DRAFT
FINAL REPORT –

1996 Fire Emission Inventory

WGA/WRAP

PREPARED BY AIR SCIENCES, INC.
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EXECUTIVE SUMMARY

The Fire Emissions Joint Forum (FEJF) of the Western Regional Air Partnership (WRAP) has completed an air emissions inventory for fire on wildlands in the 13-state WRAP Region. The inventory includes emission estimates and activity data for wildfire and prescribed fire over calendar year 1996. The FEJF collected activity data for fire events from federal and state agencies, arrived at data quality objectives, devised emission calculation routines, estimated emissions for all fire events, and published database and dispersion model ready digital files of the resulting inventory.

The purpose of the wildland fire emission inventories is to further the WRAP's charge of supporting member states' Regional Haze State Implementation Plans. Along with emission inventories from other types of sources, the 1996 wild and prescribed fire emission inventories will be used by the Emissions and Air Quality Modeling Forums to test run WRAP-wide air quality dispersion models.

Building the emission inventory involved many technical steps shaped by extensive stakeholder and expert discussion. Driven by dispersion model demands, the FEJF decided to produce an *event based* emission inventory placing fire emissions at coordinate locations on specific days. Federal and state records of individual fire events were collected. Activity records were checked for completeness and quality for fire size, fuel loading, date, and location. Fuel loading and emission factor tables along with diurnal consumption and plume profiles were developed from the literature, expert and professional judgment, and stakeholder input. Spreadsheet and geographic information system software were used to store and calculate the inventories.

Limitations of this emission inventory include omission of fire events and variable data quality due to the variety of data sources used. Furthermore, estimating emissions from wildland fire involves considerable scientific uncertainty. This FEJF deliverable also does not include an emission inventory of burning on agricultural lands.

This report presents a wildfire and prescribed fire emission inventory for 1996 covering the 13-state modeling domain for the WRAP Region. The methods developed for this study may be refined and utilized for future air emission analyses.

Executive Summary of Fire Activity and Emissions from Wildfires and Prescribed Fires in 1996

	Wildfire	Prescribed fire	Total
Number of individual fires	1,348	14,696	16,044
Area burned (acres x 10^3)	5,030 (90%)	555 (10%)	5,585
Fuel consumed (tons x 10^3)	48,085 (90%)	5,243 (10%)	53,328
$PM_{2.5}$ emissions (tons x 10^3)	648 (93%)	44 (6%)	694

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SECTION 1

INTRODUCTION

This report documents a project to prepare a historical fire emissions inventory for the year 1996. The term *fire* refers inclusively to wildfire, wildland fire managed for resource benefits (formerly prescribed natural fire), prescribed fire and agricultural fire. This work is sponsored by the Western Governors Association and directed by the Emissions Task Team (ETT) of the Fire Emissions Joint Forum (FEJF) of the Western Regional Air Partnership (WRAP). The FEJF was formed to assist the WRAP in addressing the Grand Canyon Visibility Transport Commission's (GCVTC) Recommendations on Fire (June 1996 Report to EPA). The FEJF is currently addressing a broad range of smoke effects, including consideration of public nuisance effects, public health effects, and visibility and regional haze effects. The work described in this report provides the emissions inventory that is needed to establish the performance of the WRAP's dispersion model to estimate the air quality impact of smoke from fire.

1.1 Project Background and Need

The FEJF prepared two fire emission inventories for 1996 for the 13-state geographical domain of the WRAP. First, the FEJF prepared (during spring / summer of 2001) an emission inventory of wildfire emissions for July 1996. This inventory was to fulfill a request of the WRAP's Emissions and Air Quality Modeling Forums in order to set up and test run the dispersion modeling tools to be used for the modeling runs in support of regional haze State Implementation Plans (SIPs) as required by the Regional Haze Rule. The July 1996 emission inventory was also expected to be useful to begin to relate historical wildfire activity and emissions to historical ambient monitoring data (from the IMPROVE network) in Class I areas. The July 1996 inventory included emission estimates for eleven pollutants: total suspended particulate matter (TSP), particulate matter 10 microns and less in aerodynamic diameter (PM10), PM2.5, elemental carbon (EC), organic carbon (OC), volatile organic compounds (VOC), methane (CH_4), ammonia (NH_3), oxides of nitrogen (NO_X), carbon monoxide (CO), and sulfur dioxide (SO_2).

The July 1996 inventory was relatively simple, relying on acres burned per day and location (from United States Department of Agriculture – Forest Service [USDA – Forest Service] ICS-209 incident reports and other federal land manager [FLM] databases), the United States Environmental Protection Agency's (USEPA) Compilation of Emission Factors document (AP-42) default fuel loading values, and AP-42 (and other related technical documents) for emission factors. Parameters not included in the July 1996 inventory include vegetative type, actual fuel loading, fire phases (e.g., flaming, smoldering), and consumption efficiency. Preparation of the July 1996 emissions inventory also served as a "dry run" for the FEJF's effort to prepare additional, more comprehensive and more detailed emission inventories for fire. Important lessons were learned pertaining to emission estimation techniques, smoke plume characteristics, application of geographic information science methods and preparation of precisely formatted, model-ready SMOKE[1] input files.

The 1996 annual emission inventory for fire is the principle subject of this report and was prepared during the fall and winter of 2001/2002. This emission inventory was also utilized by the Air Quality Modeling Forum primarily to establish the performance of the WRAP's dispersion modeling tool. Specifically, 1996 model results were first matched with data from IMPROVE datasets. Then scatter plots and time-series plots of model results were generated to compare with IMPROVE data.[2] The 1996 emission inventory included emissions from wildfire and prescribed fire. Due to specific characteristics of the historical agricultural burning data gathered under a separate effort of the FEJF (described in Section 2.8 of this report), emissions from agricultural burning were not included in the 1996 fire emissions inventory. The inventory included estimates for twelve pollutants, the same pollutants included in the July 1996 inventory and PM coarse (PMC); defined as PM_{10} minus $PM_{2.5}$.

Like the July 1996 inventory, the annual 1996 inventory was based on empirical data of burning events. Wildfire data was assembled from ICS-209 incident reports and other FLM data sets. Prescribed fire data was compiled from state sources and augmented by other data sources (such as United States Department of Interior [USDOI] 1202 reports). The annual 1996 inventory incorporated more refined emission estimation techniques than the July 1996 emission inventory. The following is a list of refined techniques which are described in more detail in the text of this report:

- Two sets of emission factors were used ("natural" or broadcast burns and piled burns).
- Composite emission factors developed in a study of emission factors conducted by USEPA's Office of Air Quality Planning and Standards (OAQPS) were used.
- Emissions due to smoldering were estimated and added to the emissions estimates for fire events.
- Fuel loading values for each burn event were either obtained explicitly in the source activity data or obtained through application of geographical information science techniques and National Fire Danger Rating System (NFDRS) vegetation-specific fuel loading values.

1.2 Limitations to the Quality and Use of the Emissions Inventory Data

The Emissions Task Team of the FEJF recognized several features of the 1996 emissions inventory data that are important to understand prior to using the emissions inventory data. These features include:

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[1] Sparse Matrix Operator Kernel Emissions (SMOKE) Modeling System, created by MCNC.

[2] WRAP Regional Haze CMAQ 1996 Model Performance Evaluation, Wang (UC Riverside), Morris (ENVIRON), and Shankar (MCNC), presented at July 10, 2002, WRAP Section 309 SIP Coordination Meeting, Denver, Colorado.

- The emission estimates are based upon historical data of burn events in 1996. Therefore, the emission estimates should be regarded as representative of 1996 only (i.e., not necessarily a typical year). In fact, 1996 is recognized as a drought year in the Western United States. This suggests that wildfire events may have been more numerous (and larger) than a typical year. Conversely, prescribed fire events may have been smaller and fewer in number as a result of the drought conditions.
- The 1996 emissions inventory should not be used as an indicator of any trends associated with the frequency, timing, size, or location of wildfires or prescribed fires. The 1996 data can be analyzed (and are) to describe the frequency, time, size, and location of wildfire and prescribed fires, but not to suggest, for example, that prescribed fires are larger or more frequent than those that occurred during some other period of time.
- The 1996 emissions inventory is only as accurate as the source activity data upon which the emission estimates are based. The activity data are based upon extensive searches of incident reports, state data sources, and other FLM databases. While quality assurance and quality control (QA / QC) techniques were employed to ensure that data of a consistent quality were used, and while some extremely obvious errors in the data were observed and corrected, the source data are incorporated into the emissions database "as is."
- Data management systems and data reporting methods may influence the quality and availability of the source activity data. Government agencies across the various jurisdictions of the 13-state emission inventory domain have different techniques and mechanisms to gather, compile, store, and report burn data. The source activity databases reflect these differences. For example, a jurisdiction with specific permitting and burn tracking requirements may have very detailed and very large prescribed burning databases. Another jurisdiction may collect less formal anecdotal burn information. Still another jurisdiction may collect no burn data at all. Without identifying the different data management systems in place and understanding how such differences affect the quality and quantity of the source activity data, emissions from prescribed fire data in one jurisdiction should not be directly compared to emissions of prescribed fires in another jurisdiction.
- The scientific building blocks of the emission estimates have inherent uncertainties. Therefore, the emission estimates have uncertainty and should not be relied upon as being "exactly right." Parameters such as the vegetation type of a burn, the vegetation-specific fuel loading, pollutant-specific emission factors, and combustion efficiencies, to name a few, all have uncertainties associated with them. The efforts of the ETT were dedicated to using professional judgment to select the best or most appropriate parameters or methods to estimate emissions. However, other parameters and methods could have been chosen and would also be considered "reasonable" for

estimating emissions from fire. Section 7 of this report presents a quantitative assessment of the potential uncertainty of the emission estimates.

1.3 Partners and Contributors in the Project

Source activity data for wildfire and prescribed fire events were gathered, compiled into an Microsoft Excel workbook, and QA / QC'ed by John Graves, USDOI – Bureau of Indian Affairs, and Peter Lahm, USDA – Forest Service (Tonto National Forest). Also contributing to the data collection effort was Mark Fitch, Arizona Department of Environmental Quality. Personnel within federal land management agencies (USDA – Forest Service, USDOI) and state agencies contributed the source activity data and assisted with the effort of data collection and resolving apparent anomalies in the data.

The members of the Emissions Task Team of the FEJF worked through meetings, conference calls, and document review and comment to direct the efforts of the FEJF's contractor, Air Sciences, Inc. The methods for fuel loading assignments, emission factor selection, smoldering emissions estimates, and determining the physical characteristics of smoke plumes, among others, were determined through close consultation between the contractor and the ETT.

Air Sciences' responsibilities included:

- Development of the emission estimates in an Excel workbook. Lookup functions were utilized to make appropriate selections of fuel loading values, emission factors, and physical plume characteristics.
- Application of geographic information science to specifically locate burn events, determine land cover characteristics, and to perform certain QA / QC steps.
- Preparation of the specifically formatted, model-ready SMOKE input files of the fire emissions inventory.
- Preparation of the technical report for the 1996 emissions inventory for wildfire and prescribed fire. Also contributing to and / or authoring specific sections of the technical report are: John Graves, USDOI – Bureau of Indian Affairs; Peter Lahm, USDA – Forest Service, Tonto National Forest; and David "Sam" Sandberg, USDA – Forest Service, Pacific Northwest Research Station.

The members of the FEJF were briefed during Forum meetings at critical stages of the development of the 1996 emission inventory. Matters determined by the ETT and the FEJF Co-Chairs to be important to the stakeholders represented on the FEJF were brought to the Forum for consideration and consensus.

1.4 Contents of the Technical Report

The technical report is comprised this document and an accompanying CD-ROM organized as follows:

Technical Report Document

Executive Summary

1. Introduction
2. Source Activity Data
3. Emission Factor and Fuel Loading Assignments
4. Emission Calculation Methods
5. Emission Estimates
6. Comparison of the Preliminary and Refined July 1996 Inventories for Wildfire
7. Sensitivity Analysis of Wildfire Emission Estimates
8. SMOKE Modeling Files
9. References

CD-ROM

- The emission inventory SMOKE files as delivered to the Modeling Forum;
- Wildfire emission inventory Excel spreadsheet including calculations, results, and look-up tables;
- Prescribed fire emission inventory as an Excel workbook including emission inventory flat file, metadata descriptions, and look-up tables; and
- This final report as an electronic document.

The final technical report will be available in PDF format at the WRAP website www.wrapair.org and in limited quantities as a hardcopy report.

SECTION 2

SOURCE ACTIVITY DATA

This section describes the compilation of raw wildfire and prescribed fire activity data.

2.1 Fire Event Data Objectives

The Emissions Task Team of the FEJF was provided specific data resolution requirements for the 1996 fire emission inventory by the Air Quality Modeling and Emissions Forums of the WRAP. For spatial resolution, the Forums requested that each fire event be assigned a specific latitude and longitude in order to satisfy the spatial resolution goal of having each emission event resolved to the one minute of latitude and longitude. For temporal resolution, the Forums requested that the FEJF provide hourly emission estimates for each fire event.

The ETT assessed these data requirements against what was known about the nature and quality of the fire event data available. As a result, the ETT established a number of fire event data objectives that would be used to identify and utilize fire event data suitable for the 1996 fire emissions inventory. Each individual entry in the fire activity database must meet all of the fire event data objectives in order to be included in the fire emissions inventory. These data objectives are:

- A specific location for each fire event. If location data was less resolved than a specific latitude and longitude (e.g., township / range / section [TRS] or county), then geographic information science techniques were employed to assign the latitude and longitude of the centroid of the TRS or county to the burn event.
- A specific calendar day in 1996 for each fire event. Hourly emission estimates, required by the Air Quality Modeling Forum, would be developed by multiplying daily emissions by hour-specific fuel consumption rates contained in diurnal fuel consumption profiles developed for wildfire and prescribed fire by the ETT.
- A specific size for each fire event. Usually, fire size was represented in the event data as acres burned. Some fire events (mostly pile burns) were represented by the quantity of fuel consumed.
- Sufficient information to assign a fuel loading for each fire event. If fuel loading was not specifically identified for a burn event, then vegetation cover-type was used to assign a fuel loading from the National Fire Danger Rating System (NFDRS). If vegetation cover-type was not specifically identified for a burn event, then geographic information science was employed to use the location of the burn event to map to a vegetation cover-type using the NFDRS fuel model map for the United States. The vegetation cover-type returned by this mapping technique was then assigned a fuel loading from the NFDRS.

2.2 Wildfire Activity Data

This section describes the sequence of wildfire activity data sources reviewed and selected for use in the 1996 emissions inventory.

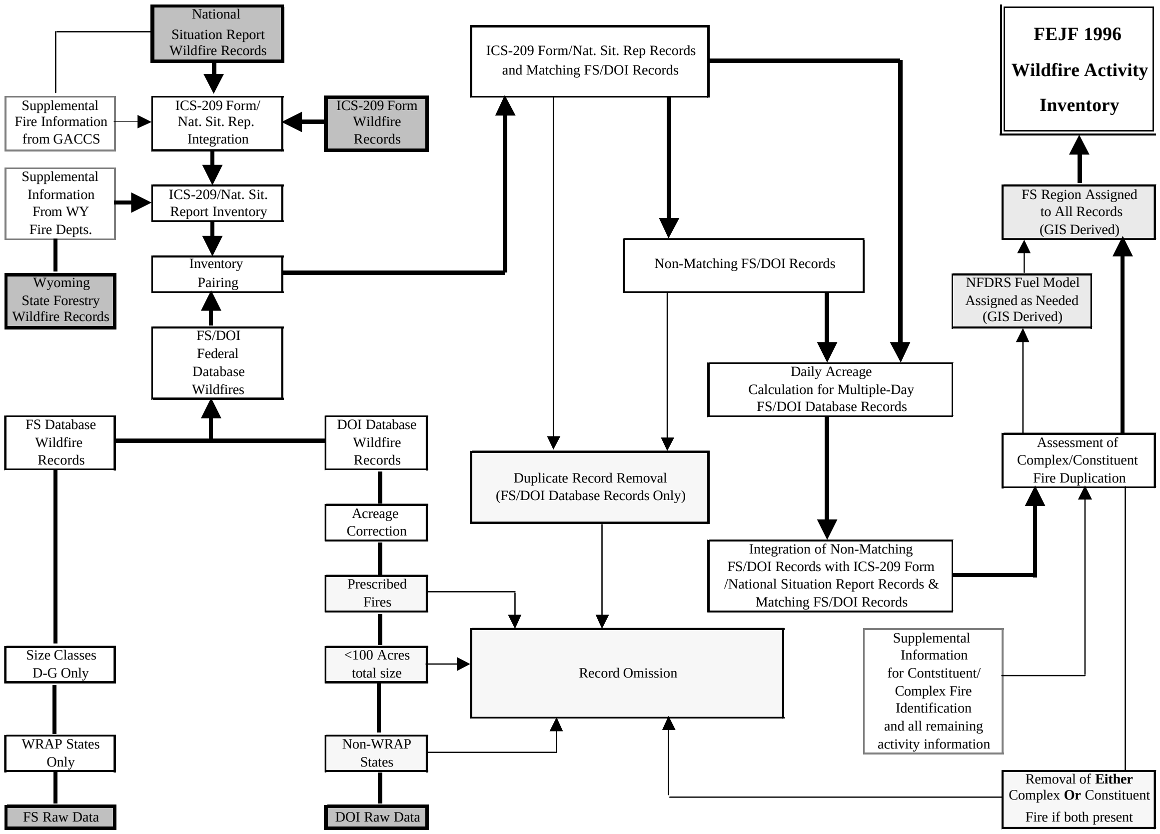
Overview. The USDA Forest Service Wildfire Statistics Publication (1991-1997) was the initial source of 1996 wildfire activity data for WRAP states. The publication provided baseline acreages burned by wildfire for each size class and state. However, the data included in the publication did not satisfy the temporal and spatial resolution data requirements nor was the activity data of sufficient detail for inventory development.

A tiered data gathering process was then initiated at the most accessible and available level of centralized federal database wildfire information. More detailed activity data with higher spatial and temporal resolution were contained in the National Interagency Fire Center's (NIFC) daily National Situation Report publication and ICS-209 wildfire forms. In addition, Wyoming State Forestry provided additional wildfire information for Wyoming. These three data sources comprise the wildland fire activity data for the FEJF's spatially and temporally refined 1996 wildland fire emissions inventory.

Figure 2.1 illustrates the methodology used and sequence of tasks executed development of the wildfire activity database. Only those wildfires and wildfires for resource benefits (WFRBs) that grew to 100 acres or larger in total size and within the WRAP states of Arizona, California, Colorado, Idaho, Montana, North Dakota, New Mexico, Nevada, Oregon, South Dakota, Utah, Washington, and Wyoming are included within the final 1996 wildfire inventory.

Department of Interior Fire Records. Fire records for Department of Interior (DOI) land management agencies (Bureau of Indian Affairs [BIA], Bureau of Land Management [BLM], Fish and Wildlife Service [FWS], National Park Service [NPS]) were submitted to the FEJF on the Wildland Fire Management Data (WFMD) compact disc (December 1999) from the Southwest Area Coordination Center. Wildfire records for the FWS, the BLM, the BIA, and the NPS were extracted from the compact disk and pooled into a single spreadsheet. Data in field names unique to a particular DOI agency were written into unique fields for that agency. Data in field names common to all DOI agencies were written into a common field shared by entries of all agencies. Wildfire records from states other than those within the WRAP region, records with a fire year other than 1996, all prescribed fires, and records indicating a total fire size less than 100 acres were removed. WFMD wildfire records did not provide a final fire size, but did provide acres burned for each of the one or more states in which a fire burned. Total acres burned were calculated for each fire record by totaling the acres burned across all states. The state designation for a fire event was determined by the state identified in the first state field for the fire event. When available, NFDRS fuel models were obtained for each fire record by using the first letter of the "fuel station" field. NFDRS fuel models were provided for 84% of the total number of DOI-1202 fires used in the final activity inventory.

Figure 2.1: Sequential Methodology for Creating 1996 Wildland Fire Activity Inventory



Sequential methodology used to create the FEJF 1996 Wildland Fire Activity Inventory from multiple data sources. Primary information sources appear in dark grey boxes, with the progression of fire records towards inclusion into the 1996 FEJF Wildfire Activity Inventory following dark arrows. All remaining records not following the dark arrows were omitted (light speckled box). Additional information, requested from GACCS or land management agencies, was occassionally needed if the temporal, spatial, or activity information provided was insufficient, as indicated by boxes with dashed borders. NFDRS fuel models and FS Region (dark grey box) were assigned using GIS as needed.

USDA Forest Service Fire Records. Text files for the USDA Forest Service (FS) were received electronically from the National Interagency Fire Center (NIFC) as individual report queries (RLLGFIR5, FLLGFIR3, FLENVIR1, FLEVENT1 and FLEVENT3) of the National Interagency Fire Management Integrated Database (NIFMID). Only wildfires larger than 100 acres in size, within the WRAP region, and only for the calendar year 1996 were queried. Using FS Region, Forest, District and fire number as delineators, the results of the report queries were integrated into a single spreadsheet. “Strategy met date” was used as the control date for FS records.

FEJF’s Initial Federal Fire Database. Records of the DOI and FS spreadsheets were then combined together to produce a single “federal database” spreadsheet. Where possible, data in fields common to both DOI and FS datasets, such as “fire name,” were placed in single fields. Data in fields unique to either FS or DOI agencies were not combined. The field names of all available information received electronically from DOI agencies (Table 2.1), and the USDA FS are shown below. Fields common to both tables (appearing as bold text) were used to determine the approximate timing and location of a given wildfire, as well as to ascertain generalized activity information such as fuel type and acreage burned.

Initial review of the federal database information revealed a considerable discrepancy in the annual total number of fires and acres burned in each state compared to the figures reported in the USDA Wildfire Statistics Publication. Furthermore, records in the federal database contained approximate temporal information but not the daily fire size growth data needed for the emissions inventory. The next step of the data gathering process was retrieval of 1996 National Situation Reports and ICS-209 forms. These data sources would likely provide the best temporal and spatial resolution and could also be used to resolve acreage discrepancy issues among information sources.

National Situation Reports. The National Situation Report, published by NIFC, summarizes national daily resource usage and significant (i.e. greater than 100 acres) wildfire activity. Each daily report indicates the name, state location, responding agency designator, and total fire size. General location and vegetation information is usually summarized for the larger, multiple-day wildfire events. Daily acreages for fire events growing larger than 100 acres in size were transcribed into a new spreadsheet (from hardcopy) along with the report date, fire name, agency, and state location. Vegetation descriptions and specific location information (e.g., latitude and longitude) were added to the spreadsheet when available. Agency names were associated with agency unit designators using the NIFC Unit Identifiers (NFES 2080[2] publication (April, 1999)). After the spreadsheet was populated with available data, the date field was adjusted to accommodate the delay between the occurrence of the fire event and the publication

Table 2.1: DOI Wildfire Occurrence Database Field Names

Agency names appearing in bold next to field names indicate reporting unique to that agency. Records in fields with names appearing in bold were integrated between DOI and FS databases, and used to construct the final wildfire activity inventory. (*) Indicates fields that were used to calculate total acres burned for DOI wildfire records.

