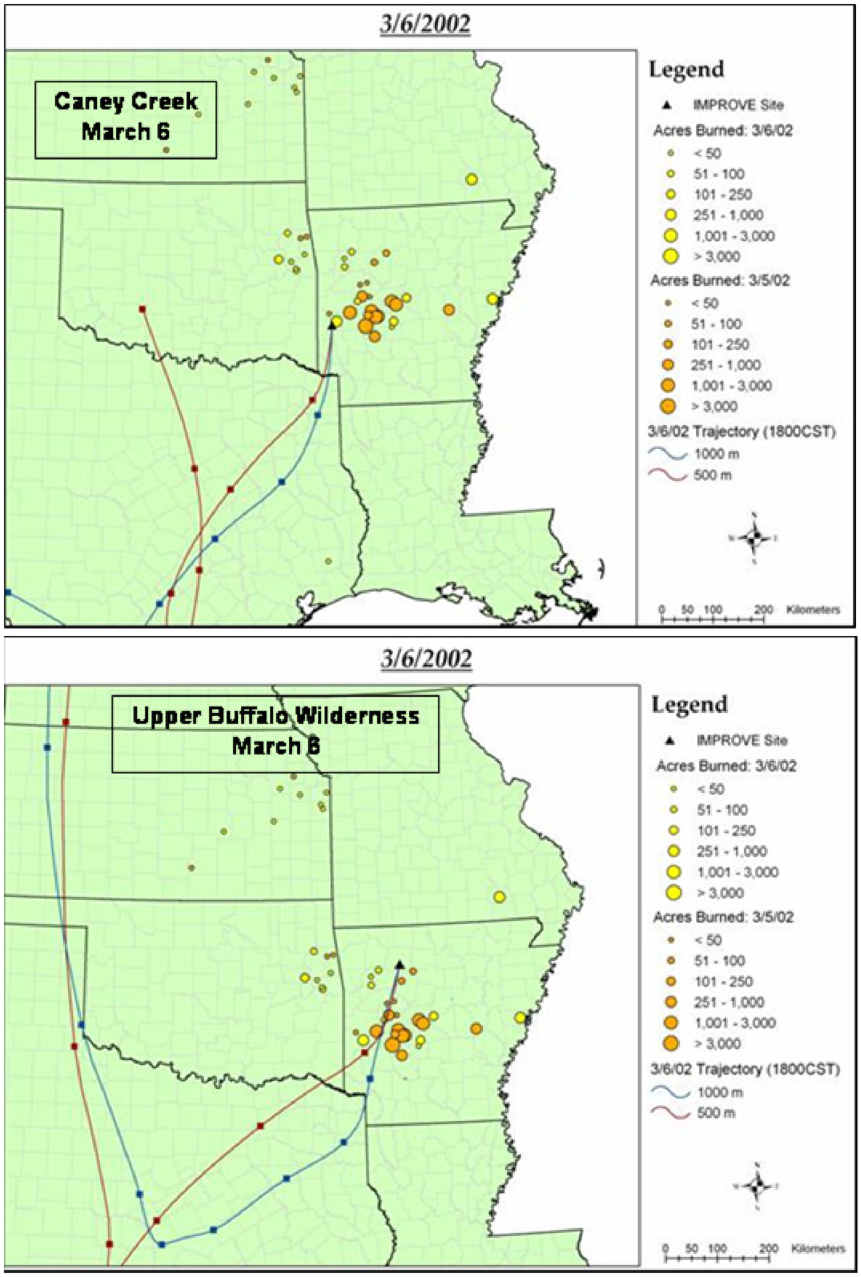


Figure C-11. Air mass trajectories and associated fires for March 6. Squares along each trajectory are placed every 6 hours.

