APPENDIX A

EMISSION ESTIMATION METHODS FOR THE CENRAP PLANNED BURNING EMISSION INVENTORIES

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EMISSION ESTIMATION METHODS FOR THE CENRAP PLANNED BURNING EMISSION INVENTORIES

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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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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:

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

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

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

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[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

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