UNIT ID	MATERIAL	WIND MIN
YEAR	IGNITION FACTOR	FLAME MAX
FIRE NUMBER	CLASS PEOPLE	FLAME MIN
FIRE TYPE	AGE	ROS MAX
GENERAL CAUSE	SEX	ROS MIN
SPECIFIC CAUSE	ACTIVITY	NFFL FUEL MODEL
PEOPLE	DAMAGE	TEMP MAX
NET CHANGE	**STATE**	TEMP MIN
FIRE NAME	OWNERSHIP	HUM MAX
AREA NAME	FIRE NUMBER	HUM MIN
LATITUDE	VEG TYPE	WIND MAX
LONGITUDE	ACRES*	WIND MIN
COST CODE	STATE	FLAME MAX
OWNER	OWNERSHIP	FLAME MIN
FISCAL YEAR	FIRE NUMBER	ROS MAX
FISCAL 1	VEG TYPE	ROS MIN
FISCAL 2	ACRES*	PREBURN TONS / AC
PROBLEM CLASS	STATE	CONSUMPTION %
TOWNSHIP	OWNERSHIP	PREBURN TONS / AC
RANGE	FIRE NUMBER	CONSUMPTION %
SECTION	VEG TYPE	PREBURN TONS / AC
MERIDIAN	ACRES*	CONSUMPTION %
UTM ZONE	STATE	PREBURN TONS / AC
UTM EASTERN	OWNERSHIP	CONSUMPTION %
UTM NORTHERN	FIRE NUMBER	PREBURN TONS / AC
DATE DISCOVERED	VEG TYPE	CONSUMPTION %
TIME DISCOVERED	ACRES*	FIRE ESCAPE **(NPS)**
TYPE DISCOVERED	STATE	ESCAPE NUMBER **(NPS)**
ACRES DISCOVERED	OWNERSHIP	PECIAL BLM FLAG **(BLM)**
DATE INIT ATTACK	FIRE NUMBER	DAY OF WEEK STARTED
TIME INIT ATTACK	VEG TYPE	INVESTIGATED?
TYPE INIT ATTACK 1	ACRES*	SUSPECT KNOWN?
TYPE INIT ATTACK 2	STATE	SUSPECT TYPE
TYPE INIT ATTACK 3	OWNERSHIP	REF PROJECT NUMBER
TYPE INIT ATTACK 4	FIRE NUMBER	PNF COMPLEXESCAPE
TYPE INIT ATTACK 5	VEG TYPE	PNF COMPLEX VALUES
AMOUNT INIT ATTACK 1	ACRES*	PNF COMPLEX FUELS
AMOUNT INIT ATTACK 2	STATE	PNF COMPLEX DURATION
AMOUNT INIT ATTACK 3	OWNERSHIP	PNF COMPLEX AIR QUALITY
AMOUNT INIT ATTACK 4	FIRE NUMBER	BEN-PRGM FOREST ACRES **(BLM)**
AMOUNT INIT ATTACK 5	VEG TYPE	BEN-PRGM RANGE ACRES **(BLM)**
ACRES INIT ATTACK	ACRES*	BEN-PRGM WILDLIFE ACRES **(BLM)**
DATE CONTROLLED	STATE	BEN-PRGM HAZ-RDN ACRES **(BLM)**
TIME CONTROLLED	OWNERSHIP	BEN-PRGM WTERSHD ACRES **(BLM)**
ACRES CONTROLED	FIRE NUMBER	BEN-PRGM ECOSYTM ACRES **(BLM)**
ACRES TOTAL	VEG TYPE	BEN-PRGM OTHER ACRES **(BLM)**
DATE OUT	ACRES*	NAME
TOPOGRAPHY	UNIT	TITLE
ASPECT	PLOT NUMBER	DATE
SLOPE	PLOT OBJECTIVE	NAME
ELEVATION	FIRING STRATEGY	TITLE
NFDRS STATION	FIRING METHOD	APPROVED DATE
FUEL STATION	COST PER ACRE	
BEHAVIOR	NFFL FUEL MODEL	
BURN INDEX	TEMP MAX	
ADJ CLASS	TEMP MIN	
RVC	HUM MAX	
FORM OF HEAT	HUM MIN	
CERTAINTY	WIND MAX	
EQUIPMENT		

Table 2.2: National Interagency Fire Management Integrated Database Field Names
Records in fields with names appearing in bold were integrated between DOI and FS databases, and used to construct the final wildfire activity inventory.

FIRE IDENTIFICATION NUMBER	**TOWNSHIP**
FOREST SERVICE REGION	**RANGE**
FOREST IDENTIFIER	**SECTION**
DISTRICT IDENTIFIER	**LATTITUDE**
FIRE YEAR	**LONGITUDE**
FIRE NUMBER	**NFDRS FUEL**
STATE	SLOPE
SIZE CLASS	ASPECT
TOTAL ACRES	ELEVATION
DISCOVERY DATE	VEGETATION CLASS
DISCOVERY TIME	IGNITION DATE
FIRE NAME	IGNITION TIME
STRATEGY MET (CONTROL) DATE	

date of fire data in the National Situation Report. Specifically, one calendar day was subtracted from the entry date for each wildfire event.

To help build on the inventory created from the National Situation Reports and achieve more precise location and fuels information, copies of 1996 ICS-209 wildfire forms were obtained from the Geographic Area Coordination Centers (GACCs) of the WRAP Region. Forms were received from Northern and Southern California, Eastern and Western Great Basin, Rocky Mountains, Northern Rockies, Pacific Northwest, and Southwest GACCs. Wildfire information included on the ICS-209 forms varied. The key information typically captured included:

- county,
- report date and time,
- incident name and number,
- state,
- agency,
- unit designation,
- legal location,
- latitude/longitude,
- fire size,

- percent contained,
- start date and time,
- observed fire behavior, and
- a vegetation description (occasionally available).

Report times were used to select the most recent reported acreage for each burn day if multiple reports were completed within one burning period. The most recent reports were selected to reflect the maximum daily acreage burned between burning periods. These usually included reports completed towards the end of the day after wildfire activity diminished, or reports completed during the morning hours of the next burn day.

The initial data entered into the FEJF's wildfire activity database were the data from the National Situation Reports. This data was augmented with data from the ICS-209 forms. The fire name, report date, agency and unit designation, and fire were used to correlate daily data for fires included in both the National Situation Reports and ICS-209 forms. For the daily fire size field, the ISC-209 forms were presumed to be the primary information source.

In terms of the daily fire size field, records in the FEJF's wildfire activity database can be described as follows:

- Some fire records (approximately 20%) have daily fire size data from the National Situation Reports Only.
- Some fire records did not appear in the National Situation Reports and daily fire size data comes from the ICS-209 forms only.
- Some fire events were included both data sources. In all of these instances, the daily fire size data from the ICS-209 form was used. ICS-209 form data were also used to accommodate wildfire growth for multiple day fires.

<u>Adjustments for Apparent "Negative" Fire Growth.</u> Daily growth was calculated for each fire day as the difference between a fire's reported size from one day to the next. On occasion, a fire exhibited negative growth as a fire's size was reported to be smaller than it was the day before. For example, the "Canyon Fire" fire in Table 2.3 below, reported on Day 3 as growing to as large as 150 acres, actually never grew to larger than 100 total acres between the time it was first reported (50 acres), and the time a final ICS-209 form was completed (100 acres). In the FEJF database, the Canyon Fire showed negative growth on report Day 3. In reality, the Canyon Fire should have shown growth in the database after its largest reported size on Day 2. The apparent negative growth showing on report Day 4 may be explained as the difference between estimated acres burned at the time of reporting on Day 3 and the determination of actual acres burned upon

control or containment on report Day 4. Physical measurement of the Canyon Fire perimeter or a geographic position system measurement may have been used for the more accurate fire size data on report Day 4.

Table 2.3: Corrected Wildfire Daily Reported Size

A wildfire's daily reported size corrected to reflect a positive daily growth value. The original fire size and representative growth are shown on the left side of the table, with the acreage adjustment and positive growth on the right. A fire's final size was calculated as the sum of all positive growth values.

Date	Fire Name	Fire Size[a] (acres)	Growth[b] (acres)		Fire Size[aa] (acres)	Growth[bb] (acres)
7/25/96	Canyon Fire	50	(+) 50		--	(+) 50
7/26/96	Canyon Fire	100	(+) 50	→	--	(+) 50
7/27/96	Canyon Fire	150	(+) 50		100	(+) 0
7/28/96	Canyon Fire	100	(-) 50		--	(+) 0
					Acres Total	100

a Fire size as reported on ICS-209 Form.

aa Corrected fire size to reflect only positive growth values. No change indicated by (--).

b Positive and negative growth calculated as the difference between reported sizes.

bb Positive growth calculated as the difference between reported sizes.

To correct for apparent negative growth in fire size, a fire's latest, largest reported size was substituted for the reported size for the day or days between the largest reported size and a fire's earlier, largest reported size. Fire sizes reflecting negative growth that spanned multiple days were corrected similarly to the example illustrated in Table 2.3. For each day, acreages identical to that of the fire's earlier and largest reported size was assigned to reflect zero growth for that day. The total size of a fire was calculated as the sum of all positive daily growth values between the initial report date and the final report date.

<u>Spatial and Vegetative Cover Data Issues.</u> The reporting of spatial and vegetative cover information for fires in the FEJF wildfire database was often incomplete from one day to the next. Daily reports for a five-day fire event, for example, may have only reported a legal location or vegetation description on two of the five daily ICS-209 forms. The spatial and fuels information from these two reports were then used to fill in the needed information for each of the other three daily fire records. This "gap filling" method was used to populate as many records as possible with accurate spatial and fuels information.

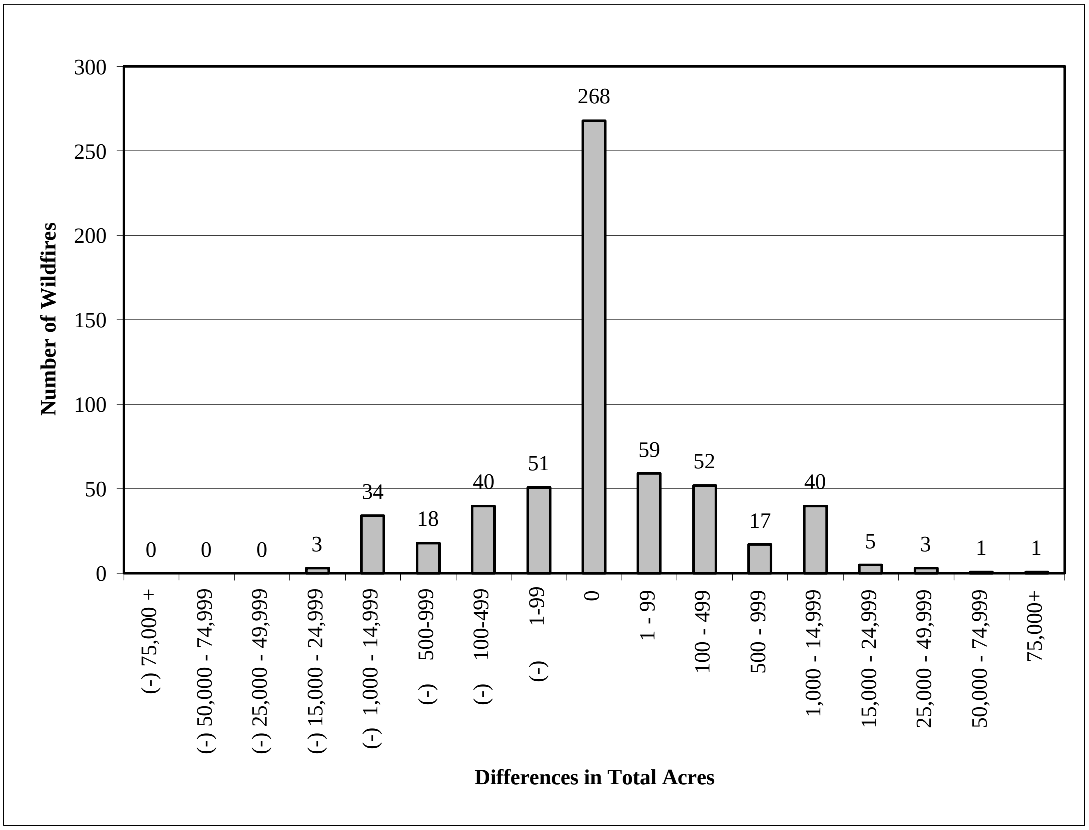
Gap filling could not be achieved for daily National Situation Report fire records that were not associated with at least one ICS-209 form. Therefore, spatial and fuels information was requested from the appropriate GACC or dispatch so that each fire record had at location information (at least a coordinate pair or legal location) and a preliminary fuel type description.

<u>Final Database Review Process.</u> Upon completion of the federal database (from electronic downloads) and ICS-209 form / National Situation Report inventory (as described above), an evaluation of the activity information was performed in an effort to determine the accuracy of each inventory. Initially, a comparison was made between fire acreages and number of fire events in the database and the baseline acreages and number of fire incidents depicted by the USDA Wildfire Statistics Publication. Prior to this evaluation, it was first necessary to determine fire occurrences that appeared in both the ICS-209 form and National Situation Report Inventories. Common fields from each inventory, such as fire name, fire number, total acres burned, legal location and / or latitude and longitude, state, and agency was used during the analysis to sort and pair records into two new spreadsheets of data; one containing matching fire records common to both inventories, and one containing non-matching fire records unique to only the federal database inventory.

All federal database records were first assumed to have a matching ICS-209 form / National Situation Report record. All federal database records not having an ICS-209 form / National Situation Report association were removed and placed in a separate spreadsheet for further review. Matching records shared the same or similar fire names, and burned in the same or similar place and time. Matching records often also demonstrated identical final fire sizes between those reported by the federal FS / DOI databases and ICS-209 forms. Fires were never matched based solely on the total acreage burned, although acreage was an important parameter considered during the pairing process. Figure 2.2 illustrates the range of difference between the final fire sizes of matching records, with nearly half (46%) of matching fires having identical acres burned. Assuming the accuracy of a fire's final size as it appears in the federal database inventory, the slightly skewed (+5%) distribution indicates that the ICS-209 forms / National Situation Reports are slightly more prone to over-report a fire's final, total size.

Figure 2.2: Distribution of differences in total fire size as reported between ICS-209 forms/National Situation Reports and Federal Database Records.

The total fire size as reported from federal database records was subtracted from the size calculated from the daily acreages of the ICS-209 forms / National Situation Reports.



During the pairing and review process, an acreage anomaly was discovered for DOI fire records. Numerous fires appearing in both the ICS-209 form / National Situation Report inventory and federal database inventories, having identical fire names, fire numbers, or similar spatial and temporal qualities were determined to be the same fire occurrence. However, total acres burned as listed in the DOI federal database records were consistently an order of magnitude higher than the total acres burned as derived from ICS-209 forms and National Situation Reports. It was concluded that the DIO federal database records were in error and, for the purpose of this final FEJF database review, total acres burned for wildfire records in the DIO federal database were adjusted (decreased by an order of magnitude).

Another issue encountered was the discovery of duplicate records within the federal database inventory. Prior to and during the separation of federal database records into the matching and non-matching record spreadsheets, an extensive analysis was conducted to review and discard duplicate records. The determination that a fire record was a duplicate record was facilitated by a tiered sorting of federal database records by state and fire name, then by acres burned and available spatial and temporal information. Grouped fire records believed to be the same fire event were then reviewed for similarities in location and timing. Records determined to be dissimilar from the grouped records were determined to be non-duplicate records and removed from the grouping. Records remaining within the group sharing similar locations and overlapping burning periods were then ranked for completeness. The record having the best available temporal, spatial, and vegetation information was retained. For matching fires common to both the federal database and ICS-209 forms / National Situation Reports, the federal fire record that indicated total acres burned nearest or identical to the calculated total acres burned from the ICS-209 form and / or National Situation Report, and where possible for the same agency, was selected if all of the considered records provided complete information.

Duplication among non-matching fires was determined using the methods described above. However, since actual acreage could not be verified, the record with the largest total fire size and having the most complete information was retained. Uncertainty in a duplicate determination (i.e. the only significant difference between two fires was the number of acres burned) was resolved by retaining both records. If the spatial and temporal parameters of two fire records were similar but not identical, a difference greater than 1,500 acres between the reported fire sizes was used to make the final determination that the two records were not duplicates.

The location information from the matching federal database records was used to gap fill the daily fire records from the ICS-209 form / National Situation Report inventory in much the same way as ICS-209 form fire records were used to gap fill fire records of the National Situation Report inventory. In addition, matching DOI federal database records provided ICS-209 form / National Situation Report records with an NFDRS fuel model assignment. During this integration process, ICS-209 form / National Situation Report fire records were supplemented with whatever spatial information may have been needed (with the exception of county name) from the federal database records, and the fuels information of ICS-209 form / National Situation Report records were greatly enhanced (including vegetation description and / or NFDRS fuel model classification). For each matching wildfire, NFDRS fuel models, latitude / longitude coordinates, and legal locations were added as needed from the single federal record to the one or more daily ICS-209 form / National Situation Report records.

The non-matching record spreadsheet was populated with all remaining federal database records not integrated or duplicated with fire records already appearing in the matching spreadsheet. DOI fires with a corrected final size of less than 100 acres were removed. Because the wildfires appearing in this dataset had no available paper record, and represented a significant percentage of the total acres burned between the matching and non-matching spreadsheets, the fires were developed into daily accounts of activity information. For each non-matching fire record, acres per day was calculated by dividing the total acres burned by the total number of days between the discovery date and the control date. Daily acreages were calculated for most of the non-matching federal database wildfires; however, the burn duration for a number of records could not be determined due to either a missing discovery date and / or control date, and were therefore omitted. Both matching and non-matching spreadsheets were then reunited into a single spreadsheet for further refinement and processing. This reunion led to the creation of the draft 1996 FEJF wildfire activity inventory; practically complete both temporally and spatially, with NFDRS fuel models assigned to the majority of the wildfires. An analysis of the acreages burned for each information source and for each state could finally be conducted, the results of which are presented in Table 2.4.

Table 2.4: Reported Acres Burned for Each Information Source and Each WRAP State

Reported acres burned for each information source and each WRAP state. Total acres burned are similar for the FS / DOI federal database and ICS-209 form / National Situation Report inventories, and the USDA Wildfire Statistics Publication. The FEJF Inventory was created by combining the ICS-209 form / National Situation Report records with supplemental, non-matching FS / DOI database records. The non-matching federal database acres added to the ICS-209 form / National Situation Report acres for each state are identified.

State	USDA Statistics	USDA FS Dataset	DOI Dataset*	FS & DOI Dataset**	209 / Situation Reports	FEJF Inventory	FS / DOI Acres Added***
AZ	178,960	121,883	18,756	140,639	178,532	**200,544**	22,012
CA	657,378	391,445	401,532	792,977	640,004	**918,081**	278,077
CO	96,730	27,671	54,844	82,515	67,540	**88,957**	21,417
ID	734,315	136,674	736,721	873,395	835,001	**924,537**	89,536
MT	205,280	20,450	67,647	88,097	176,112	**185,882**	9,769
ND	9,979	300	1,951	2,251	0	**2,251**	2,251
NM	162,574	59,388	73,681	133,069	130,828	**186,915**	56,087
NV	566,698	17,393	612,987	630,380	866,304	**949,415**	83,110
OR	545,985	260,770	321,436	582,206	712,901	**755,791**	42,891
SD	13,393	4,621	7,636	12,257	5,236	**13,272**	8,035
UT	537,889	54,999	435,589	490,588	487,199	**731,981**	244,782
WA	48,130	3,807	115,702	119,509	49,405	**132,310**	82,905
WY	512,904	35,578	301,727	337,305	166,576	**358,279**	191,702
WRAP Total	**4,270,215**	**1,134,979**	**3,150,208**	**4,285,187**	**4,315,638**	**5,448,215**	**1,132,575**

*Total acres for all Department of Interior wildfires reduced by an order of magnitude.

**Total acres of matching and non-matching fire records (duplicates, <100 acres, no discovery / control date removed).

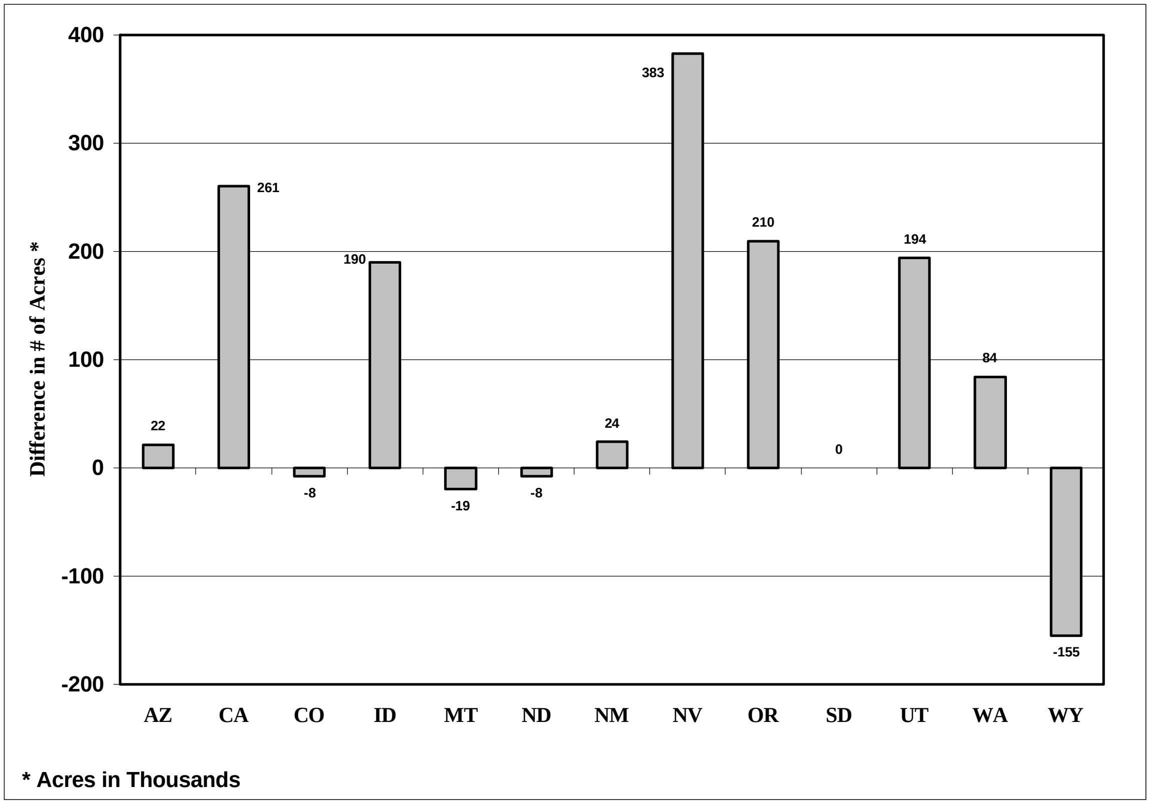
***Total acres from FS / DOI wildfires added to ICS-209 Form / National Situation Report acres for each state.