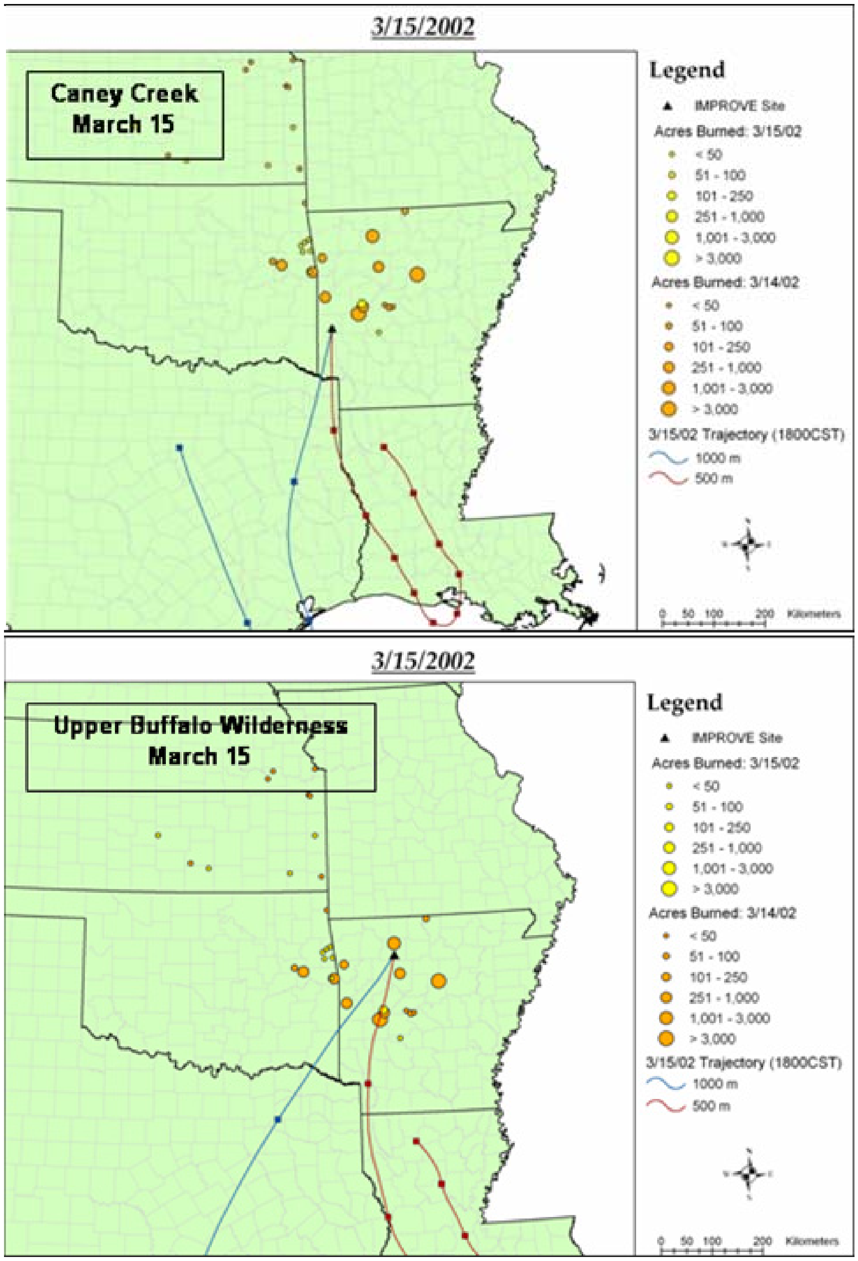


Figure C-12. Air mass trajectories and associated fires for March 15. Squares along each trajectory are placed every 6 hours.