For all states except South Dakota there was a difference in acres burned greater than 1000 acres, between the draft FEJF activity inventory and the USDA Wildfire Statistics Publication, with acres burned in the draft FEJF activity inventory typically being higher than those reported by the wildfire statistics publication for most states (Figure 2.3)**.**

Wyoming Wildfire Activity Information. The relatively large negative difference in acres burned in Wyoming revealed an absence of fire activity in the draft FEJF inventory when compared to the activity levels in the other WRAP states, with all available source data exhausted. Wyoming Department of Forestry officials indicated that due to budget and personnel limitations, ICS-209 forms were completed for some, but not many wildfires in 1996. Supplemental activity information for Wyoming was made available and processed using the methodology described above as though actual ICS-209 forms had been submitted. The new fire records generally included date, total acres, county, and legal location. Legal locations were absent for many records. Some fuel descriptions and missing legal locations were obtained through direct communications with volunteer fire department contacts from the county in which the fire burned. With such little information to work with, determination of duplication between existing matching ICS-209 form / National Situation Report and non-matching federal database existing records was difficult. After best attempts at pairing were made, non-duplicated records were included in the draft FEJF inventory. The inclusion of the supplemental records increased the existing acres burned in Wyoming by 155,000 acres, thereby considerably narrowing the margin of difference of the annual number acres burned between the draft inventory and the statistics publication.

Figure 2.3: Differences in Acres Burned

Differences in the Annual Number of Acres Burned Between the FEJF Draft Inventory and the USDA Wildfire Statistics Publication for WRAP States. For a majority of the states, the inventory comprises more acres than are reported by the publication, with Wyoming having a distinct shortfall.



Analysis of the total acres burned as indicated by the federal databases, the ICS-209 forms / National Situation Reports, and the USDA Wildfire Statistics source revealed approximate similarities of the total acres burned for each source (Table 2.4), compared to the total acres burned in the draft inventory calculated from daily acreages. This is especially true for California, Idaho, Nevada, Oregon, and Utah (Figure 2.3). Even without the inclusion of additional acres for Wyoming, the draft inventory demonstrated a significant surplus in total number of acres burned despite attempts to thoroughly review information sources and prevent duplication of records.

Fire Complexes and Constituent Fires. One possible explanation for this surplus was the double counting of acres between fires reported as complexes in addition to the acres reported for constituent fires. Complex fires were first identified and tagged if the word complex appeared next to the fire name. Additionally, National Situation Reports and ICS-209 forms were reviewed for further identification of complexes and the names of all fires that may have burned as part of the complex. Records for each state were also sorted only by location and date so all fires having the same or similar temporal and spatial occurrences could be evaluated. Field offices were contacted for constituent identification if no constituent fires could be identified for a tagged complex. Because the records of the individual fires provided more precise spatial resolution and fuels information, the records for complex fire events were removed from the inventory if the total acres burned of the complex fire approximated the sum of the total acres burned of all constituent fires. However, some complex records were retained and constituent records discarded if the total acreage of a complex fire, including all constituent fires, was significantly higher than the total combined sum of total acres burned of the constituent fires.

The removal of complex fires ultimately reduced the total number of acres burned in the draft FEJF inventory by over a half million acres. The final number of fires and acres burned are summarized for each information source before and after processing in Table 2.5 below. Numbers appearing in bold indicate the number of fires and acres burned that were retained for inclusion into the final FEJF Wildfire Inventory. This includes: non-matching federal database records, ICS-209 form / National Situation Report records, and Wyoming state records that were not duplicated, were 100 acres or larger in total size, were not prescribed fires, and were either individual fire records or part of a larger complex. The total acres of the final FEJF inventory was 15% larger than indicated by the USDA Wildfire Statistics Publication, and contained 14% fewer fires.

Using Montana State University's Environmental Statistics Group's graphical locater website, internet resources were utilized to translate known spatial information for any fire that may have been missing a county, legal location or coordinate pair. For example, a fire's known legal location was used to ascertain the missing latitude, longitude, and county. Similarly, if only latitude and longitude were known, legal location and county may have been derived. Wherever possible, a fire's legal location was used as the primary location source if other spatial parameters were needed. After all spatial information had been obtained, the degrees, minutes, and seconds of each coordinate were subsequently converted into decimal degrees using ((degrees + (minutes / 60) + (seconds / 3600)*(-1)).

Table 2.5: Summary of Acres and Number of Fires

Final summary of the acres and number of fires among information sources before and after processing and comparison between the total annual number of fires and acres appearing in the final FEJF Inventory and those reported by the USDA Wildfire Statistics Publication.

Category Description	Total Number of Acres Burned	Total Number of Fire Records
FS / DOI Database Total	6,187,665	2,643
FS / DOI Duplicate (Omit)	-403,148	-80
FS / DOI Complex (Omit)	-279,649	-38
FS / DOI Non-Matching (Omit)	-1,359,596	-135
FS / DOI Prescribed Fires (Omit)	-107,137	-162
FS / DOI Matching Integrated (Omit)	-3,085,805	-590
FS / DOI Acres <100 (Omit)	-39,297	-1,169
FS / DOI Non-Matching Retained	913,034	469
Sitrep / 209 Inventory Total	4,315,638	795
Sitrep / 209 Complex (Omit)	-353,910	-22
Sitrep / 209 Inventory Retained	3,961,728	773
Wyoming State Total	409,775	135
Wyoming State Duplicate (Omit)	-254,579	-29
Wyoming State Retained	155,196	106
FEJF Wildfire Inventory Total	**5,029,958**	**1,348**
Wildfire Statistics Total	**4,270,215**	**1,561**
Difference	759,743	-213

Location Data. For fires missing latitude, longitude, and legal locations, the field office of the fire's respective agency was contacted to obtain either a coordinate pair or legal location. A vegetation description was also requested from field offices for any fire not already having a vegetation description or NFDRS fuel model assignment. For a handful of Wyoming State Forestry records, county was the best spatial resolution that could be provided for a number of fires. County centroid was used to populate the latitude and longitude and legal location fields of these fires. Field offices also occasionally collaborated total fire size with their records. Discrepancies were resolved by adjusting the total fire size for an increase or decrease of total acres burned by increasing or decreasing the daily growth value of the last or last few daily fire records. Fires not meeting the 100-acre criteria were subsequently removed from the inventory.

FS Regions were assigned to all wildfires using a fire's latitude / longitude coordinates and Geographic Information Systems. Generation of FS Region Number and Name were conducted through the Oregon Department of Forestry. Following the generation of FS Regions, state designations were changed for some fires using legal location if a fire's coordinates placed the fire in a state on the FS Region map overlay that was different than the state identified in either ICS-209 forms / National Situation Reports or the federal database inventory.

Fuel Loading Data. NFDRS fuel models for fires missing a fuel model were generated using GIS techniques. GIS-derived NFDRS fuel models were assigned to roughly 27% of the total number of wildfires in the final FEJF wildfire activity inventory. NFDRS fuel models already assigned to a fire record were not changed, unless obvious errors were observed (i.e. Southern Pine in Washington State). In these rare instances, vegetation descriptions in conjunction with the GIS-derived fuel model were used to determine which fuel model would most accurately reflect the vegetation type burned. For fires records for which no NFDRS fuel model was provided, and for which the GIS-derived fuel model indicated a “barren,” “water,” or “agricultural” designation, a fire’s vegetation description was solely used to determine the final fuel model. Less than 10% of the wildfires that were assigned an NFDRS fuel model were assigned models using vegetation description only.

2.3 Wildfire Activity Data QA/QC Procedures

Quality assurance and control measures were applied to wildfire activity information after all 1996 wildfire records were transcribed into electronic format from paper copies of ICS-209 and National Situation Report forms. After transcription was completed, more than 3% of the total number of fire records were randomly selected and reviewed to ensure that each fire:

1) Contained accurate temporal, spatial, and activity information as depicted in either the ICS-209 or National Situation Report;

2) Total fire size from ICS-209 reports were used in the instance that a fire appeared in both reporting methods and the total fire size differed;

3) Daily growth values were calculated accurately as the difference between total fire size from one day to the next, with negative growth values corrected by substituting the most recent positive growth values for the day or days for which negative growth was demonstrated, and;

4) A fire’s final size was calculated accurately as the sum of all daily growth values.

Other QA / QC measures were executed during the wildfire pairing process between the ICS-209 / National Situation Report wildfire inventory and the FS / DOI inventory. The pairing process itself ensured some degree of accuracy of the temporal, spatial, and activity information of both inventories, as these components were used to pair candidate records and could be used to identify obvious data inputting errors. (As an example, during this process, total fire sizes for matching DOI fire records were discovered to be an order of magnitude higher than the total fire sizes as reported by the ICS-209 / National Situation reports and FS / DOI records were corrected prior to the further pairing of wildfire records.) After all matching records were identified, a fire’s name, location, approximate date of occurrence, and total fire size were used to reevaluate the pairing procedure and ensure accuracy of a fire’s matching / non-matching determination.

Duplicate record determinations among matching FS / DOI database records were also reevaluated to ensure that needed information was not being deleted as duplicate records were discarded.

The substitution of missing spatial and activity components from matching records of the FS / DOI inventory to records of the 209 / Situation Report inventory were also reviewed due to the high degree of error associated with gap filling coordinates, legal location, and NFDRS fuel model from single fire records into multiple-day fire events for hundreds of fire pairs. The review was conducted using tiered sorting techniques and scrutiny of the data to identify individual fire records mistakenly assigned another fire's spatial information or NFDRS fuel model.

Remaining FS / DOI non-matching records were reviewed to ensure that no matching fire record appeared in the ICS-209 / National Situation Report dataset. During this review process, several fires were determined to be common to both inventories, although they did not share identical fire names. This was often a result of a misspelling or partial spelling of a fire's name as it appeared in the FS / DOI dataset. The record having the least complete information was removed from the dataset. If both records contained complete account of spatial, temporal, and activity information, the record having the smaller total fire size was removed. Non-matching records were further reviewed for duplication that may not have been initially apparent. Incomplete records or records having more than a 1,500 acre difference and burning at approximately the same time and place were removed from the final activity inventory.

The completed draft 1996 wildfire inventory consists of fire records from both ICS-209 / National Situation Report and FS / DOI inventories. Fires burning during complex fire events (individual fires managed as a single event due to temporal and spatial proximity) were identified and reviewed. Land management agencies were asked to provide the names of constituent fires for complexes identified in ICS-209 form and National Situation Reports for which constituent fire names were not disclosed. A QA / QC review of complex and / or constituent fires that were discarded due to combined reporting was conducted to ensure that acreages were correctly represented in the FEJF dataset.

The total number of fire records and total number of acres burned from the original FS / DOI inventory were used to ensure that each fire and acre were accounted for in the FEJF wildfire activity inventory. This crucial step was to ensure that the multiple decisions made to ultimately include fire records in the database were appropriate.

Prior to and during creation of the activity inventory, the total number of fires and total number of acres burned (size classes D-G) in each state were compared between figures published in the USDA Wildfire Statistics Publication to those derived in the activity inventory. This provided a reasonable "baseline" estimate for which a state-by-state account of wildfire activity information could be assessed. The comparison was not used to set an upper-limit in the total number of acres or number of fires for any state, but rather a reasonable approximation of activity information that should be captured for each state, from all data sources, within the activity inventory. After the inventory was completed, final acres and fire numbers were compared for each state to illustrate differences and similarities of total acres burned. (This QA / QC step identified significant disparities in the data. For example, the total number of acres burned in Washington, as reported within the USDA statistics publication [48,130 acres] was incorrect. The total fire size for the largest fire in Washington, as provided by the FS / DOI database for the Cole Creek Fire, was confirmed by independent field office inquiry. The total acres burned by the Cole Creek Fire [57,520 acres] alone surpassed the total number of acres reported in the wildfire statistics publication.)

2.4 Prescribed Fire Activity Data

2.4.1 Requested Information

All available 1996 wildland prescribed fire activity information was requested at the state and federal levels from smoke management and air quality officials for each state of the WRAP region. As individual fire records would be needed to satisfy rather precise temporal, spatial, and activity criteria for modeling purposes, any information that could be used to ascertain a prescribed fire's location (i.e. legal location, latitude / longitude coordinates, and county), timing (burn date or season) or duration, and such fuels information as vegetation type, acres burned, tons burned, burn type (piles or broadcast) was specifically requested. There was no de-minimus activity level for the requested prescribed fire information. Officials were also asked to include any information about land ownership (private, federal, state, etc.) and, if possible, to indicate how complete the prescribed fire data were with respect to capturing *all* prescribed fire activity throughout the state (or region) and during calendar year 1996.

2.4.2 Data Sources

Prescribed fire information was received electronically (database or spreadsheet format) from smoke management or air quality officials for Arizona, California, Northern Idaho, South Dakota, Montana, Washington, Oregon, Wyoming and Colorado. New Mexico, Southern Idaho, and Utah provided spatial and temporal data via facsimile, and no information was received from Nevada and North Dakota. Generally, information received from interagency or state-facilitated smoke management programs encompassed prescribed fire data for multiple federal and state land management agencies of a state or region. Some activity data were received independently from individual federal and state agencies.

Prescribed fire information from the 1996 Wildland Fire Management Data CD-ROM (December, 1999), submitted by the Southwest Interagency Coordination Center, was also utilized as a primary information source for Department of Interior (DOI) Agencies for some states in which prescribed fire information was incomplete or not submitted at all. The CD-ROM provided a detailed summary of prescribed fire activity reported by Department agencies (Bureau of Indian Affairs, National Park Service, Fish and Wildlife Service, and Bureau of Land Management) for individual prescribed fire projects reported on DOI-1202 wildland fire forms. With the exception of several ranger districts in southern Idaho and New Mexico, the USDA Forest Service offered no independent prescribed fire information except for information that was collected and submitted through a smoke management program.

2.4.3 Data Evaluation

Information received from smoke management programs and independent sources not already in spreadsheet format were exported from database or transcribed from hard copies into separate spreadsheets. The temporal, spatial, and activity information contained within individual fire records for all sources was then reviewed to evaluate and ensure that each fire record reflected:

- a specific ignition date or burn duration,
- a precise burn location, and
- a quantity of fuel consumed.

Records were removed if:

1) an ignition / accomplishment date was not indicated, or
2) the date indicated an ignition / accomplishment date other than 1996;
3) no fuel was consumed, as indicated by a zero value for both acres burned and tons burned, and
4) the record did not indicate either a legal location or latitude / longitude coordinate pair.

For a few records missing latitude / longitude coordinates and legal location, precise spatial specificity was achieved through assigning a random location within the state, county, and land management area designated in the fire record. Other prescribed fire records that included general temporal, spatial, and activity information but not the required, specific data elements were retained. For example, if a fire record indicated a multiple-day burn duration between an ignition date and an end date, but not a specific burn date, the record was retained because the required information could be obtained from the information provided. Similarly, if the record indicated a legal location where a latitude / longitude pair was needed, the record was retained because the latitude / longitude pair could be derived.

Fire records having complete or sufficient spatial, temporal, and activity components were processed so that they could be uniformly placed, as completely as possible, into a single prescribed fire activity inventory. The inventory was structured to accommodate available information common to most information sources, and to satisfy the resolution required for emissions inventory development. Some activity information, fuel moisture for example, was not integrated in the composite activity inventory because most information sources did not report fuel moisture information.

Common fields such as burn number, burn type, agency, fuel type, burn date, acres burned (piled and/or non-piled), fuel loading (piled and/or non-piled) in total tons and tons per acre, legal location, latitude/longitude, state and county name were available in most information sources for most fire records. Required fields, such as latitude/longitude and fuel loading, which were not common to a particular information source or absent from individual records were acquired, either through calculation or inference from other information that was provided as part of the record (see examples listed above). The methodology employed to build a consistent quality prescribed fire activity inventory from the disparate information sources is described below for each critical parameter.

1) Temporal: Single fire records indicating a burn duration greater than one day (i.e. the start/ignition date differed from the end/control date) were developed into a number of multiple, daily records equaling the burn duration with a maximum burn duration of seven days beginning with day of ignition. This operation was performed on less than 1% of the total number of prescribed fires. If only a single date was provided, either a request date or an accomplishment date, the date was used as both the ignition date and the end date, thus producing a single-day burn event.

2) Spatial: Air Sciences Inc. utilized geo-referencing techniques to obtain required latitude/longitude coordinate pairs and county information from the legal locations provided with fire records. Latitude/longitude coordinate pairs were geo-referenced from the legal location for 96% of the total number of prescribed fires. Including the records for which FIPS identification was provided (but not used as a county identifier), county was determined for 94% of the total number of fires. Of the fires for which county was determined by geo-referencing techniques, the latitude/longitude coordinates provided directly from federal/state information sources were used to obtain the county for 3% of prescribed fires. County was indirectly determined for the remaining 97% of fire records by geo-referencing latitude/longitude coordinates that were derived through geo-referencing legal locations. This two-tiered process was performed to utilize location data provided directly from an information source whenever possible.

3) Activity: Fuel loading, when missing, was assigned to fire records by averaging the known fuel loads of other fire records that burned within the same state. The fuel loading of fires averaged had the same or similar burn and vegetation types, and wherever possible, shared the same agency and fire name as the fire with the missing loading. This technique was performed for only 4% of the total number of prescribed fires, the majority of which (97%) were submitted from Idaho. Other records processed in this way were for fire events in Montana, Oregon, and Washington.

It was necessary to use default NFDRS fuel loading values in the event that they were not provided and could not be determined. Only 4% of total number of prescribed fires were assigned fuel loadings from NFDRS fuel models, including all DOI-1202 fires and all fires submitted from the USFS in New Mexico. Of DOI-1202 fire records, NFDRS fuel models were not provided for 66% of the fires. In these instances, an NFDRS fuel model was assigned to each fire using geo-referencing techniques. Air Sciences Inc. utilized a fire's latitude/longitude coordinates (2%) and legal location (98%), and an NFDRS fuel model map overlay to assign NFDRS fuel models. The map was derived from a combination of satellite imagery used to create a landcover database for the conterminous U.S. (Loveland and others, 1991), and ground data sampled from across the U.S. (Burgan and others, 1997). A table of NFDRS fuel model fuel loadings were used to assign loading values.

For both state and DOI-1202 fire records with a burn duration greater than one day, the fire's total fuel loading and total acres burned were divided by the total number of burn days to derive the fuel loading and acres burned for each day. Acres burned and/or total fuel loading was divided by burn duration for less than 1% of the total number of fire records.

In the absence of a burn type designation, a "non-piled" burn type was assumed. Burn type was only used to categorize piled/non-piled activity information if the activity information provided was not already separated into a piled or non-piled burn type. For example, if total acres burned and total tons burned for both piled and non-piled burn types were already provided as part of the original activity information, then the burn type provided with the fire record, or assumed in the absence of a burn type specification, was not used. If the activity information was not already separated, on the other hand, then the prescribed fire's activity information was categorized as a non-piled. All DOI-1202 fire records and USFS New Mexico Fire records were assumed to be non-piled burn types because burn type was not specified for these records.

For DOI-1202 fire records only, the total acres burned for each fire record were corrected by an order of magnitude due to an acreage anomaly that was detected while creating the wildfire activity inventory. To ensure the appropriateness of this adjustment, the annual, recalculated acreages for the FWS lands were confirmed for all western states though independent peer review. With one exception, recalculated acres for each state matched acre for acre with those provided directly from the FWS. Total acres burned were corrected prior to the division of multiple burn days into single day events.

In the partial or total absence of data gathered from other federal and state agencies, 1996 DOI-1202 fire records were introduced into the prescribed fire activity information for some states. Essentially, records were used to substitute activity information for individual DOI land management agencies (FWS, BIA, NPS, and BLM) in states that did not provide any prescribed fire information at all, underreported activity, or simply did not capture activity information for one or more DOI agencies. Total annual number of acres burned was used to assess and compare activity for each state and federal agency between the DOI-1202 records and the non- DOI-1202 federal and state records. Activity information from DOI-1202 records was introduced to the state and federal information as a supplement to, or replacement for fire activity if additional information may have been needed.

A state-by-state account of the prescribed fire information most common to all information sources processed for inclusion into the 1996 prescribed fire activity inventory is described below, along with specific methods that were applied to process fire records from each state. Table 2.6 summarizes the detail of available temporal, spatial, and activity information received from state and non- DOI-1202 federal information sources, and reflects the total number of fire records reviewed, rejected, and retained for inclusion into the 1996 prescribed fire activity inventory for each state. To better illustrate the spatial, temporal, and activity information of each individual information source, and to demonstrate the necessity for inclusion of DOI-1202 activity information to state and non- DOI-1202 federal records, Table 2.6 does not summarize fire activity introduced from DOI-1202 records. Instead, the methodology used to process DOI-1202 records, and the comparative assessment and subsequent inclusion or rejection of DOI-1202 activity information is presented following the state-by-state descriptions of the prescribed fire activity information.

Table 2.6: Spatial, Temporal and Activity Detail of Information

		AZ	CA	CO	MT	N ID	NM	OR	SD	S ID	UT	WA	WY
Agency Information	**State**	X	CDF	X	X	X		X	X		X	X	X
	Private	X			X	X		X	X			X	X
	FS	X	CARB	X	X	X	X	X		X		X	X
	DOI	X	CARB	X	X	X		X				X	X
Temporal Information	**Ignition Time**			X				X					
	Ignition Duration							X				X	
	Begin/Ignition Date	X		X			X	X	X	X		X	
	End/Control Date	X		X	X	X	X	X	X	X		X	
	Monthly										X		
	Seasonal		CDF										X
	Annual		CARB										
Spatial Information	**Lat/Lon**	X							X	X			
	T/R/S	X		X	X	X	X	X	X			X	X
	County Name/FIPS	X	CDF	X			X	X	X	X	X	X	X
Activity Information	**Fuel Moisture**							X				X	
	Fuel Size Class							X				X	
	Non-Pile Loading	X		X	X	X		X	X	X		X	
	Non-Pile Acres	X		X	X	X		X	X	X		X	X
	Pile Loading	X		X	X	X		X		X		X	
	Pile Acres/# Piles	X		X	X	X		X		X		X	X
	Pile Type	X			X	X		X				X	
	Total Loading	X	CARB	X	X	X		X		X		X	
	Total Acres	X	CDF	X	X	X	X	X		X	X	X	
	Species	X		X				X	X			X	X
	NFDRS		CDF				X						
	Duff Depth	X						X				X	
Unit Information	**Harvest Date**							X				X	
	Burn Prescription							X				X	
	Burn Type	X		X	X	X		X	X	X		X	
	Topography				X	X		X				X	
	Rain/Snow-Off							X				X	
	Weather Station							X				X	
Total Number of Records		673	234	74	4,154	1,894	14	3,589	4	198	22	7,194	137
Total Number of Records Removed		0	234	2	2,246	1,123	0	0	0	1	22	0	137
% Total Records Removed		0%	100%	3%	54%	59%	0%	0%	0%	1%	100%	0%	100%
Total Number of Records Retained		**673**	**0**	**72**	**1,908**	**771**	**14**	**3,589**	**4**	**197**	**0**	**7,194**	**0**
Total Acres Retained		**49,717**	**0**	**19,211**	**74,987**	**29,129**	**10,010**	**137,508**	**2,129**	**30,205**	**0**	**126,868**	**0**

Spatial, temporal, and activity detail of information submitted from individual agencies or multi-agency smoke management programs. Some or all of the information that was received could not be incorporated into the activity inventory due to insufficient spatial, temporal, and/or activity resolution.

Arizona

Arizona's Interagency Smoke Management Program provided detailed prescribed fire information for state (Arizona State Land Department) and federal (FWS, FS, NPS, BIA, DOD, BLM) agencies that included tribal and some privately managed controlled burns. Daily PM_{10} emissions in total pounds were included in the information submitted, but were not included in the activity inventory. All prescribed fire activity information submitted from Arizona was retained.

Each daily fire record included a burn number, name, and ignition date, acres burned by burn type (broadcast activity, broadcast natural, piled, underburn activity, underburn natural) and/or vegetation type (grass, brush, pinion juniper, ponderosa pine), fuel loading burned in tons per acre for each burn type and vegetation type, and either a latitude/longitude coordinate, legal location, or both. All records also included county name, and vegetation type (ponderosa pine, pinion juniper, brush, and grass) were available for most records.

Total tons per acre burned were calculated for each record as the sum of all fuel loadings of each fuel type. GIS techniques were utilized to derive latitude/longitude coordinates from legal location for 91% of Arizona fires. The remaining 9% of the records indicated a legal location within Tribal lands. For Arizona fires within reservation boundaries, latitude/longitude coordinates were derived from the legal location using Montana State University's Environmental Statistics Group's graphical locater website due to geo-referencing technical issues.

California

The California Air Resources Board (CARB) and the California Department of Forestry and Fire Protection (CDF) both provided prescribed fire information for California. Some fire records received from both sources were not included within the final activity inventory because of insufficient temporal and spatial resolution.

Information for 1996 received from CARB included an annual account of agricultural burning, wildfire, and prescribed fire events at the county, air basin, and air pollution control district level (APCD) for multiple land management agencies. Burning activities for individual agencies were not identified. Records for each county, air basin, and APCD level were further categorized by fire type and burn purpose. Activity information was summarized by total tons of material burned for agricultural and prescribed fires, and by acres burned for wildfires. Also available for each county, air basin, and APCD, and for each fire and burn type combination, was annual tons of ROG, CO, NO_x, SO_x, and PM_{10} emissions.

CDF fire records included the total number of acres burned for each season, county, and CDF unit for the fiscal year 1997 (fall of 1996, winter spring and summer of 1997). The predominant NFDRS fuel model of the county and unit was also included for each record.

Colorado

Prescribed fire records from participating state (Colorado Department of Forestry and Colorado Department of Wildlife) and federal (NPS, BLM, FS) agencies were received from the Colorado Smoke and Open Burning Program. Two records indicating a burn year other than 1996 were removed. $PM_{2.5}$, PM_{10}, TSP, and CO emissions were provided for each burn project.

Prescribed fire records received from Colorado indicated burn number, burn name, agency and unit information, county, legal location, burn date, begin / end date and time, single or multiple fuel types (grass, sage, oak / aspen, oak / brush, aspen, pine, other), burn type (piled / non-piled) and total acres burned for all non-piled and some pile type burn records. For non-piled burn types, the acres burned, the available fuel loading in tons per acre, and the percent consumption of the available fuel loading were provided for each fuel type. For piled burn types, the total number of piles burned, the volume of each pile in cubic feet, and percent of the total volume consumed were provided.

Colorado prescribed fire activity information required extensive processing because fuel loading was not readily available for non-pile and piled burn types. To calculate the total fuel loading for non-piled burn types, the available fuel loading was multiplied by the percent of fuel consumed for each fuel type. The total fuel loading was then calculated by adding the tons per acre burned among all fuel types together and multiplying by the total number of acres burned. The total fuel loading of pile burns required conversion of pile volume to pile pounds. Following the direction of Colorado's smoke program, each cubic foot was assumed a mass of thirty-eight pounds. After the total mass in pounds was calculated for each pile, the percent total consumption and total mass were multiplied to derive the total mass consumed. Total pounds of fuel consumed were then converted into total tons consumed, and total tons per acre were calculated for pile type burn records that included total acres burned.

Total fuel loading and acres burned were divided by the total number of burn days to obtain daily acres and loading burned for fires burning longer than a single day. Daily prescribed fire activity information was calculated for 40% of the total number of Colorado prescribed fires. Latitude / longitude coordinates were derived for 94% of Colorado fires from legal locations using GIS.

Montana / Northern Idaho

The Montana / Idaho State Airshed Group Smoke Monitoring Unit provided prescribed fire information for Montana and Northern Idaho. Records for Federal (FS, BIA, and BLM), and state

(DNRC) agencies were submitted. Records for many private forestry companies were included. Agency names for a number of fire records could not be identified, and more than half the records in both states had an accomplishment year other than 1996, had no accomplishment date at all, or had a null acreage burned. Montana / Northern Idaho fire records typically contained agency name, agency unit name, airshed number (used to determine in which state a fire burned), burn type (pile, right of way, wildlife, broadcast activity, underburn, unspecified), fuel type (timber, shrub, litter, grass, brush, unspecified), pile type (hand, landing, dozer, jackpot), legal location, total acres burned and total tons per acre.

The fuel loading for some Montana / Northern Idaho fires was derived through averaging the known fuel loadings of the same or similar fuel and burn types and ownerships within each state. Most Montana fire records were submitted with a fuel loading. Sixty-four percent (64%) of Northern Idaho's prescribed fires were submitted with incomplete activity information. Fuel loading in total tons was the only other calculated field for Montana and Northern Idaho fire records. County and latitude / longitude coordinates were obtained using GIS for all Montana and Northern Idaho records.

New Mexico

Two of five National Forests in New Mexico, the Carson and Gila National Forests, submitted prescribed fire information that included burn name, legal location, fire behavior fuel model, start date / ignition date and control date / end date, and total acres burned. Fire behavior fuel models were converted to NFDRS fuel models for each fire (Aids to Determining Fuel Models for Estimating Fire Behavior by Hal E. Anderson, INT 122).

County and latitude / longitude coordinates were obtained using GIS for all New Mexico fire records. NFDRS default fuel loads were substituted as the fuel loading for each fire, as the Carson and Gila national forests did not provide actual fuel loadings.

Oregon

Oregon State Forestry provided a comprehensive prescribed fire inventory consisting of federal (FS, BLM, BIA), state (Oregon Department of Fish and Wildlife, State and County Forestry, Oregon Department of Forestry), and private timber industries. All Oregon prescribed fire information was included within the prescribed fire activity inventory. Many of the fields provided, however, could not be used in the activity inventory, as most other sources did not have such detailed information. No emissions estimates were submitted with Oregon's prescribed fire activity information.

Oregon fire records were received as two separate sets of information. One set contained individual burn project information, such as topography, burn type, available fuel loading, legal location, county, etc. The other set provided a daily summation of accomplishment information, such as actual fuel loading and acres burned, ignition date, fuel moisture, and other weather-related data. Records were linked and integrated among the datasets using a project's burn number as a unique identification key. All non-essential fields were removed prior to including Oregon's prescribed fire information into the prescribed fire activity inventory.

Records consisted of burn number, owner name, agency name, burn type (broadcast activity, broadcast natural, piled, underburn natural, underburn activity), species type (ponderosa pine, mixed conifer, douglas fir, cedar, hemlock, grass, sage, juniper), and pile type (grapple, hand, right of way, landing and tractor). Also included were ignition dates, county FIPS identification, total acres burned, and tons per acre burned for broadcast burn types and total tons burned for pile burn types.

Fuel loading in total tons was calculated for non-piled burn types and tons per acre were calculated for all piled burn types from the information provided. Latitude/longitude coordinates and county were assigned to all records using GIS and a fire's legal location.

South Dakota

South Dakota State Forestry provided prescribed fire records that included fire name, burn type (non-piled only), total acres burned, fuel loading in tons per acre, fuel type (grass/ponderosa pine), latitude/longitude coordinate pairs, and land ownership. Several private and a single state record were included within the information. Fuel loading in total tons was the only calculated field for South Dakota fire records. No emissions estimates were submitted with South Dakota's prescribed fire activity information.

Southern Idaho

The Idaho Department of Environmental Quality submitted hard-copy prescribed fire information received from the USFS, Intermountain Region. Only one record was removed because burn date was not provided. No emissions estimations were submitted with Southern Idaho's prescribed fire activity information.

Records included burn name, ignition date and end date, county, national forest and ranger district, latitude/longitude, total acres burned, elevation, burn type (broadcast or piled), burn purpose, and pre-burn fuel loading in tons per acre. Total fuel loading and acres burned were divided by the total number of burn days to obtain daily acres and loading burned for fires with burning longer than a single day. The fuel loading for some of the pile type fire records from this information source were derived by averaging the known loadings of other pile burn types throughout the state, and of the same forest if possible. Fuel loading in total tons was the only other calculated field. Fuel type for all fire records was determined based on fuel loading. Although species types would not be used in the final activity inventory, fuel loadings of less than five tons per acre were assumed to be grass, five to fifteen tons per acre brush, and greater than fifteen tons per acre timber. These designations were made with the expert judgment and guidance from fire and air quality officials of the Fire Emissions Joint Forum's Emissions Task Team.

Utah

Forestry, Fire and State Land Department's prescribed fire information was received from the Utah Division of Environmental Quality. The information could not be used, as only the total number of fires and acres burned by county and month were provided. No emissions estimations were submitted with Utah's prescribed fire activity information.

A separate, additional account of activity information was also received from the Utah Department of Environmental Quality. The information was received electronically, and included acres burned in 1996 by both prescribed and wildfire for each county. Table 2.6 does not reflect information from this source because the prescribed fire activity information could not be separated from the wildfire activity. Emissions estimates in tons per year for PM_{10}, CO, VOC, and NO_x were submitted for each county. Because this information included wildfire activity, and was not temporally or spatially specific, neither of the two sets of activity information received from Utah were used in the prescribed fire activity inventory.

Washington

Prescribed fire records for federal (DOD, FS, BLM, FWS), state (Department of Natural Resources, State Parks, Department of Transportation), and numerous private timber companies were received from the Washington Department of Natural Resources. All of the records received from Washington were included within the prescribed fire activity inventory, although many of the available fields could not be utilized. Emissions estimations included total daily NMHC, CH_4, CO_2, CO, TSP, PM_{10}, and $PM_{2.5}$. Daily TSP was also quantified for each burn type.

Records captured burn date, burn number and name, agency or land owner name, legal location, county FIPS identification, burn type (broadcast activity, pile, underburn natural, underburn activity), pile type, (grapple, hand, dozer, tractor, landing), fuel type (ponderosa pine, mixed conifer, douglas fir, cedar, hemlock, grass, sage, juniper). Total acres burned, total tons burned, and tons burned for both landing and non-landing pile types were also provided.

Total pile tons burned was calculated as a product of landing and non-landing tons burned. As projects can consist of both broadcast burning and pile burning, the total pile tons burned was subtracted from the total tons burned to obtain the fuel loading for the broadcast portion of the burn project. Tons per acre were subsequently calculated for both piled and non-piled burn types. Latitude/longitude coordinates and county were assigned to all records using GIS and a fire's legal location.

Wyoming

An inventory of permitted prescribed fire activity was received from the Wyoming Department of Environmental Quality. The inventory included federal (BLM, NPS, FS), state (Interagency Coordination / Dispatch, Wyoming Department of Game and Fish), and the prescribed fire activity of private landowners. No information was provided that confirmed if any of the burning actually occurred, or if so, exactly when it occurred. As a result, none of Wyoming's information could be used. TSP was estimated for the majority of burn projects in Wyoming's prescribed fire activity information, along with the anticipated seasonal distribution (expressed in terms of percent of total emissions).

Records did include burn name, agency name, county name, burn type (broadcast activity, broadcast natural, jackpot, pile), pile type (machine, tractor unspecified), fuel type (sagebrush, brush, grass, wood), and the total number of acres or piles permitted. Most records contained legal location and some included the anticipated burn duration in hours or days. The seasonality of the activity was conveyed as the percentage of seasonal emissions to the projected annual emissions.

Department of Interior 1202 Reporting (All States)

The DOI-1202 fire report form records of the Wildland Fire Management CD-ROM contain detailed prescribed fire activity information for individual burn projects for all DOI land management agencies. Unfortunately, as daily reporting of prescribed fire activity is not required, only the annual, total number of acres burned is reported for each project. Furthermore, fire reports do not capture the available or consumed fuel loading of the project area. The reports do however provide sufficient activity information and enough spatial and temporal specificity to allow for an approximation of the fuel type, fuel loading, and approximate timing of each fire. This approximation, although rough, is particularly valuable for those states where little to no prescribed fire activity information was submitted.

DOI-1202 fields common to the prescribed fire information submitted by state and federal agencies include: burn name, burn number, agency name, agency unit name, state abbreviation, total acres burned, latitude / longitude, legal location, discovery date, and control date. Most records contained a NFDRS fuel model designation. Records did not reference a specific burn type, or specify the name of the county in which a fire burned. All fires were appointed a "non-piled" burn type designation, and were assigned a NFDRS fuel model, if necessary, and county using the legal location and geo-referencing techniques. For each record, total acres burned were recalculated to reflect a reduction of the reported acres by an order of magnitude. For fires burning longer than seven days, control dates were changed to indicate a control date of seven days after the date of ignition. For any fire burning longer than a single day (i.e. the discovery date equaled the control date), total acres burned were further divided by the total number of days between the control date and end date. Only four records were removed because no activity information or spatial information was reported.

The annual number of acres burned among retained records for both DOI-1202 fire reports and other state and federal information sources were compiled to summarize prescribed fire activity information by state and agency, the results of which are presented in Table 2.7. The upper half of Table 2.7 illustrates acres burned for all agencies in each state among information provided directly from federal or state agencies. For non-DOI agencies, this includes the DOD, FS, private organizations, state agencies, and all unidentified agencies. The BIA, NPS, BLM, and FWS are included within the DOI information. Activity information as reported by DOI-1202 fire records is illustrated just below the state and federally reported activity. For each agency and state, the total difference in the number of acres burned is indicated. Federal or state-provided DOI activity was subtracted from the DOI-1202 reported activity of the same state and agency. Negative numbers reveal acres that were not included within the original state and federal information, but are included within the DOI-1202 information. Positive values indicate the possible over-reporting of activity data in state and federal information. Also indicated within the DOI-1202 reported activity section is the total number of DOI acres evaluated for each state, the total number of acres that were not included within a state's information, and the total number of DOI-1202 acres that were retained for each state.

Acres appearing for DOI agencies in bold or grey text were evaluated to assess the possibility of activity information being underreported or absent for a particular DOI agency in each state. For DOI agencies in both the state / federal reported activity and DOI-1202 reported activity sections of Table 2.7, activity information and associated differences appearing in grey reflect a difference in activity among State / Federal and DOI-1202 information sources that is not significant (acres are equal and there is no difference). Grey acres burned and differences indicate the possible over reporting of acres in state / federal information (acres are higher in the state / federal information and there is a positive difference). Gray acres burned and differences also indicate as an insignificant underreporting (acres are lower in the state / federal information, but at least 50% of the total acres reported by DOI-1202 reports is accounted for, and a negative difference is indicated). DOI-1202 acres were not added to existing state and federal information for these states and agencies, because the acres were mostly or entirely accounted for in the state / federal information.

Activity information and associated differences appearing in bold, on the other hand, reflect activity rates appended into state / federal information from DOI-1202 records. Very little or none of the total acres as reported by DOI-1202 reports were included within state / federal information, or no information was provided at all (acres are lower in the state / federal information, less than 10% of the total acres reported by DOI-1202 reports is accounted for, and there is a negative difference). With the inclusion of DOI-1202 fires for DOI agencies, the final, cumulative acres burned for all states, agencies, and information sources is presented below the

DOI-1202 reported fire activity information in Table 2.7, along with the percentage increase of total acres that were contributed by supplemental DOI-1202 records.

Table 2.7: Annual Acres Burned (State/Federal and DOI-1202)

State/Federal Reported Activity		AZ	CA	CO	ID	MT	ND	NM	NV	OR	SD	UT	WA	WY
Acres Burned (Non-DOI Agencies)	DOD	11	0	0	0	0	0	0	0	0	0	0	698	0
	FS	32,199	0	18,601	36,644	29,016	0	10,010	0	64,478	0	0	10,224	0
	PRIVATE	21	0	0	13,775	37,250	0	0	0	68,165	225	0	115,423	0
	STATE	308	0	587	3,827	2,568	0	0	0	1,080	1,904	0	0	0
	UNKNOWN	0	0	0	5,088	5,423	0	0	0	50	0	0	0	0
	Total Acres	32,539	0	19,188	59,334	74,257	0	10,010	0	133,773	2,129	0	126,345	0
Acres Burned (DOI Agencies)	BIA	10,001	0	0	0	538	0	0	0	329	0	0	0	0
	BLM	0	0	3	0	192	0	0	0	3,406	0	0	0	0
	FWS	3,419	0	0	0	0	0	0	0	0	0	0	523	0
	NPS	3,758	0	20	0	0	0	0	0	0	0	0	0	0
	Total Acres	17,178	0	23	0	730	0	0	0	3,735	0	0	523	0
Total Acres Retained		49,717	0	19,211	59,334	74,987	0	10,010	0	137,508	2,129	0	126,868	0
02 Difference in Reported Activity		AZ	CA	CO	ID	MT	ND	NM	NV	OR	SD	UT	WA	WY
Difference Between 1202 & Non-1202 Acres Burned (DOI Agencies)	BIA	-5,218	-18	-1,400	0	337	0	-20,921	-5	-4,534	0	0	-6,411	0
	BLM	-46	-6,094	-497	-5	0	0	-300	-1,115	2,256	0	-400	0	-7,941
	FWS	1,091	-7,926	-37	0	-804	-11,371	-300	-7,452	-8,514	-297	-140	-362	0
	NPS	-466	-6,268	-214	0	-229	0	-421	-46	0	-3,400	-175	-85	-1,837
Total Acres Evaluated		21,817	20,306	2,171	5	1,426	11,371	21,942	8,618	14,527	3,697	715	7,381	9,778
Total Acres Rejected		21,771	0	0	0	393	0	0	0	1,150	0	0	885	0
Total Acres Retained		46	20,306	2,171	5	1,033	11,371	21,942	8,618	13,377	3,697	715	6,496	9,778
		AZ	CA	CO	ID	MT	ND	NM	NV	OR	SD	UT	WA	WY
Cummulative Total Acres (All Sources)		49,763	20,306	21,382	59,339	76,020	11,371	31,952	8,618	150,885	5,826	715	133,364	9,778
% Increase with Supplemental 1202 Sources		0.1%	100.0%	10.2%	0.0%	1.4%	100.0%	68.7%	100.0%	8.9%	63.5%	100.0%	4.9%	100.0%

Table 2.7 shows the annual number of acres burned for each state and agency, as reported by state / federal and DOI-1202 information sources. State / federal reported activity was submitted independently or collectively by land management agencies, whereas DOI-1202 reported activity was obtained directly from DOI-1202 reporting for DOI agencies. Total acres burned for DOI agencies were evaluated between information sources to assess the possible underreporting of acres reported for DOI agencies by other state and federal sources. For a particular state and agency, the total acreage burned was compared to the total acres burned as reported from DOI-1202 reports. If differences were positive or equal, all activity information was assumed to be accounted for in the state / federal information, and no additional DOI-1202 activity was needed. If differences were negative, and at least 50% of the DOI-1202 reported activity was reflected for the same state and agency in the state / federal information, the majority of activity information was assumed to be accounted for in the state / federal information. Total acres burned and associated differences appearing in gray reflect these assumptions, and indicate that no activity was introduced for that agency from DOI-1202 reporting. Total acres burned and associated differences appearing in bold indicate an assumed underreporting in the state / federal information greater than 90%. The activity information from state / federal sources was supplemented from DOI-1202 reporting for these agencies. The cumulative, total number of acres burned for all states and agencies is indicated, along with the percent increase in total acres created by the supplemental DOI-1202 activity information.

2.5 Prescribed Fire Activity Data QA/QC Procedures

Prescribed fire activity records were sequentially numbered before processing to allow for comparison between the retained, processed records of the final activity inventory and the records as they originally appeared in the activity information submitted by inter-agency or independent federal and state sources or DOI-1202 reports. Subsequent to “tagging” the records, activity information was processed for each source, independently, to ensure consistency in the way fields were calculated or modified and to minimize the likelihood of error during processing. Between three and one hundred percent of the total number of prescribed fire records from each information source were selected from the final activity inventory (depending on the total number of fires contained within the source). Each field of every record in the inventory was evaluated via spreadsheet as having identical information as the same field of the original record, or if the field of the inventory record was calculated, that the calculated value could be reproduced from values provided as part of the original record. Records not included within the final activity inventory were also reviewed to ensure that sufficient information was not in fact provided, and that the rejection of the record was justified.

All calculated activity information for fire records appearing in the final activity inventory were additionally checked for accuracy by recalculating (via spreadsheet formula) total tons, total acres, and total tons per acre for both piled and non-piled burn types, recalculating total tons, total acres, and total tons per acre for all burn types, and subtracting the recalculated values from the original values. If no difference was found, fields were assumed to be calculated properly (fuel was neither lost nor gained). A macro-scale comparison (total number of fire records, total number of acres burned, total tons burned was then conducted for each information source that assured all activity information and fire records were accounted for between the original set of activity information, the activity information that was removed, and the activity information that was retained for inclusion into the prescribed fire activity inventory.