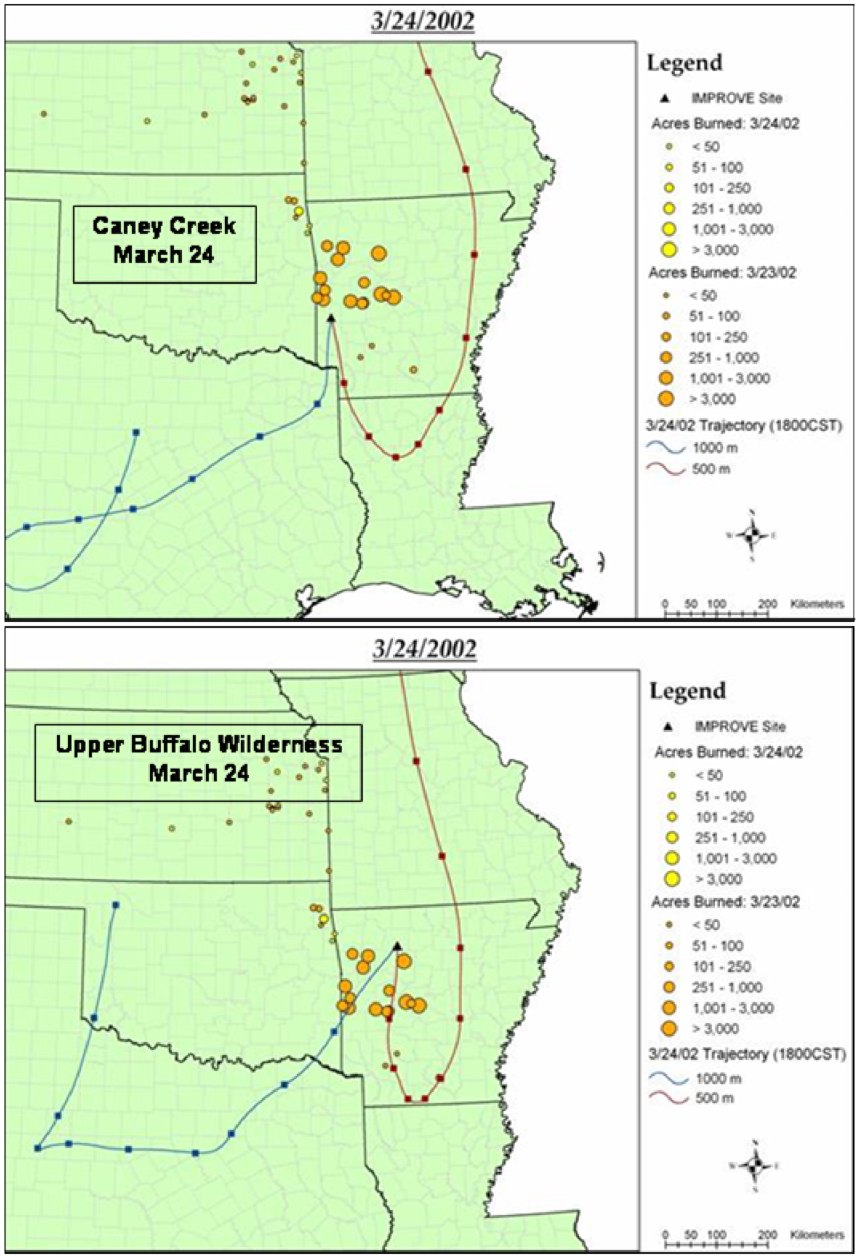


Figure C-13. Air mass trajectories and associated fires for March 15. Squares along each trajectory are placed every 6 hours.

C.9 EFFECTS ON VISIBILITY

We have demonstrated a potential connection between prescribed burn occurrence and elevated EC and KNS emissions at Upper Buffalo Wilderness via comparative analyses of ambient data and fire history data and air mass trajectories. In order to assess the impact that the elevated emissions have on visibility, we plotted the median $PM_{2.5}$ mass compositions of the annual, best visibility, and worst visibility data sets from Upper Buffalo Wilderness in order to compare them to the mass and visibility compositions measured on the select dates March 6, 15, and 24, as illustrated in **Figure C-14**. The $PM_{2.5}$ mass compositions consist of the measured NH_4NO_3, $(NH_4)_2SO_4$, soil elements, OCM, and EC mass concentrations. The worst visibility data set is characterized by high $(NH_4)_2SO_4$ and OCM measurements, while the best visibility data set is characterized by relatively low concentrations of all the species. Since $(NH_4)_2SO_4$ does not derive from wood smoke, and OCM can derive from other sources, the species that dominate poor visibility conditions are not necessarily connected with emissions from wood smoke.