Total acres burned for DOI-1202 fire records were reduced by an order of magnitude to account for an apparent acreage anomaly discovered during the review of wildfire activity information for the 1996 wildfire emissions inventory. To ensure appropriateness of the reduction of prescribed fire acreages (assuming the same anomaly for wildfire acreages), the annual, recalculated acreages for the FWS lands were confirmed for all western states though independent peer review. With one exception, WRAP-wide, recalculated acres for each state matched acre for acre with those provided directly from the FWS.

Following internal quality assurance/quality control procedures, all prescribed fire activity information was sent out to all WRAP states for review. The activity information included the processed prescribed fire records from inter-agency or federal and state information sources, as well as the additional fire records that were introduced from DOI-1202 prescribed fire records. Records that were omitted subsequent to processing were not included. Parties were asked to review and compare the inventory to their records and report back any significant deviation in the total acres burned, the total fuel loading, and the total number of fire records, as well as the fuel loads and acres burned for the various fuel types and burn types of individual fire records. Changes, if any, discovered during the review process should be discussed.

2.6 Prescribed Fire Geo-referencing Using GIS

Many of the records in the prescribed fire activity dataset did not have latitude and longitude coordinates. Determining coordinates for every fire was imperative to the completion of the final emission inventory. In order to be accepted by the dispersion model, pairs of geographic coordinates were necessary. Many records without coordinates did have location information in the form of a Township Range and Section (TRS) code of the Public Land Survey System (PLSS). A geographic information science algorithm was developed to convert, or geo-reference, TRS codes to a latitude and longitude coordinate pair. This method was used to estimate coordinates for prescribed fire events that did not otherwise have a coordinate pair.

2.6.1 The GIS Algorithm

Available in the public domain is a PLSS map of townships and ranges (NationalAltas.gov). This digital map depicts the name, location and perimeter of recognized townships and ranges in the WRAP region. A “Township and Range” is, in its perfect form, a square– six miles on a side. There are generally 36 one-square-mile Sections in a Township and Range. The Sections are designed to be numbered 1 through 36 in a zigzag fashion, starting at the upper right corner and ending in the lower right. Furthermore, every Township and Range is tied to a local Meridian. A PLSS parcel is uniquely identified by Meridian Township Range (MTR) and then the Section number. In reality, the size, shape and organization of these land descriptions, as surveyed on the land, vary due to local conditions.

The PLSS map available for the WRAP region only had explicitly mapped information to the Township and Range level. That is, Section boundaries were not included. At the same time, it was an objective of the Fire Emissions Joint Forum to locate fire points to a precision of about one mile. An algorithm was developed to utilize the Section information in the fire record to arrive at the most precise latitude and longitude possible. The fundamental steps of the algorithm were:

1. Convert the fire record's PLSS information to an MTR and Section code;
2. Locate that MTR on the PLSS map;
3. Within the MTR, estimate the location of the center of the Section;
4. Identify the latitude and longitude of this point; and
5. Record the estimated geographic coordinates in the activity record.

Each prescribed fire activity record was queried for Meridian Township Range and Section information. Any record that did not have sufficient or decipherable information could not be geo-referenced by this method. Records that had an MTR code had that information queried in the PLSS digital map. MTR values that were either not officially recognized in the NationalAltas.gov map or were bogus values would not be located by the GIS. Fire records containing this technically invalid PLSS information could not be geo-referenced by this method.

All activity records that had a Township and Range identified in the map were then further positioned using Section number. The algorithm went through a number of checks to see how close to the ideal the Township and Range appeared to be. This informed the confidence of the fine geo-referencing. Shapes that were about 36 square miles and square could have a Section located (given the zigzag, top-to-bottom layout) with relatively high confidence. Other shapes, albeit having a matching MTR name, that were more irregularly shaped, small, split in two, etc. indicated a relatively lower confidence of a precise Section center.

Confidence codes for this geo-referencing algorithm were defined and recorded in the activity data. Along with a latitude and longitude, each fire activity record received a "confidence code" that indicated if no coordinate could be obtained or the relative success of locating the Section in the MTR shape.

2.6.2 Results on the Prescribed Fire Activity Dataset

Of the entire prescribed fire activity database, 14,414 records originally lacked coordinates and were subjected to this geo-referencing method. As a result, 11,962 records (83%) were geo-referenced with extremely high confidence. An additional 1,505 records (10%) were located inside a non-ideally shaped Township and Range. Lastly, 419 fire events (3%) were paired with a Township and Range having such a convoluted shape, that the MTR's center was simply used as the coordinate. In total, around 96% of the fires lacking coordinates were geo-referenced to at least Township and Range, and most down to Section.

A second county-based geo-referencing method was applied to the remaining records. Activity records that had a state and county name were geo-referenced based on that information. Coordinates for the center of each county of the WRAP region were known in the geographic information system. Activity records that had neither source supplied coordinates nor passed through the TRS location algorithm with success were located by county. Some 254 activity records (2%) were assigned the same location as the center of their county.

In the end, only 274 of all the activity records needing coordinates could not be geo-referenced by these techniques. This is 1.8% of the total raw activity dataset.

2.7 GIS-based Quality Assurance

Wildfire

The wildfire activity data underwent quality assurance checks of its location information. The error checking performed on the wildfire activity data was to identify and flag fire records of the activity database that were not internally logical. The error checking largely relied on geographic information system (GIS) techniques. The fire activity database described in Section 2 was "frozen" as definite set of source data. In general, edits and "corrections" were not made to this finalized dataset. A formal QA/QC of the source data was done internally by the Emissions Task Team as described above.

Error checking began with confirming that all fire records had a valid state and county pair. In the emission calculation sheet each fire was assigned a state and county FIP code, based on a set of lookup tables. There were seven fires with a mismatch between state and county name, that is, the reported county names did not exist in that particular state. For these fires, the reported latitude and longitude were assumed to be correct. The coordinates were entered online on TerraServer (http://terraserver.homeadvisor.msn.com) to locate the fires and revise the state and county names. For the records identified in the table below, the county label was actually edited to the name presumed to be correct.

Table 2.8: List of Corrections to County Names and State Designations for the Wildfire Activity Inventory

Record numbers	Fire name	County name and State: Raw data	County name and State: Corrected county	FS Region in raw data set
49-50	Chambers 1	Petroleum, AZ	Apache, AZ	Southwestern
333	Bouquet 2	Graham, CA	Los Angeles, CA	Pacific Southwest
1261-1287	Dam	Wallowa, ID	Fergus, MT	Northern
2330-2332	Lake	Modoc, MT	Silverbow, MT	Northern
2361-2363	Pipe Organ	Gooding, MT	Grant, WA	Pacific Northwest
4513-4514	Lake	Modoc, WA		
4533	Phoenix	Blaine, WA	Klickitat, WA	Pacific Northwest

Remaining error checking compared the latitude and longitude coordinates (lat/lon) against other location information present in the activity database. Lat/lon coordinates were located spatially in a GIS. The plotted points could then be overlaid on independent geographic data. Fire points were overlaid on maps of U.S. states, counties, and the Public Land Survey System (PLSS) commonly called Township Range Section (TRS). References to state, county, and TRS also existed in the activity database, thus providing the basis for error checking.

Fires located by latitude and longitude were overlaid on a map depicting state boundaries. This identified five events landing outside the U.S. landmass or in a state other than the one labeled in the database. The analysis revealed 2 fires (0.1%) with potentially incorrect state labels. These two fires plotted in a different state than the incident label would suggest. One is close to a state border and the fire location is again assumed to be more precise than the state line in the GIS. The last fire plots in Wyoming but the database records the incident in Montana. On closer inspection, the point appears to be due south of the “correct” Montana county. Specifically, the longitude is reasonable but the latitude appears to be about three degrees south.

Fires plotted by their geographic coordinates were also compared to a nationwide county map. This analysis took the same form as the state-to-state comparison. The fires with state discrepancies (as described above) were not excluded from this analysis. A total of 102 fires (7.6%) did not have matching county names. A visual inspection of the distribution of these fires showed they were not limited to any particular state. Some seemed to be located near county borders and could be flagged due to, again, the different scale of the error check map. But this was not the majority case, with many fires plotting in interior locations of counties.

Fire points were checked against a small scale nationwide map of major water bodies. Two incidents were found to be within Salt Lake. Closer inspection revealed them to most likely have occurred on an island of the lake.

Lastly, the fire points were overlaid on a Public Land Survey System map depicting Township and Range. This dataset did not include Section detail. We compared the complete Meridian Township and Range cited in the database to that acquired in the overlay. Of the 1348 fires in the dataset, 392 could not be assessed using this technique (29%). They either did not fall in a legally valid Township and Range or did not have proper Meridian information in the activity dataset to perform the comparison. Of the incidents that could be compared, 715 fires matched reported Township and Range, and 241 did not, 75% and 25%, respectively. Visual inspection of the distribution of these inconsistent records shows them distributed throughout the domain. More information on that process is needed to explain this logical inconsistency.

Prescribed Fire

The prescribed fire activity dataset was scrutinized using geographic information science techniques in an identical process to wildfire. Logical inconsistencies were identified and recorded in the activity dataset. Certain flaws were considered "fatal" and, while remaining in the activity dataset, the record was "dropped" from the emission inventory. The activity dataset was supplied with 15,173 records. In total, 477 activity records (3.1 percent) were dropped due to insufficient or inconsistent data.

All prescribed fire activity records were confirmed to fall within the landmass of the thirteen-state WRAP region. For 275 records, lack of coordinate information forced the fires to be dropped from the emission inventory (see Section 2.6). An additional 20 records had coordinates supplied in the raw activity dataset that were found to be outside the WRAP region. Thus a total of 295 records were excluded from the emission inventory due to lack of valid latitude and longitude coordinates.

Prescribed fire activity records had raw location information compared to similar information derived from the record's coordinates. Points for the fires were compared to maps of states, counties and lakes. When comparing the latitude and longitude of a fire to the state it was reported to occur in, 86 records were mismatched. A significant number of these mismatched fires involved Washington, Oregon and California. Another 65 records, while matching with respect to state, fell in a different county than specified in the activity information. The records with a mismatched state were dropped from the inventory. This inconsistency was deemed to be too confounding. Records with mismatched counties were deemed to have less potential error and were carried forward to the emission inventory. The county name corresponding to the coordinate location became the permanent county designation, for purposes of the emission inventory.

When overlaying fires with a map of lakes, two fires in North Dakota were found to be within the perimeter of a lake. Upon visual inspection, these fires were likely in a legitimate location, albeit close to the shoreline. These fires were not dropped due to the results of this lake check. (These two fire records were eventually dropped however, because of a lack of fuel loading information.)

Prescribed fire activity records were confirmed to have a viable fuel loading value with which to calculate emissions. A total of 96 records were dropped because insufficient fuel loading information was available. These were all records which 1) did not report a tonnage of fuel consumed in the activity record and 2) a valid NFDRS fuel model type could not be obtained using GIS (see Section 3.2).

The 477 prescribed fire activity records not being carried forward to the emission inventory were marked as "dropped" in the activity dataset.

2.8 Agricultural Burning Activity Data

At the outset of the effort to prepare the 1996 emission inventory for fire, the ETT intended to include emission estimates for agricultural burning across the 13-state WRAP modeling domain. Under a separate contracting effort, the WRAP / FEJF contracted with Eastern Research Group, Inc. (ERG) to compile agricultural burning activity data for the WRAP region. ERG compiled a WRAP region-wide agricultural burning activity data set that the ETT considered for inclusion into the 1996 fire emissions inventory. The ERG agricultural burning dataset met the original objectives established for the project. However, much of the data in the agricultural dataset did not meet the ETT's established fire activity data requirements. Specifically, many data records did not meet the temporal resolution requirements of a calendar day in 1996. Also, many agricultural burning data records were resolved to the county level. In short, the agricultural burning data did not meet the ETT's established goal of developing a spatially resolved historical emission inventory for 1996.

The following section is a brief description of ERG's agricultural burning dataset and some of the methodologies used to develop the dataset. For a more complete description of the dataset and methods please see ERG's report titled "Alternatives to Agricultural Burning."

2.8.1 ERG Agricultural Burning Dataset

The effort to build an agricultural crop residue burning activity dataset relied on a Fire Emissions Joint Forum contract with ERG (ERG, 2001). Compiling agricultural burning activity data for the WRAP region was divided into two tasks: 1) assessing crop production and 2) assessing agricultural burning activity (ERG, 2001). The agricultural activity dataset was built from various sources using a gap-filling approach. The result is an inventory of agricultural activity covering many crop residues over the entire fifteen-state WRAP region.

There were three sources of crop production data: The National Agricultural Statistics Service (NASS) Database for 1996, state agricultural statistics reports for 1996, and the 1997 NASS Census of Agriculture. These three sources were consulted, in that order, to fill out a region-wide crop production dataset (ERG, 2001). The objective was to collect a figure of acres harvested by crop for each county in the WRAP region. Data modeling techniques to disaggregate the small-scale national data to counties were employed. Quality control procedures were in place to monitor the significant amount of data download and transcription. The crop production dataset was quality assured using checks on state totals, checks on calculations, and inter-comparing the raw datasets.

Detailed agricultural burn records were sought to construct a WRAP region-wide agricultural burning activity database (ERG, 2001). Agricultural burning information from several states, WRAP, and WESTAR were compiled into a single database. The presence of detailed data sources for portions of the WRAP domain unfortunately contrasts with a paucity of information for the remainder. Gap-filling based on state aggregates, survey information, and professional judgment was applied to complete the agricultural burning database. Quality assurance and control procedures were developed to check the inclusion of burn activity and monitor the gap-filling methods.

GIS techniques were applied to both the agricultural harvesting and agricultural burning databases (ERG, 2001). Each dataset was imported to GIS and mapped over the WRAP region. The top ten crops, by respective activity, were mapped for illustration and quality assurance. Additionally, the agricultural burning dataset was integrated with the Biogenic Emissions Landuse Database (BELD), version 3.1. BELD is a multi-source spatial land cover dataset at a nominal spatial resolution of one kilometer. BELD was used as a framework to allocate the county burning activity estimates to a sub-county level.

SECTION 3

EMISSION FACTOR AND FUEL LOADING ASSIGNMENTS

3.1 Emission Factors

An emission factor suite was devised to apply to wildfire and prescribed fire activity data. The emission factor suite included lookup tables for wildfire, prescribed broadcast burns and prescribed pile burns. The twelve pollutants included were total suspended particulate matter (TSP), particulate matter less than 10 microns in diameter (PM_{10}), particulate matter less than 2.5 microns in diameter ($PM_{2.5}$), elemental carbon (EC), organic carbon (OC), non-methane volatile organic compounds (VOC), methane (CH_4), ammonia (NH_3), oxides of nitrogen (NO_x), carbon monoxide (CO), sulfur dioxide (SO_2) and coarse particulate matter– defined as the difference between PM_{10} and $PM_{2.5}$ (PMC). The emission factor suite consists of two lookup tables. One emission factor table is for wildfire and prescribed broadcast fires ("natural burns"). The second lookup table is for prescribed pile burns ("pile burns"). A list of the emission factors is given in Table 3.1.

Two emission factor references were considered for this project: the US Environmental Protection Agency's AP-42 section 13.1 and an emission inventory methods survey report (Battye, 2001) funded by the US EPA Office of Air Quality Planning and Standards, or "OAQPS report." The emission factor suite is a compilation of emission factors and emission factor relationships (multipliers) from both documents. The emission factor table for natural burns is based on the OAQPS report. This reference contained the most information for the wide array of emission factors desired. Almost all emission factors for natural burns were taken from Table 39 of the OAQPS report. The listings for "averaged" (across the researchers' data domain), "overall" (combined flaming and smoldering combustion phase) emission factors were extracted from the table. An emission factor for TSP did not appear in the OAQPS report and is the single emission factor for natural burns taken from AP-42. The AP-42 data utilized is the "Short needle, Conifer" broadcast burn entry of Table 13.1-3. The overall combustion phase ("fire" in the table) for "Total Particulate" was extracted.

The emission factor table for pile burns is a result of emission factors taken directly from the two references and applying multipliers appearing in the OAQPS report. This compilation was performed because there is no single source of pile emission factors for all the pollutants required. Pile emission factors for TSP, PM_{10}, PM2.5, and CO were taken directly from the AP-42 Table 13.1-3 listing for dozer piled conifer logging slash debris. Other emission factors are based on an AP-42 pile entry and then adjusted by an empirical relationship identified in Table 39 of the OAQPS report. In this manner, pile emission factors for EC and OC are calculated from $PM_{2.5}$ while VOC and NH_3 are based on CO. Lastly, the pile emission factor for CH_4 is based on a relationship with combustive efficiency identified in Table 39. A combustive efficiency of 0.9 is used (Battye, 2001 p25).

For both the natural burn and pile burn emission factor lookup tables, PM Coarse is calculated as the difference between the PM_{10} and $PM_{2.5}$ factors as derived above. All emission factors were converted to pounds per short ton from grams per kilogram.

Table 3.1: Summary of Emission Factors

Summary of emission factors (EF) in pounds per ton for wildfire and prescribed burning. In the case of piled fuels, when two sources are mentioned, the first source refers to the emission factor and the second to the empirical relationship used to derive that emission factor. The value in parentheses represents the emission factors used in the draft wildfire inventory for July 1996.

	Wildfire		Prescribed fire- Piled fuels		Prescribed fire Non-piled	
Pollutant	EF	Source	EF	Source	EF	Source
TSP	34.1 (17.1)	AP42	12.0	AP42	34.1	AP42
PM_{10}	28.1 (13.0)	OAQPS	8.0	AP42	28.1	OAQPS
$PM_{2.5}$	24.1 (11.7)	OAQPS	8.0	AP42	24.1	OAQPS
Elemental Carbon	1.5 (1.1)	OAQPS	0.6	AP42, OAQPS $PM_{2.5}$ * 0.072	1.5	OAQPS
Organic Carbon	11.6 (7.4)	OAQPS	4.3	AP42, OAQPS $PM_{2.5}$ * 0.54	11.6	OAQPS
VOC	13.6 (6.2)	OAQPS	6.3	AP42, OAQPS CO * 0.085	13.6	OAQPS
CH_4	13.6 (7.7)	OAQPS	7.7	OAQPS 2*(42.7-43.2*CE)	13.6	OAQPS
NH_3	1.3 (1.7)	OAQPS	0.5	AP42, OAQPS CO * 0.0073	1.3	OAQPS
NO_x	6.2 (4.0)	OAQPS	6.2	OAQPS	6.2	OAQPS
CO	289 (140)	OAQPS	74.3	AP42	289.0	OAQPS
SO_2	1.7 (2.0)	OAQPS	1.7	OAQPS	1.7	OAQPS
PM coarse	4.0 (1.3)	$PM_{10} – PM_{2.5}$	0.0	$PM_{10} – PM_{2.5}$	4.0	$PM_{10} – PM_{2.5}$

3.2 Spatial NFDRS Fuel Loading Assignment

As part of the overall effort to assign fuel loadings to all fires, a spatial overlay technique was developed to assign per-acre fuel loadings from the NFDRS Fuel Model Map (Burgan, 1998). While the overlay was applied to all fires in both the prescribed and wildfire activity databases, the fuel loading assignments were only used if the original source activity data did not include fuel loading information.

The NFDRS overlay is a multi-step process using a geographic information system. This procedure is applied to each record in the activity database. The cooridnates of the fire is located on the fuel map and the fuel model identified at the point is recorded. The specific steps are:

1. A mappable point for the fire is created from its latitude and longitude.
(Activity records are geo-referenced based on their latitude and longitude.)

2. The fire point is converted to the different map projection of the NFDRS map. (Geographic coordinates are projected to Lambert Equal Area Azimuthal.)

3. The fire point is "dropped" on the NFDRS Fuel Model map. (The intersected grid cell is identified.)

4. The fuel model at that point, as a coded number, is identified. (Numeric fuel model attribute value is extracted from the grid cell.)

5. The numeric fuel model name is saved to the fire activity record. (Numeric fuel model code is written to a newly created field in the activity database.)

6. The numeric code is translated to the standard NFDRS Fuel Model letter code. (For all records, fuel letter is looked up by fuel number and saved in a new field.)

This procedure was applied to the entire activity database. Most fires received a valid NFDRS Fuel Model code. However, there were instances when a fuel model was not obtained. Activity records that had no coordinate information did not receive a value from the map. Likewise, records that had invalid coordinates outside the United States did not overlay on the map. Some areas of the NFDR map are categorized as "ag", "water", and "barren." Activity records intersecting those areas received the respective non-fuel code and ultimately did not receive a fuel model from this process.

3.3 Wildfire Fuel Loading

Fuel loading for the wildfire inventory was derived using NFDRS fuel model categories (Cohen and Deeming, 1985). Each fire event was ascribed a NFDRS fuel model category using a spatial overlay of the fire location with the NFDRS layer (above). A summary of the default NFDRS fuel loadings for both dead and live fuels is shown in Table 3.2. In addition to the NFDRS fuel loadings, additional fuel loading values were added to each category, to adjust for fuel present in duff and tree crowns (Personal communication, David Sandberg). Finally, the total fuel loading was calculated for each NFDRS fuel model by ascribing a percent of fuel consumed by fire to each fuel category, and summing the subtotals for each fuel category. For wildfire, fuel consumption of all dead and live fuels was assumed to be 100%, duff consumption 50% and crown consumption 62% (Personal communication, David Sandberg). Although Table 3.2 presents the full set of 20 NFDRS fuel models, only 13 of the fuel models were actually present in the wildfire emission inventory for the WRAP region. The most common NFDRS fuel models in the wildfire emission inventory were sagebrush-grass, western annual- and perennial grasslands, and pine-grass savanna, models T, A, L, and C, respectively (Table 3.2; Table 5.2).

3.4 Prescribed Fire Fuel Loading

Similar to the approach in wildfire, fuel loading for prescribed fires was obtained by applying a GIS overlay of the file locations with the NFDRS fuel model layers (above). However, since greater than 95 percent of the prescribed fires were reported with values for both acreage and total amount of fuel burned, fuel loadings derived from the NFDRS overlay were used only in 4.5 percent of the data. The basic fuel loading values for each fuel class used for prescribed fire were the same as those used for the wildfire inventory (Table 3.2). However, the total fuel loadings in the prescribed fire inventory were somewhat lower than those for wildfire (Table 3.2), since the prescribed fire inventory used a different set of assumptions regarding relative fuel consumption. In the prescribed fire inventory the fuel consumption of 1000-hr fuels was set at 50%, and crown consumption at 0% (Personal communication, David Sandberg). An exception was 31% consumption for crown biomass in Alaskan black spruce, but since this fuel model was not present in the WRAP database, this difference did not affect fuel load estimates.

Table 3.2: Summary of Fuel Loading and Consumption by NFDRS Model for Wildfires

Dead and live fuel loadings were based on Cohen and Deeming (1985). For relative fuel consumption values for wildfire and prescribed fire see section 3.2. Values in parentheses indicate total fuel loading for prescribed fire. An asterisk (“*”) after the NFDRS model description indicates the wildfire emissions were augmented for smoldering consumption.

NFDRS Abbr.	NFDRS model description	Total (Rx fire) (tons/acre)	Dead fuels (tons/acre)				Live fuels (tons/acre)		Additional (tons/acre)	
			1-hour	10-hour	100-hour	1000-hour	Fine wood	Herbaceous	Duff	Crown
A	Western grasses (annual)	0.50	0.20	0.00	0.00	0.00	0.00	0.30	0.00	0.00
B	California chaparral	19.5	3.50	4.00	0.50	0.00	11.50	0.00	0.00	0.00
C	Pine-grass savanna	4.7	0.40	1.00	0.00	0.00	0.50	0.80	4.00	0.00
D	Southern rough *	15.6 (10.6)	2.00	1.00	0.00	0.00	3.00	0.75	7.70	8.00
E	Hardwood litter (winter) *	3.8	1.50	0.50	0.25	0.00	0.50	0.50	1.10	0.00
F	Intermediate brush	15.0	2.50	2.00	1.50	0.00	9.00	0.00	0.00	0.00
G	Short needle (heavy dead) *	43.5 (25.6)	2.50	2.00	5.00	12.00	0.50	0.50	18.20	19.20
H	Short needle (normal dead) *	27.5 (15.0)	1.50	1.00	2.00	2.00	0.50	0.50	16.90	18.70
I	Heavy slash *	55.1 (49.1)	12.00	12.00	10.00	12.00	0.00	0.00	18.20	0.00
J	Intermediate slash *	34.0 (31.2)	7.00	7.00	6.00	5.50	0.00	0.00	16.90	0.00
K	Light slash *	14.4 (13.1)	2.50	2.50	2.00	2.50	0.00	0.00	9.70	0.00
L	Western grasses (perennial)	0.75	0.25	0.00	0.00	0.00	0.00	0.50	0.00	0.00
N	Saw grass *	5.0	1.50	1.50	0.00	0.00	2.00	0.00	0.00	0.00
O	High pocosin *	46.1 (45.1)	2.00	3.00	3.00	2.00	7.00	0.00	58.20	0.00
P	Southern pine plantation *	16.4 (10.2)	1.00	1.00	0.50	0.00	0.50	0.50	13.30	10.00
Q	Alaskan black spruce	57.6 (48.8)	2.00	2.50	2.00	1.00	4.00	0.50	57.90	26.80
R	Hardwood litter (summer) *	3.1	0.50	0.50	0.50	0.00	0.50	0.50	1.10	0.00
S	Tundra *	19.3 ()19.1	0.50	0.50	0.50	0.50	0.50	0.50	32.60	0.00
T	Sagebrush-grass *	4.5	1.00	0.50	0.00	0.00	2.50	0.50	0.00	0.00
U	Western pines *	19.1 (10.3)	1.50	1.50	1.00	0.00	0.50	0.50	10.60	14.20

SECTION 4

EMISSION CALCULATIONS

4.1 Data Management and Emissions Calculation Software Tools

Wildfire

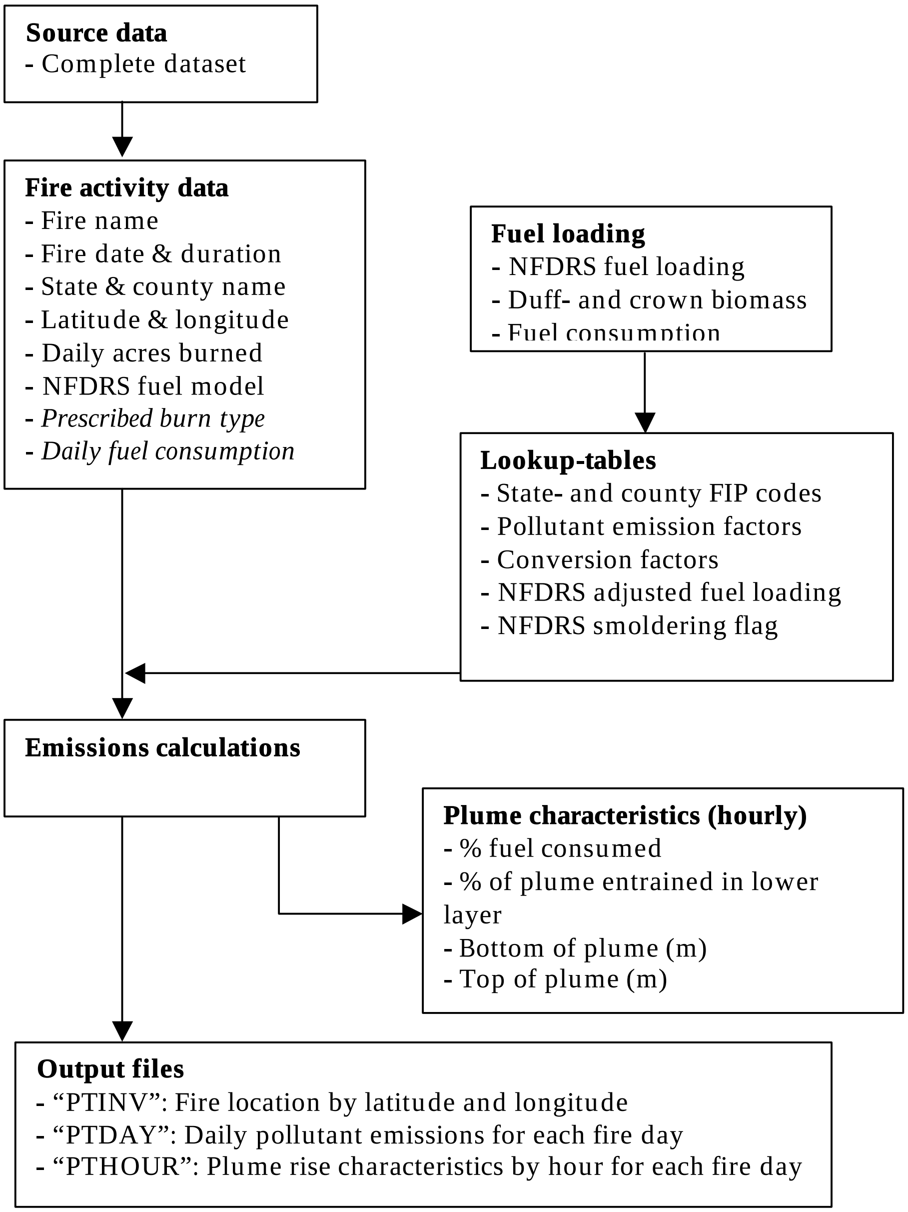
Microsoft Excel and ESRI ArcView GIS were used as the software tools to manage the wildfire and prescribed fire activity data and to build the corresponding emission inventories. For the wildfire emission inventory process, Excel was used for all processes. The wildfire emission inventory required two separate Excel spreadsheets due to the limitation of Excel's maximum file size. Each spreadsheet contained the same input and processing information, but had different templates to create the output files for modeling purposes. The source data contained the fire activity data that served as the basis for the emission calculations (Figure 4.1). A subset of variables from the source data was used in the calculation of the emissions and in the output files. Lookup tables were used to reference the following parameters for each fire day (Figure 4.1): 1-state FIP code, 2-county FIP code, 3-time zone, 4-pollutant specific emission factors, 5-unit conversion factors, 6-adjusted NFDRS fuel loadings, and 7-a "smoldering flag" (indicating which NFDRS model is corrected for smoldering emissions). The adjusted NFDRS fuel loading values were calculated in a separate worksheet (Figure 4.1). Finally, plume characteristics were calculated using data on fire size and fuel type from the calculation sheet as input information, and saved in an output sheet that creates PTHOUR (Figure 4.1).

Prescribed Fire

ArcView GIS was used exclusively for data management and calculation for the prescribed fire emissions inventory. Raw activity data was brought in from Excel then processed, in a similar fashion to the wildfire data, inside ArcView. Activity records were assigned FIP code, time zone, fuel loading, emission factors, unit conversion factors, and "smoldering flags". Fuel loadings and emission factors were looked-up then emissions calculated using scripts in ArcView.

Figure 4.1: Flowchart of Data Processing Stream for Wildfire and Prescribed Burning Activity and Emissions.

The fields indicated in italics in the fire activity data box were only available for and used in the prescribed burning database.



4.2 Total Fuel Consumption

Wildfire

Wildfires were reported as individual fires and as the total number of fire days. Thus, a wildfire that burned over three days was reported as one fire, referred to as a fire event, and as three fire days. The source data of wildfire activity contained both the total acreage of a fire as well as acreage consumed on a daily basis. The latter was calculated as the difference in fire size on that day and the fire size the day before. If no fire growth occurred during that period, the daily acreage was set to zero. Total fuel consumption was calculated as:

$$\text{Fuel consumed (tons)} = \text{Acres burned (acres)} * \text{Fuel loading (tons per acre)} \qquad \textbf{Equation 4.1}$$

Fuel loading calculations were based on the NFDRS fuel model (Section 3). Each fire in the database was assigned a NFDRS model code using the GIS methods describe above. The NFDRS model was then used to assign each fire an "adjusted fuel loading." The adjusted fuel loading was based on the default NFDRS loadings, additional duff and crown biomass, and fuel consumption.

Prescribed Fire

The calculation of total fuel consumption for prescribed fire was as follows. The acreage of each burn was derived directly from the source data. The majority of the prescribed burning records also had a value for total fuel burned reported. Thus, for many of the prescribed fires the amount of fuel consumed was taken directly from the source data. A small subset of records had a value for acreage but not for fuel loading. In these cases fuel consumption was calculated by multiplying the acreage with a fuel loading based on a NFDRS fuel model. The NFDRS fuel model was derived using the fire location in a spatial overlay with NFDRS models, using GIS techniques (Section 3.4). The latter approach was applied for 655 cases (4.5%) in the prescribed burning database.

4.3 Pollutant Emissions

Wildfire

Pollutant emissions were calculated for each fire day in the database according to:

Equation 4.2

$$\text{Daily emission (tons)} = \frac{\text{Acreage burned (acres)} * \text{Fuel load (tons/acre)} * \text{Emission factor (lbs/ton)}}{2000\ \text{(lbs/ton)}}$$

In equation 4.2 the denominator is a conversion factor from pounds to short tons. A subset of NFDRS fuel models was corrected for additional smoldering emissions (Table 3.2). Smoldering emissions were assumed to be 17 percent of the emissions of the previous day (Personal communication, David Sandberg). Thus, the total emissions on the second day of wildfire with smoldering emissions was calculated as:

$$\text{Emission}_{\text{total day 2}} = \text{Emission}_{\text{day 2}} + \left(\text{Emission}_{\text{day 1}} * 0.17\right) \qquad \textbf{Equation 4.3}$$

Moreover, for those NFDRS fuel models with smoldering emissions, one additional fire day with smoldering emissions only was added into the database after the last reported day of each fire:

$$\text{Emission}_{\text{day after}} = \text{Emission}_{\text{last day}} * 0.17 \qquad \textbf{Equation 4.4}$$

A sensitivity analysis for the 1996 wildfire emissions inventory showed that adding smoldering emissions for the existing fire days in the database added 11% emissions compared to the emissions without a smoldering adjustment. Adding an additional smoldering day to each NFDRS fuel model with smoldering emissions added another 1.2%, leading to an overall increase in emissions of 12.2%. A second smoldering day after the last reported fire day would have added only 0.2% in emissions and was not implemented. This is justified in that the error associated with other input parameters of the emission calculation is likely much higher than this 0.2% difference.

Prescribed Fire

Emissions for prescribed fires were calculated in a similar way to wildfires. Essentially the same process was employed but using two emission factor tables and different smoldering conditions. Emission factors for prescribed fire events were different for each burn type, pile and broadcast burn type (Table 3.1). Based on the activity record's burn type designation, the proper lookup table was applied. Smoldering calculations were based on 1) whether the fire was deemed to smolder and 2) the amount of smoldering assumed. Piles were presumed not to smolder and only broadcast burns with a fuel density of greater than five tons per acre incurred smoldering emissions. The quantity of pollutants emitted the following day due to smoldering was defined as 8.5 percent of the day before.

All activity records in the prescribed fire database were defined as single day events. That is, each day of activity has a distinct entry in the database. Moreover, there is no linkage between the days to consistently identify multi-day events. Therefore, for each day that was flagged to smolder, smoldering emissions were assigned to the very next day by "inserting" a smoldering-only activity record. The formula for this variation of the smoldering calculation delineated for wildfire can be expressed as:

$$\text{Emission}_{\text{day after}} = \text{Emission}_{\text{event day}} * 0.085 \qquad \textbf{Equation 4.5}$$

4.4 Plume Profile

In the wildfire and prescribed fire emission inventories, a plume profile is assigned to each daily fire event. The plume values include: the top and bottom of the plume (PTOP and PBOT, respectively; both expressed in meters above ground elevation), and the percent of emissions entrained within the surface layer of the atmosphere (LAY1F), defined as the first 80 meters above the ground. These three plume parameters are established and assigned for each of the 24 hours of each daily fire event. All of the plume values were assigned based on the limited information available for each fire event, including fire size (or fire area grown per day) and either a reported fuel loading or the National Fire Danger Rating System (NFDRS) fuel model.

The plume profile scheme is based on a mixture of the incomplete science related to these variables augmented by expert opinion and preliminary research results. Normally, plume rise is predicted using hourly information on (a) the heat release rate from each fire, (b) the spatial pattern of heat production, and (c) the vertical temperature profile and wind speed profile above each fire. Unfortunately, estimates of buoyant efficiency and entrainment efficiency cannot be made based upon the scant information available for historical prescribed fires or on current models. Therefore, estimates of buoyant efficiency and entrainment efficiency must be derived from preliminary results and expert knowledge. This plume profile scheme was developed by David Sandberg (personal communication) on behalf of the Fire Emissions Joint Forum.

Based largely on expert judgment, the following steps were taken to assign plume characteristics to each of the normalized fires in the 1996 inventories:

1. Estimate the hourly heat release and emissions rate for each fire using a standard diurnal consumption template that was formulated based on expert opinion. The WRAP Emissions and Modeling Forums requested hourly rates of fire emissions. To satisfy this temporal requirement, daily emissions for each wildfire and prescribed fire event in the inventory were apportioned to hourly emissions using the standard diurnal consumption template presented in Table 4.1.

Table 4.1: Standard Diurnal Consumption Template Used to Distribute Fire-Total Heat Production and Emissions

Hour	1	2	3	4	5	6	7	8	9	10	11	12
% Per Hour	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	2.00	4.00	7.00
Hour	13	14	15	16	17	18	19	20	21	22	23	24
% Per Hour	10.00	13.00	16.00	17.00	12.00	7.00	4.00	0.53	0.53	0.53	0.53	0.53

The PTDAY input files included daily tons of emissions for each fire event. The Emissions Task Team provided the standard diurnal consumption template to the Emissions and Modeling Forums at their request, and Forum members subsequently processed the daily fire emissions into the hourly emission rates required by the SMOKE dispersion model.

2. Calculate daily virtual fire acreages to normalize the virtual plume diameter based on fuel loading (or spatial fuel density) including crown fuels consumed.

The virtual acreage was calculated by multiplying the actual fire size by the square root of the normalized pre-burn fuel loading. This was done in order to relate fuel loading to the characteristic “stack” diameter of the plume. For wildfire and prescribed fire days, the total fuel loading was normalized to 13.8 tons per acre, which is the total surface loading plus crown biomass for NFDRS fuel model U (western pines).

$$\text{Acreage}_{\text{virtual}} = \text{Acreage}_{\text{actual}} \cdot \sqrt{\text{Fuel Loading} / 13.8}$$ **Equation 4.6**

Days added to model smoldering for the day after an original activity day also had a virtual acreage computed. For wildfires, an additional 13.5 percent of the acres the day before were assumed to smolder the following day (see above). To model the heat release for these smoldering-adjusted events, the acreage for that day was set as 13.5 percent of the *original* acreage of the day before.

$$\text{Wildfire Acreage}_{\text{virtual}} = \text{Acreage}_{\text{day before}} * 0.135 * \sqrt{\text{Fuel load} / 13.8}$$ **Equation 4.7**

Prescribed fires were modeled with less smoldering occurring on the day after. An acreage equivalent to 6.2 percent was modeled to be emitted during smoldering the following day. And, to repeat from the smoldering discussion above, only certain prescribed burns were assumed to smolder at all.

$$\text{Prescribed Acreage}_{\text{virtual}} = \text{Acreage}_{\text{day before}} * 0.062 * \sqrt{\text{Fuel load} / 13.8}$$ **Equation 4.8**

For the purpose of assigning a specific plume profile to each fire event, five virtual acreage size classes were established. The virtual acreage size classes are shown in Table 4.2.

Table 4.2: Virtual Acreage Size Classes

Class	1	2	3	4	5
Size (acres)	0 – 10	>= 10 – 100	>= 100 – 1,000	>= 1,000 – 5,000	>= 5,000

3. Calculate the vertical plume profile (i.e., the height, in meters above ground elevation, at the top and bottom of the plume) for a perfectly buoyant energy source for each hour for each fire based on virtual daily fire acreage.

   For each virtual size class, the following variables were encoded: size-related buoyant efficiency (BE_{size}), the maximum possible top of plume, and the minimum possible bottom of plume. All were expressed as a function of virtual acres. The hourly table contains a buoyant efficiency (BE_{hour}) that varies with the time of day during the fire. The values for these variables are shown in Table 4.3 (showing variables as a function of fire size) and Table 4.4 (showing BE_{size} as a function of hour of day).

Table 4.3: Fire-Related Parameters as Function of Fire Size Classes

Class	1	2	3	4	5
Size (virtual acres)	0 – 10	>= 10 – 100	>= 100 – 1,000	>= 1,000 – 5,000	>= 5,000
BE_{size}	0.4	0.6	0.75	0.85	0.9
P_{top} max (m)	160	2,400	6,400	7,200	8,000
P_{bot} min (m)	0	300	800	1,600	1,600

Table 4.4: Buoyant Efficiency as Function of Hour of Day

Hour	1	2	3	4	5	6	7	8	9	10	11	12
BE_{hour}	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.06	0.10	0.2	0.4
Hour	13	14	15	16	17	18	19	20	21	22	23	24
BE_{hour}	0.7	0.8	0.9	0.95	0.99	0.8	0.7	0.4	0.06	0.03	0.03	0.03

Equations were used to calculate P_{top}, P_{bot} as a function of time of day and size of the fire (again, expressed in terms of virtual acres). Note that the calculations use an hourly value for buoyant efficiency and heat release value based on fire size, also referred to as a normalized fire growth.

The hourly top of the plume was calculated as follows:

$$Ptop_{hour} = (BE_{hour})^2 * (BE_{size})^2 * Ptop_{max}$$ **Equation 4.7**

where BE is the buoyant efficiency looked up from the hourly or size class tables. The hourly bottom of plume was similarly calculated as:

$$Pbot_{hour} = (BE_{hour})^2 * (BE_{size})^2 * Pbot_{min}$$ **Equation 4.8**

4. Lastly, an equation was used to calculate LAY1F, the proportion of emissions fumigated into the first atmospheric layer (below 80 m). LAY1F was calculated as the arithmetic inverse of the hour specific buoyant efficiency multiplied by the size specific buoyant efficiency.

$$Lay1F_{hour} = 1 - (BE_{hour} * BE_{size})$$ **Equation 4.9**

Using equations 4.7 through 4.9 the bottom and top of the atmospheric plume as well as the proportion of the plume fumigated into the first atmospheric surface layer were all scaled to fire size, fuel loading (incorporated in virtual acres calculation) and hour of the day. Figures 4.2 through 4.5 illustrate the relationships described above.

Figure 4.2: Buoyant Efficiency

The relationship between buoyancy efficiency and time of day (after Personal communication, David Sandberg.

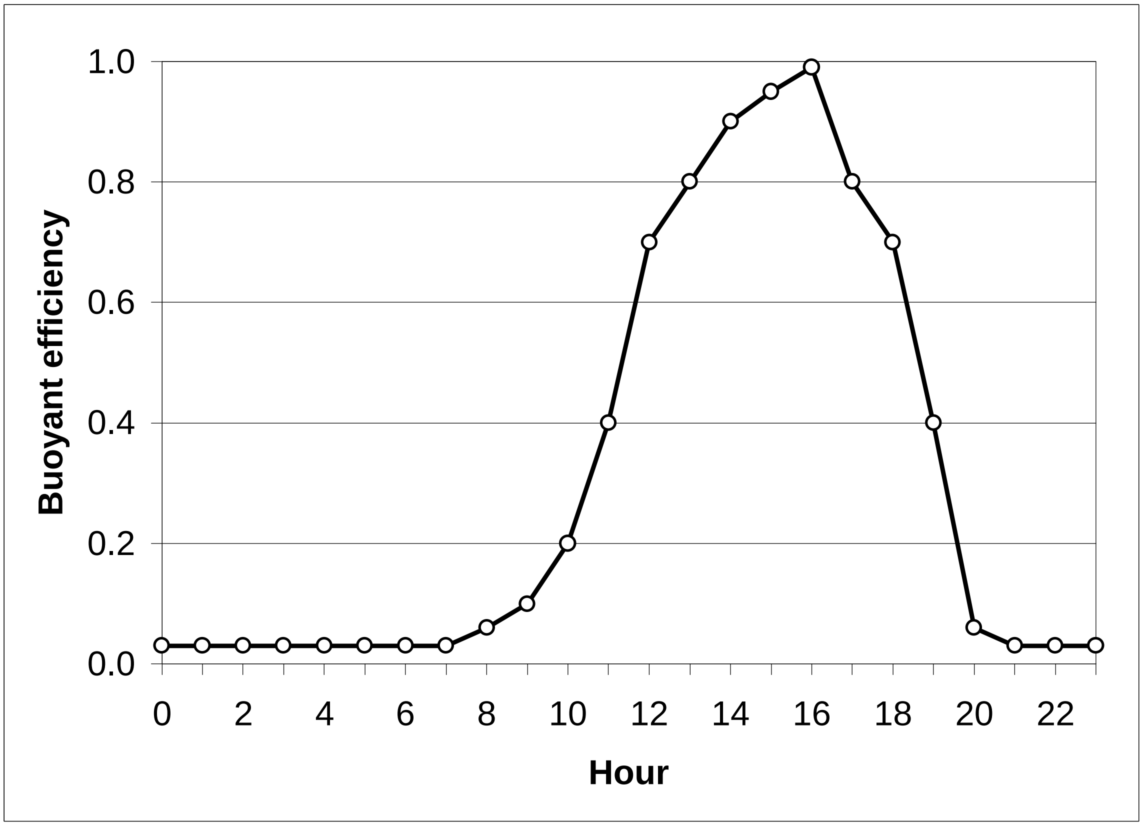


Figure 4.3: Projected Top of Plume

The projected top of the atmospheric plume (m) as a function of time of day and fire size (after Personal communication, David Sandberg). Fire sizes represent the upper cutoff of the fire size categories. The lowest line represents the 10 acres cutoff. Note the logarithmic scale on the y-axis.