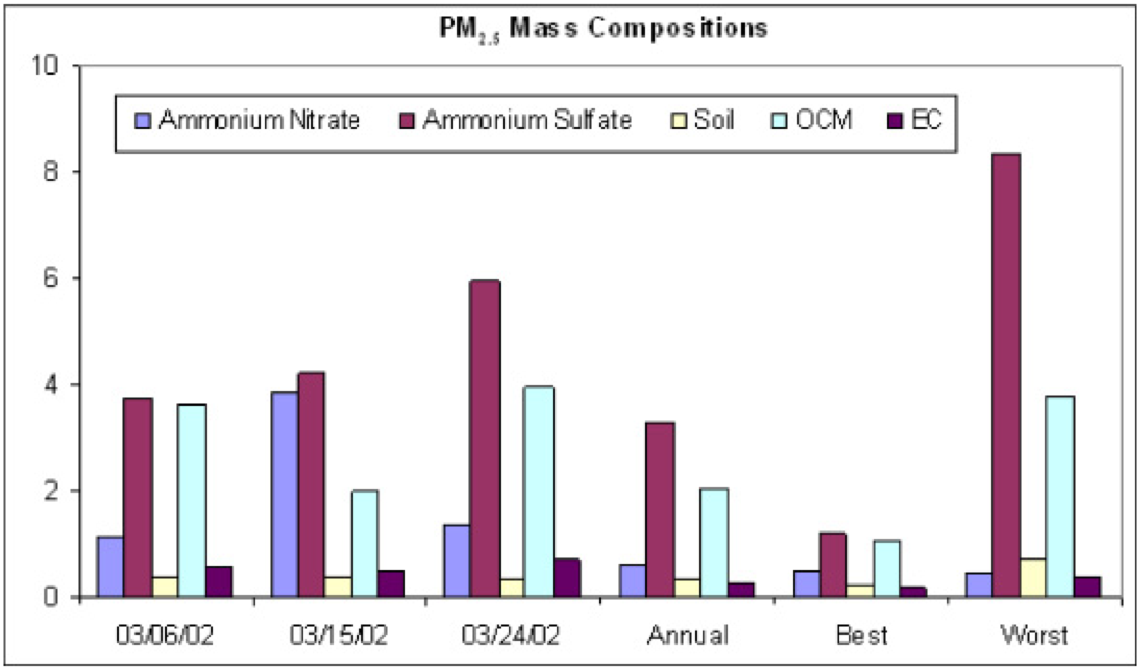


Figure C-14. $PM_{2.5}$ mass compositions for select dates and for the annual, best visibility, and worst visibility data sets.

C.10 CONCLUSIONS

Speciated $PM_{2.5}$ data collected at IMPROVE sites in Class 1 areas in Arkansas were used to determine whether such data can help to examine the influence of prescribed burning and determine if burns in the emission inventory significantly impact the $PM_{2.5}$ composition and visibility reduction. Overall conclusions include:

- Speciated $PM_{2.5}$ data at IMPROVE sites are useful for characterizing sources impacting $PM_{2.5}$ and visibility reduction, including burns.
- Influence from specific known burns (as seen by elevated concentrations of EC or K) can be seen on select days when the meteorology is conducive for transport.
- Days when high OC or EC concentrations are observed at the sites do not always coincide with known burns; however, the emission inventory is not complete and may be

missing burns in the areas of influence on these days, such as southern Oklahoma and eastern Texas.

- Meteorology plays an important role in determining the areas impacted by prescribed burns.
- EC, the primary marker of smoke, is a relatively small part of both the $PM_{2.5}$ mass and light extinction.
- Ammonium sulfate is generally the largest contributor to the $PM_{2.5}$ mass and light extinction; this component does not originate from burns. This finding is consistent with other work in the Midwest and CENRAP region including Big Bend National Park and Seney Wildlife Refuge.

C.11 RECOMMENDATIONS FOR FUTURE WORK

Additional analyses could be conducted to better quantify the influence of burns on visibility impairment. Such analyses could include:

- Apply analyses conducted in this task to additional IMPROVE sites, such as in Kansas or Minnesota to investigate whether results in this task are indicative of trends 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-hour (i.e., IMPROVE, 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.
- Develop a better conceptual model of $PM_{2.5}$ in the CENRAP region:

  – *Are there differences in $PM_{2.5}$ composition and meteorology among different locations in the CENRAP region?* Significant differences in $PM_{2.5}$ concentrations and composition among sites in different geographic locations within the CENRAP region may provide insight into $PM_{2.5}$ transport and formation. For example, a surface high pressure system located over the Upper Midwest will often drive southeasterly winds across the CENRAP region, which can transport higher levels of $PM_{2.5}$ from upwind sources within major population centers.

  – *How are $PM_{2.5}$ concentrations and visibility dependent on large-scale meteorological patterns?* The effect of large-scale synoptic patterns on $PM_{2.5}$ concentrations and regional haze is a critical issue because synoptic patterns affect transport, vertical and horizontal dispersion, formation, and the impact of local emissions on an area. For example, transport of warm, moist air from the Gulf of Mexico may result in secondary particle formation within the CENRAP region, reducing visibility.

– *What are the compositional and meteorological differences between days of high and low $PM_{2.5}$ concentrations?* Differences in $PM_{2.5}$ composition may indicate different transport regimes, and might identify which species are dominant on high $PM_{2.5}$ days, both of which would assist forecasters. One useful way of examining the meteorology on these days is to perform several case study analyses of high and low $PM_{2.5}$ concentration episodes. A typical case study analysis would examine:

  - *Upper-air and surface synoptic patterns for each day*. These patterns assist meteorologists in determining the extent to which particles may be allowed to mix, or disperse. For example, an upper-level high pressure system is typically associated with sinking air, which will help to trap particles near the surface.
  - *Vertical temperature soundings whenever available*. Vertical temperature soundings give meteorologists the ability to assess the vertical structure of the atmosphere, in particular, how much vertical mixing can occur. Typically, a strong surface-based inversion will trap particles near the surface, allowing $PM_{2.5}$ levels to be high.
  - *Back-trajectories for each day*. Back-trajectories provide meteorologists with a tool for assessing whether transport of particles could have occurred within a region or from another region.