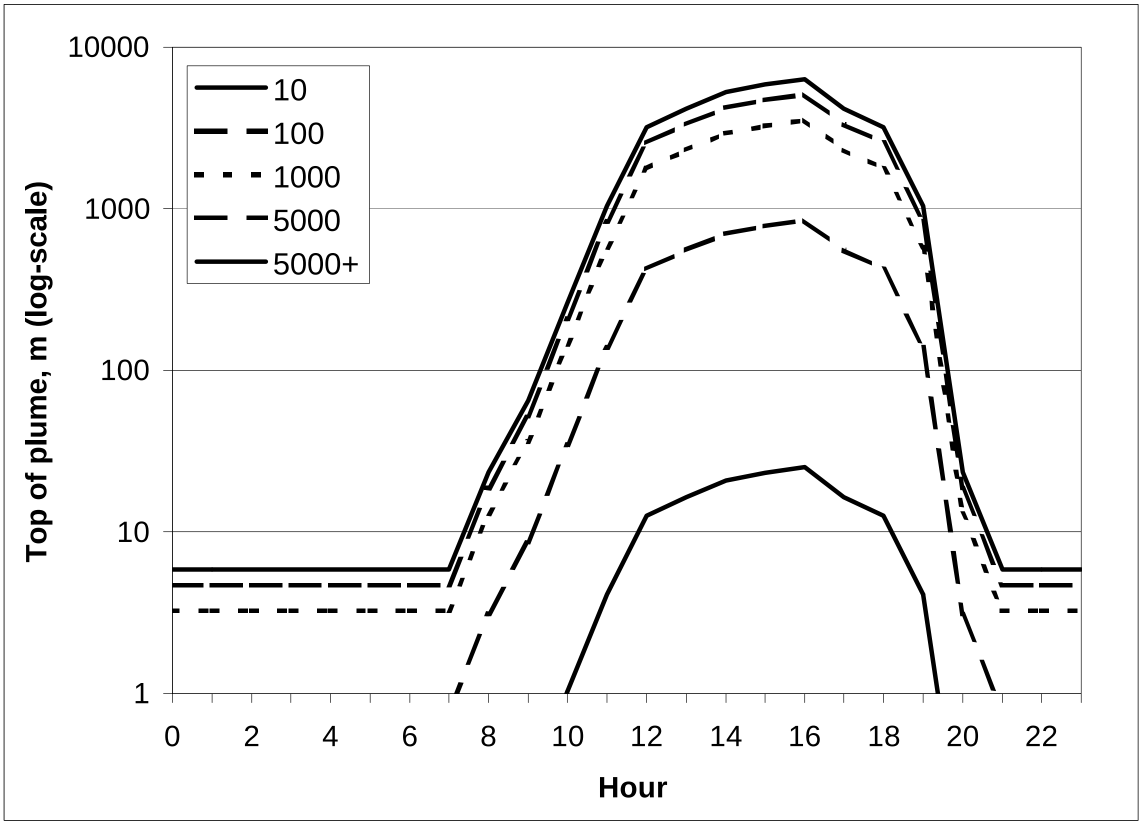


Figure 4.4: Projected Bottom of Plume

The projected bottom of the atmospheric plume (m) as a function of time of day and fire size (after Personal communication, David Sandberg). Fire sizes represent the upper cutoff of the fire size categories. The line representing the 10 acres cutoff is constant at a value of zero.

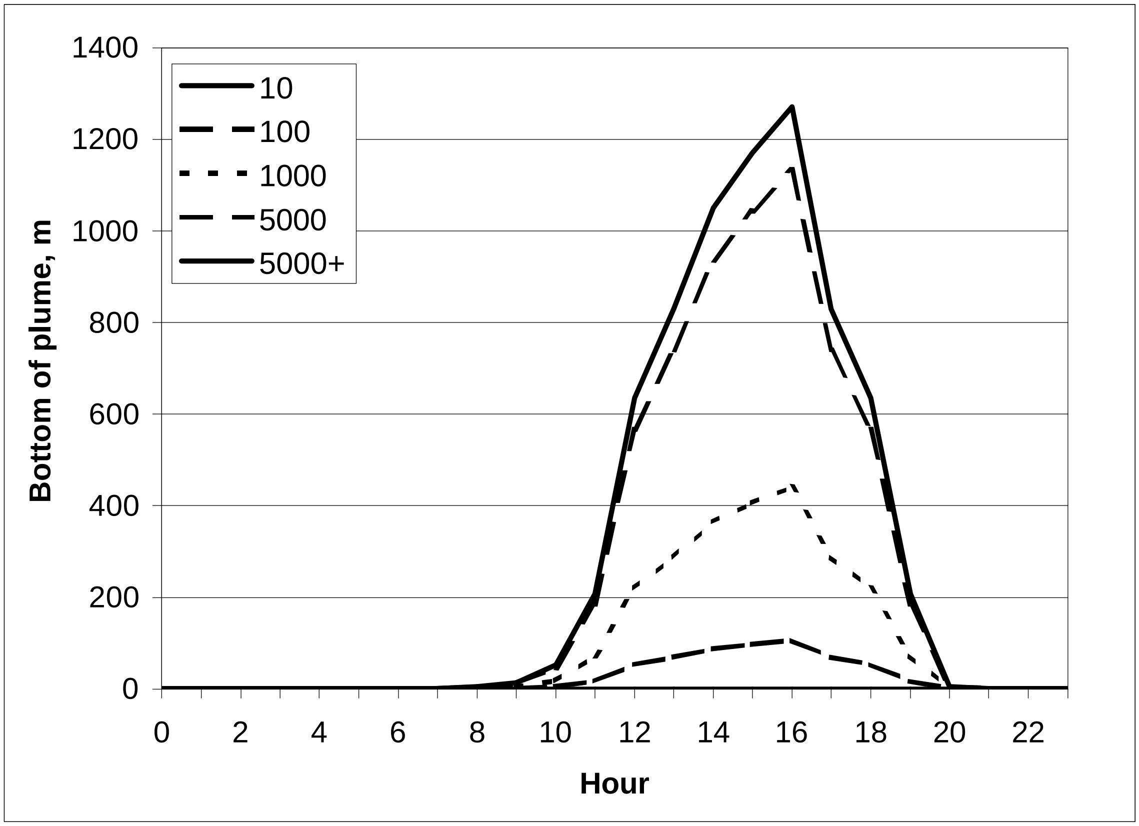
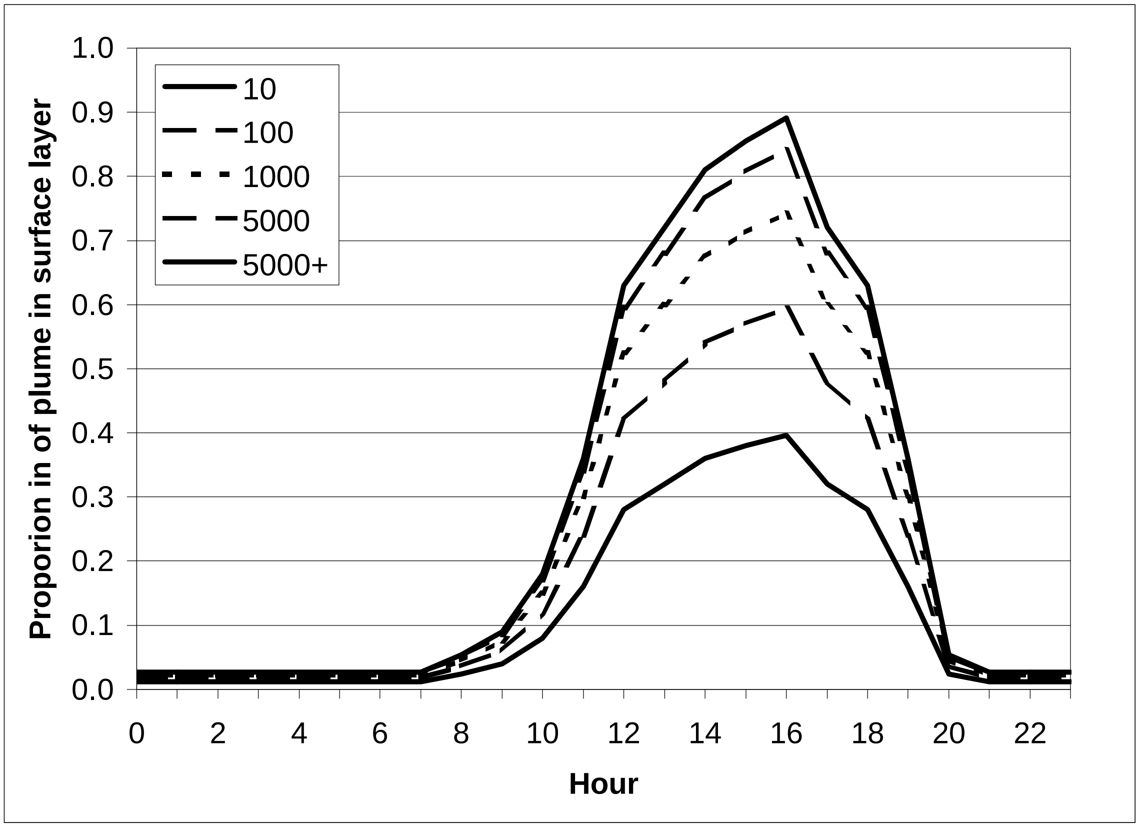


Figure 4.5: Proportion of Plume in Surface Layer

The proportion of the plume fumigation to the atmospheric surface layer (<80 m) as a function of time of day and fire size (after Personal communication, David Sandberg). Fire sizes represent the upper cutoff of the fire size categories. The lowest line represents the 10 acres cutoff.



4.5 QA/QC Procedures and Error Checking

The quality assurance of the daily fire emissions estimation process consisted of several steps. The first check consisted of assuring that the fire input data were transferred correctly from the source data to the emission calculation sheet. Next, the data in the lookup tables with the emission factors, fuel loads, fuel consumption, and conversion factors were checked for data entry errors. The cells that use these tables in their calculations were checked. Finally, the templates to produce the output files were checked against the emission and plume characteristics worksheets, by checking the formulas and references of all the output parameters. The first data entry line, last line, and random lines in between in the output files were compared to the emission and plume characteristics worksheets to ensure that the values matched. The ArcView scripts were quality assured by performing manual calculations of data entries and by computerized checks of output data completeness. The final output files (PTINV.prn, PTHOUR.prn, and PTDAY.prn) were then checked for the correct column width using WordPad and a light table (Section 8).

SECTION 5

EMISSION ESTIMATES

5.1 Wildfire Activity and Emissions

A total of 1,348 wildfires were included in the 1996 wildfire emissions inventory with a mean duration for each fire of 3.6 days. These fires led to a total of 4,902 reported fire days, and 5,311 fire days when an extra smoldering day was included for a subset of NFDRS fuel models (Table 3.2). An estimated total of 5,013*10^3 acres and 48,085*10^3 tons of fuel were consumed by wildfire in 1996. Pollutant emissions varied from 40*10^3 tons of elemental carbon to 7,770*10^3 tons of CO. The wildfire emission inventory statistics are detailed in Table 5.1.

As expected wildfire activity was highest during the summer months (Figure 5.1), and peaked in the month of August. The correlation between the number of fire events, number of fire days and acreage burned was generally quite good. However, an increase in acreage burned did not always coincide with increased fuel consumed (Figure 5.1), since the amount of fuel consumed depends on the fuel loading derived from NFDRS fuel model. Moreover, patterns in $PM_{2.5}$ emissions do not always coincide with the amount of fuel consumed, because the $PM_{2.5}$ emissions include additional smoldering emissions that are not accounted for in the fuel consumption (Figure 5.1). Wildfire activity differed widely by state (Figure 5.2). The highest fire activities, expressed as fire days, acreage and fuel consumed by fire, and $PM_{2.5}$ emissions, were observed in California, Idaho, and Oregon. Moreover, differences in fire activity between states were dependent on the parameter considered, i.e., each state showed its own unique pattern in number of fire events, total fire days, acreage burned, fuel consumed and $PM_{2.5}$ emissions. These patterns were attributed to differences in fire duration, fire size, and fuel type between states. The latter can be further illustrated by the breakdown of state data by NFDRS fuel model (Figure 5.3; Table 5.2). For example, in Oregon the wildfire acreage was approximately 4 times higher compared to Montana, yet the amount of fuel consumed and $PM_{2.5}$ emissions were approximately 10 times higher in Oregon compared to Montana. This pattern can be attributed to a higher fuel load of the Oregon fires compared to the Montana fires.

5.2 Prescribed Fire Activity and Emissions

The prescribed fire emission inventory was considerably larger than the wildfire emission inventory. A total of 14,696 individual fire days were used in the final source data (Table 5.1). The duration of each fire was set at one day, since prescribed burns tend to fall within a 24-hour period. After smoldering days were added the dataset had a total of 16,603 fire days, an increase of 13%. The total acreage consumed by prescribed burns was 555*10^3 acres, and the total fuel consumed was 5,243*10^3 tons. Total pollutant emissions varied from 3*10^3 tons to 505*10^3 tons for elemental carbon and CO, respectively.

Activity data and pollutant emissions from prescribed burning varied by month, state, and burn type (piled versus non-piled fuels). Although prescribed burning occurred throughout the entire year, two peaks could be distinguished (Figure 5.4). The first peak occurred in the spring (April, May and June) and the second, larger peak in the fall (September, October and November). In the spring the proportion of fuel burned was generally lower than the proportion of $PM_{2.5}$ emissions, whereas the opposite was true for the months of October and November. This is partially due to a lower smoldering activity in the fall compared to the spring (data not shown).

Prescribed burning activity was reported for thirteen western states, and was generally highest for Idaho, Oregon, Nevada and Washington (Figure 5.5). However, the pattern in fire activity was different from state to state. For example, although Idaho reported relatively few prescribed burns, these fires resulted in proportionally high $PM_{2.5}$ emissions. On the other hand, while Washington reported the highest number of prescribed burns, this state had relatively low $PM_{2.5}$ emissions. This difference in relative $PM_{2.5}$ emissions between these states can be attributed to a small proportion of smoldering fires in Washington (7%), and a much higher proportion of smoldering fires in Idaho (52%), as well as lower acreage and fuel loadings for the fires in Washington compared to Idaho. Finally, differences in prescribed burning activity between states from this inventory do not only depend on actual differences in burning activity, but also on the accuracy and completeness of the activity data provided by the various agencies.

Over 80% of the reported prescribed burning activity involved piled fuels (Figure 5.6). Moreover, smoldering days added to the inventory occurred only in the non-piled fuels category, since piled fuels were assumed not to smolder (Section 4.3), increasing the $PM_{2.5}$ emissions by 5%.

5.3 Total Fire Activity and Emissions

Overall, a total of 16,044 individual fires were reported, with the majority in the prescribed burning category (Table 5.1). However, the higher proportion of prescribed fires is partially due to the fact that the duration of prescribed burns was set at a default value of 1 day, whereas the duration of wild fires was set at the last day that a fire was reported. When expressed as fire days, smoldering days excluded, about 25% of the fire activity occurred as wildfires and 75% as prescribed fires. However, the total acreage burned by wildfire was considerably higher than for prescribed fire, which can be attributed to the fact that individual wildfires were significantly larger in size than prescribed burns. Accordingly, total fuel consumption and average fuel consumption per fire day was about 27 times higher for wildfires than for prescribed burning. These differences in fuel consumption led to higher proportional pollutant emissions from wildfires compared to prescribed burning, varying from 90 to 95% of total emissions, depending on the pollutant.

Table 5.1: Summary of Fire Activity and Emissions from Wildfires and Prescribed Fires in 1996
Values in parentheses represent percent of total.

Factor	Wildfire	Prescribed fire	Total
# of individual fires	1348	14696	16044
Mean fire duration (days)	3.6 (1 to 117)	Set at 1 day	n/a
# of fire days (original)	4902 (24%)	14696 (75%)	19598
# of fire days (+ smoldering)	5311	16603	21914
Area burned (acres*10^3)	5030 (88%)	555 (10%)	5585
Area burned per fire day, mean (acres, smoldering excluded)	1026	38	n/a
Fuel consumed (tons*10^3)	48085 (90%)	5243 (10%)	53328
Fuel consumed per fire day, mean (tons, smoldering excluded)	9809	357	n/a
Total emissions (tons *10^3*)*			
TSP	917 (93%)	64 (7%)	981
PM_{10}	756 (94%)	50 (6%)	806
$PM_{2.5}$	648 (93%)	44 (6%)	694
Elemental carbon	40 (93%)	3 (7%)	43
Organic carbon	312 (93%)	22 (7%)	334
VOC	366 (93%)	27 (7%)	396
CH_4	366 (85%)	30 (7%)	396
NH_3	35 (92%)	2 (5%)	37
NO_x	167 (91%)	17 (9%)	184
CO	7770 (94%)	505 (6%)	8275
SO_2	46 (90%)	5 (10%)	51
PM-coarse	108 (95%)	6 (5%)	114

Table 5.2: Percentage of Wildfires by State and NFDRS Fuel Model

The adjusted fuel load (tons per acre) is based on the default NFDRS fuel loading, added duff and crown biomass, and fuel consumption for each category (Table 3.2)

	NFDRS model (percent per state)													
Model code	A	B	C	F	G	H	I	J	K	L	R	T	U	
Adj. Fuel load	0.5	19.5	4.7	15.0	43.5	27.5	55.1	34.0	14.4	0.8	3.1	4.5	19.1	
														Total
AZ	19	3	16	12	2	3	0	7	5	0	0	29	3	100%
CA	10	24	11	17	2	2	0	0	0.4	7	0	25	3	100%
CO	4	2	9	15	0	48	0	0	0	9	0	13	0	100%
ID	39	1	3	1	14	3	0.5	0	0	0.5	0	39	0	100%
MT	12	0	31	0	7	2	0	1	0	40	1	6	0	100%
ND	63	0	0	0	0	0	0	0	0	38	0	0	0	100%
NM	2	0	28	2	11	4	0	0	7	21	0	23	4	100%
NV	39	0	7	2	0	4	0	0	0	7	0	40	0.7	100%
OR	21	0	13	0	17	2	0	2	0	2	0	43	0.9	100%
SD	13	0	19	0	0	0	0	0	0	68	0	0	0	100%
UT	17	0	12	21	4	1	0	0	0.9	3	0	41	0	100%
WA	56	0	18	0	6	0	0	0	0	0	0	21	0	100%
WY	5	0	15	1	4	2	0	0	0	54	0	21	0	100%
ALL	20	5	13	7	6	4	0.1	0.5	0.7	16	0.1	28	1.0	100%

Figure 5.1: Wildfire Activity and $PM_{2.5}$ Emissions by Month

Shown are the proportion of fire events, fire days (including smoldering days), acreage consumed by fire, fuel consumption and $PM_{2.5}$ emissions. $PM_{2.5}$ emissions include smoldering activity, while the other parameters are based on original fire days only.

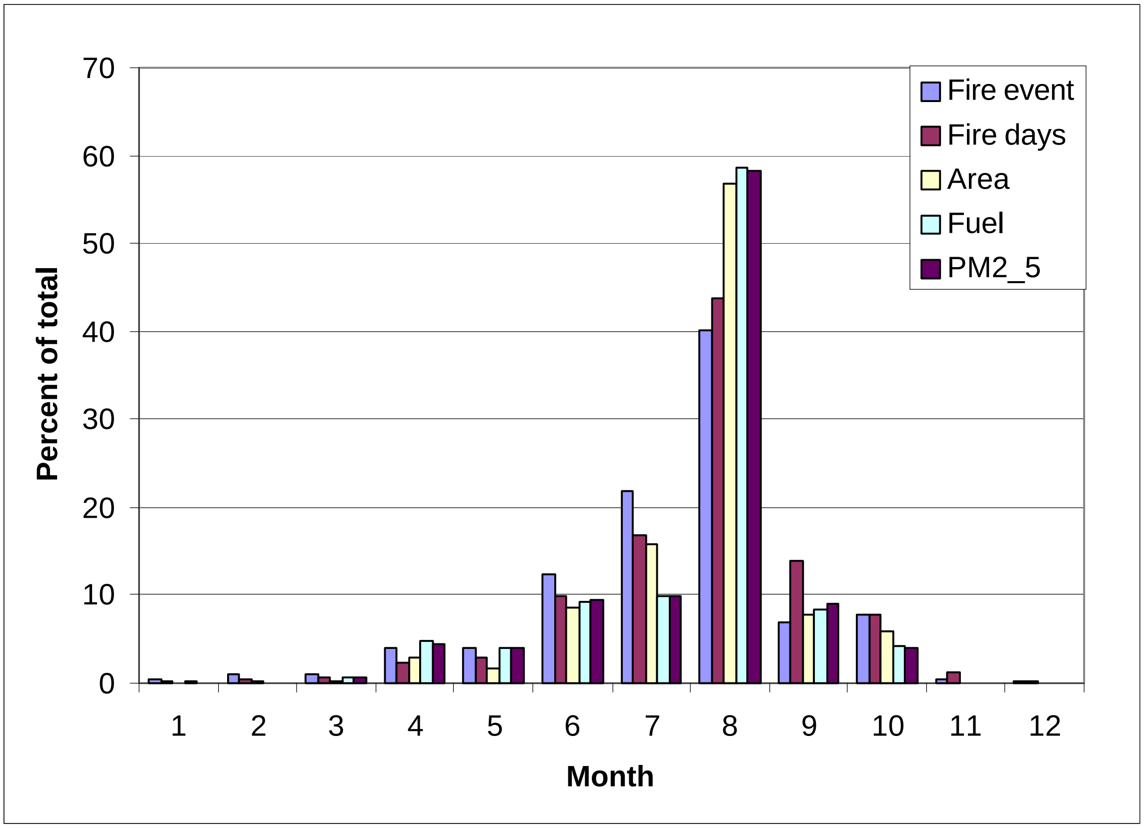


Figure 5.2: Wildfire Activity and $PM_{2.5}$ Emissions by State

Shown are the proportion of fire events, fire days (including smoldering days), acreage consumed by fire, fuel consumption and $PM_{2.5}$ emissions. $PM_{2.5}$ emissions include smoldering activity, while the other parameters are based on original fire days only.

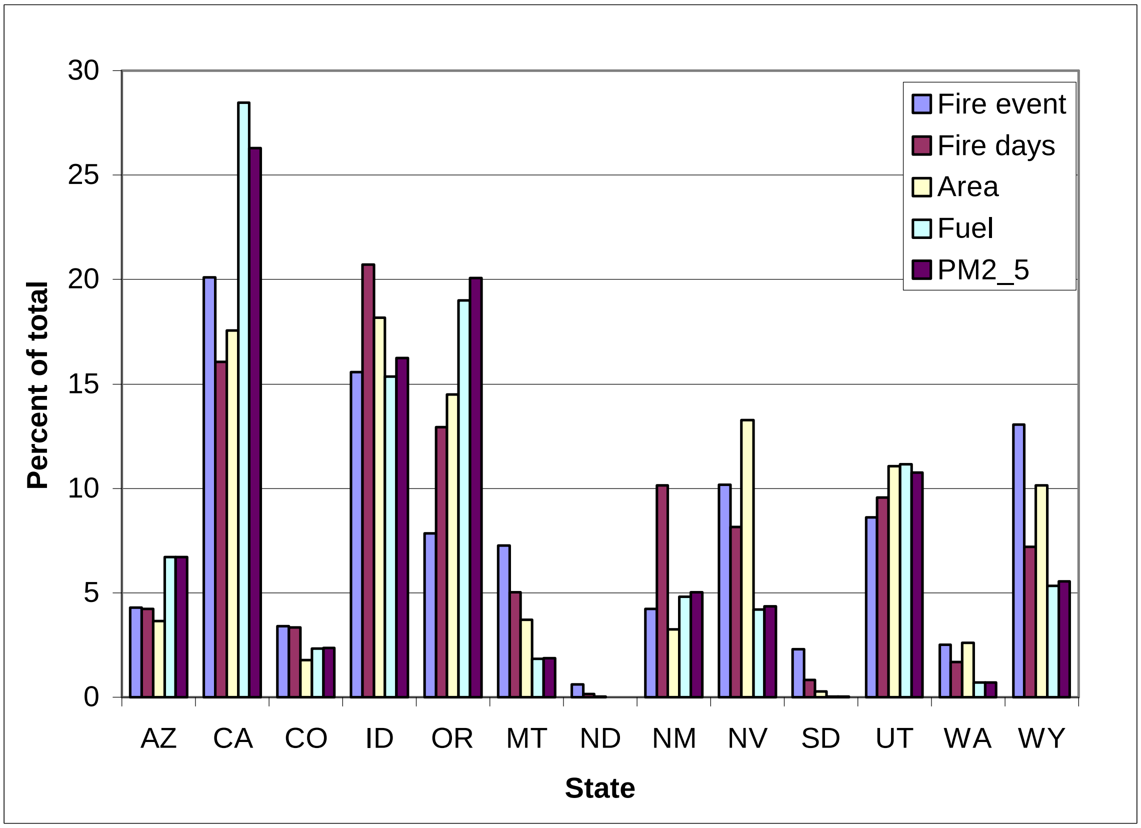


Figure 5.3: Wildfire Activity and $PM_{2.5}$ Emissions by NFDRS Fuel Model

Shown are the proportion of fire events, fire days (including smoldering days), acreage consumed by fire, fuel consumption and $PM_{2.5}$ emissions. $PM_{2.5}$ emissions include smoldering activity, while the other parameters are based on original fire days only.

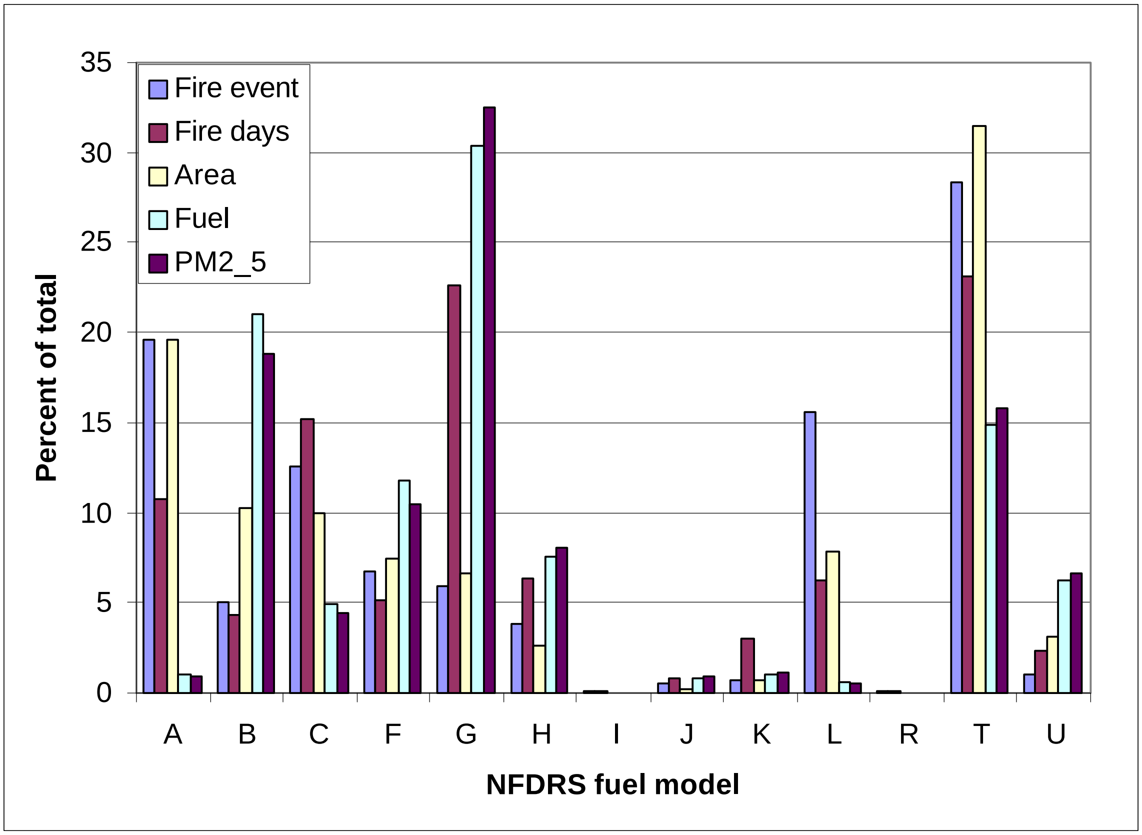


Figure 5.4: Prescribed Burning Activity and $PM_{2.5}$ Emissions by Month

Shown are the proportion of fire days (including smoldering days), acreage consumed by fire, fuel consumption and $PM_{2.5}$ emissions. $PM_{2.5}$ emissions include smoldering activity, while the other parameters are based on original fire days only.

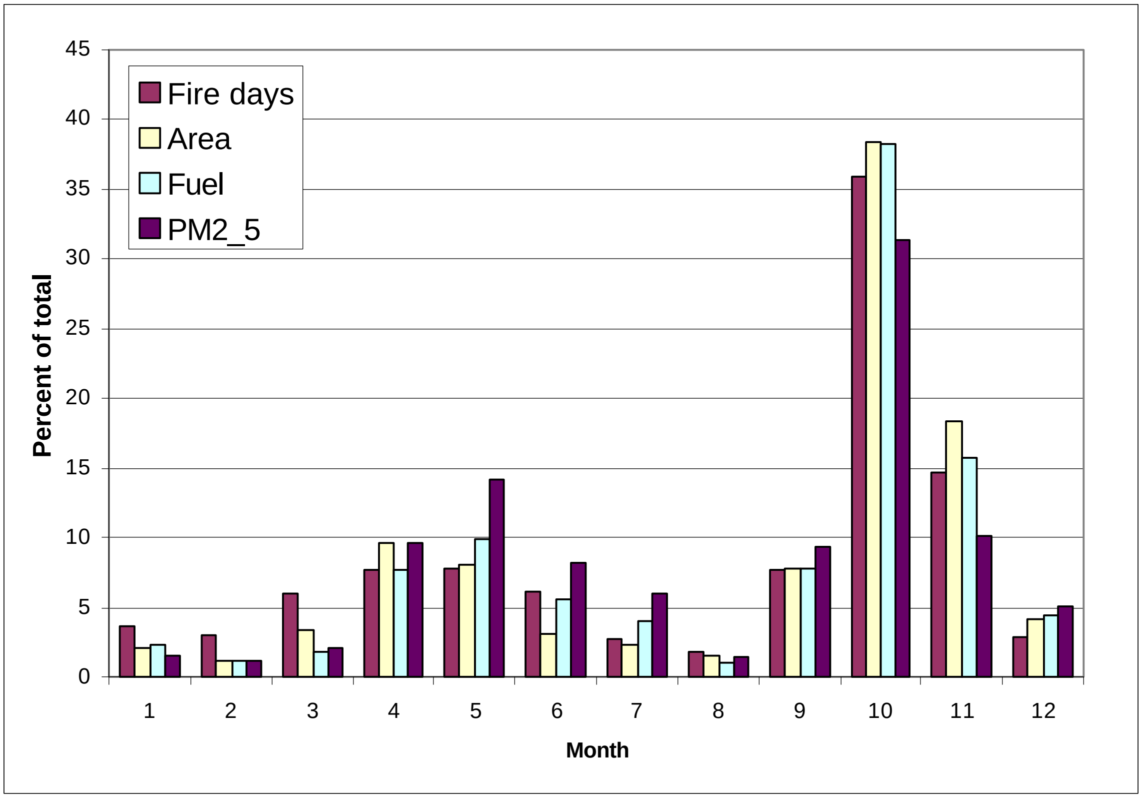


Figure 5.5: Prescribed Burning Activity and $PM_{2.5}$ Emissions by State

Shown are the proportion of fire days (including smoldering days), acreage consumed by fire, fuel consumption and $PM_{2.5}$ emissions. $PM_{2.5}$ emissions include smoldering activity, while the other parameters are based on original fire days only.

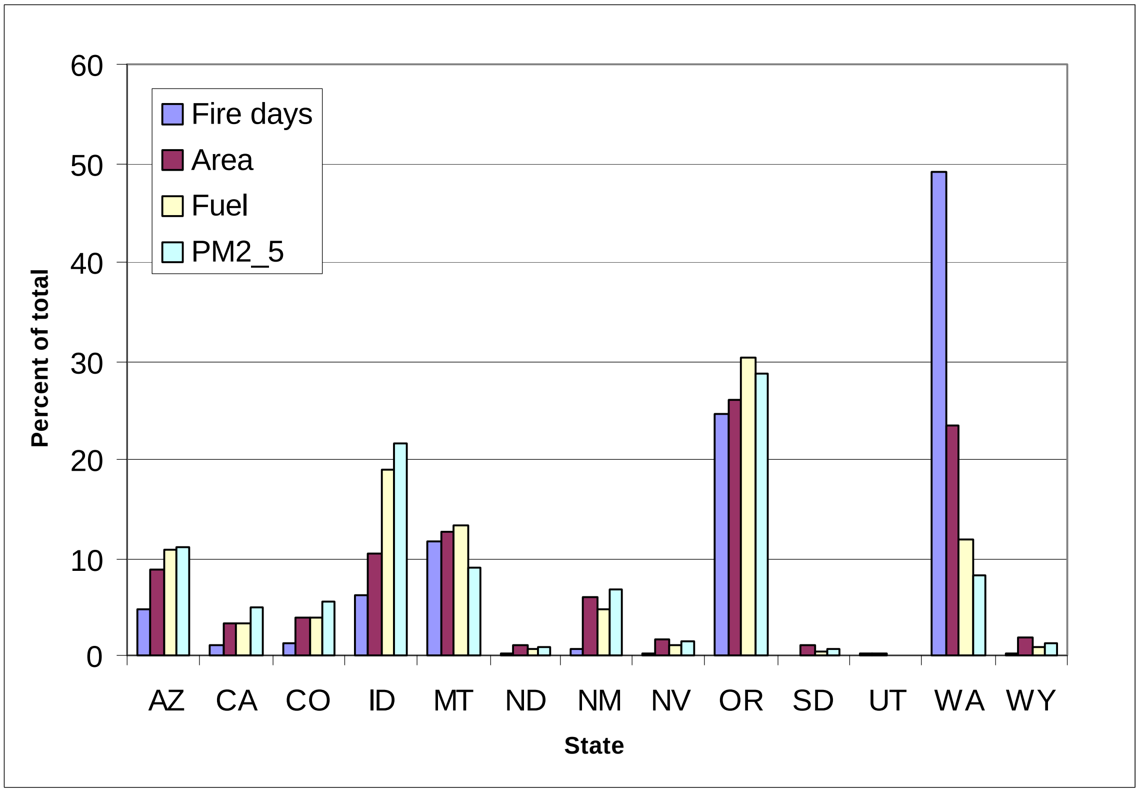
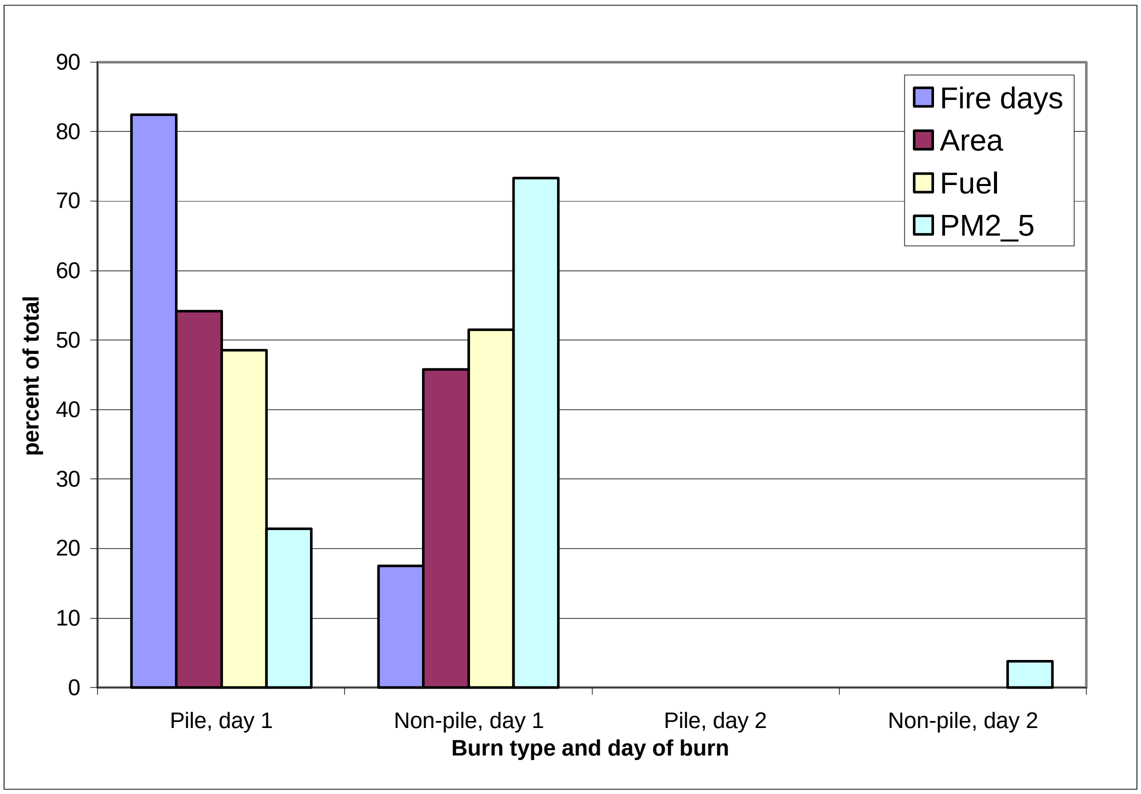


Figure 5.6: Prescribed Burning Activity and $PM_{2.5}$ Emissions by Burn Type

Prescribed burning activity and $PM_{2.5}$ emissions by burn type, i.e., pile versus non-pile burns, and day of burn, i.e., the reported days (day 1) and smoldering days (day 2). Shown are the proportion of fire days (including smoldering days), acreage consumed by fire, fuel consumption and $PM_{2.5}$ emissions. $PM_{2.5}$ emissions include smoldering activity, while the other parameters are based on original fire days only.



SECTION 6

COMPARISON OF THE PRELIMINARY AND REFINED JULY 1996 INVENTORIES FOR WILDFIRE

In the draft wildfire emission inventory for July 1996 only, fuel loading was based on the default values of the USDA Forest Service regions. Smoldering emissions were not included in the draft emission calculations. The refined data wildfire emission inventory calculates the fuel loading based on the NFDRS model, and incorporates smoldering emissions for a subset of NFDRS fuel models (Table 3.2). Moreover, the emission factors for the pollutants in the refined analyses were generally higher (Table 3.1). Finally, the draft inventory did use a slightly different algorithm to calculate plume characteristics. However, the latter did not affect the daily emission totals of the pollutants, which will be discussed in the remainder of this section. A table comparing the key statistics of the two inventories (for July) is below.

The number of fire events ignited in the month of July was slightly lower in the refined emission inventory compared to the draft emission inventory. This was due to additional QA / QC of the source data that occurred between the draft and the final data set. As a result, the refined emission inventory also had fewer fire days compared to the draft inventory, although both inventories had similar mean fire durations. The acreage consumed by wildfire in the refined inventory was 3% lower compared to the draft inventory. Overall, pollutant emissions in the refined emission inventory were 50 to 90% lower than those in the draft emission inventory, depending on the pollutant. This reduction in pollutant emissions was mainly driven by the more refined fuel loading values using the NFDRS model compared to the default values based on US Forest Service regions. Fuel consumption in the refined dataset was 75% lower than in the draft dataset. Additional smoldering emissions after day 1 of a fire, and one day after the last fire report (applied for certain NFDRS fuel models) increased emissions by about 8% in the month of July (from Table 6.1: 0.27 / 0.25 108%). The ratios of pollutant emissions of the refined versus the draft inventory depend on the differences in emission factors between the two inventories. Overall, the substantial decrease in emission estimates in the refined inventory is largely due to lower fuel loading values, fine-tuned by differences in emission factors, and to some extent in smoldering emissions and additional QA / QC of the data set.

Table 6.1: Comparison of the Draft and Refined Fire Emission Inventories for July 1996

Standard error of the mean is indicated by "se."

Factor	Draft inventory	Refined inventory	Ratio Refined / Draft
Number of fire events	307	295	0.96
Number of fire days	946	890	0.94
Fire duration (days ± se)	3.1 ± 0.3	3.0 ± 0.2	1.03
Acres burned (*10^3)	812.4	789.5	0.97
Fuel burned (tons*10^3)	18,799.8	4,713.0	0.25
TSP emission (tons*10^3), EFs as in draft inventory	160.4	44.1	0.27
Total emissions (tons10^3)*			
EFs as in final inventory			
TSP	160.4	48.1	0.30
PM_{10}	121.9	39.6	0.32
$PM_{2.5}$	109.7	34.0	0.31
Elemental carbon	9.9	2.1	0.21
Organic carbon	69.8	16.4	0.23
VOC	58.7	19.2	0.33
CH_4	72.1	19.2	0.27
NH_3	16.1	1.8	0.11
NO_x	37.7	8.7	0.23
CO	1,320.6	407.4	0.31
SO_2	18.9	2.4	0.13
PM Coarse	12.2	5.6	0.46

SECTION 7

SENSITIVITY ANALYSIS OF WILDFIRE EMISSION ESTIMATES

Underlying the calculation of the emission estimates are many input parameters. Each of these input parameters has a unique range of values, mean, and probability distribution. Based on the probability distribution of the input parameters, an estimate of the uncertainty inherent to the emission estimates presented in this report can be made. This section presents an estimate of the uncertainty in the estimates in the pollutant emissions from wildfire. Incorporated in this analysis are three parameters: reported fire size, fuel loading, and emission factors. These parameters are the most important ones in the pollutant emission calculation. Moreover, limited data were available on which the analysis could be based. Although additional factors, e.g., uncertainty in fire location, could influence the accuracy of emission estimates, no data were available to quantify the potential errors introduced into the calculation from other sources.

The uncertainty analysis of the estimated area of wildfires in the 1996 inventory was based on a subset of the reported wildfires in the inventory, i.e., those fires that came from the 209 information source. Fire size data from this source were extracted from the wildfire source data. Next, the uncertainty of the fire size estimates was derived based on a comparison of reported fire sizes from the 209-database with 1202-reports (email communication, Peter Lahm, 9/13/01). Based on this comparison a frequency distribution was derived of the absolute difference in estimated fire size between these two methods. This frequency distribution was then applied to the 209-database wildfires in the inventory. The absolute deviations were scaled based on the absolute values in the inventory, i.e., increasing fire sizes were matched with higher absolute deviations. In the last step the difference of the “adjusted fire size” relative to the reported fire size and the distribution of the relative errors were calculated. One relative standard deviation, or RSD, of this distribution corresponded to 25% of the estimated fire size (Table 7.1). In other words, in 68% of the cases one could expect the actual fire size to be within plus or minus 25% of the reported value.

The uncertainty of the fuel loading estimates is dependent on several factors. One factor is the accuracy of the spatial overlay of the fire locations with the NFDRS layer; i.e., the process that assigns each fire with a specific NFDRS fuel model. However, with the data in the inventory the accuracy of this process could not be assessed quantitatively. Once a specific fuel has been assigned to a fire a default fuel loading is assigned. Within each NFDRS fuel model there is an inherent variation in fuel loading due to site and stand variation within that category. This variation was assessed using the “Stereo Photo Series for Quantifying Natural Fuels”, Volumes I and III, for the Pacific Northwest and Rocky Mountains, respectively (National Wildfire Coordinating Group, 2000). The vegetation types in the photo series were matched with the corresponding NFDRS fuel models. Next, the average fuel loading and its probability distribution were calculated for each vegetation type (number of entries per vegetation type 4-17). The RSD for the fuel loadings in each vegetation type did not differ between forest stands and grasslands, and averaged about 60% (range 20 to 105%). In other words, in 68% of the cases one could expect the actual fuel loading to be within plus or minus 60% of the (averaged) NFDRS value (Table 7.1).

The uncertainty of the pollutant emission factors was based on a literature study on emission factors for CO, CH_4 and $PM_{2.5}$ from grassland- and cereal crop burning (Air Sciences Inc., internal report). This study was based on 8 articles from the peer-reviewed literature. From each study the mean reported emission factors for each pollutant were extracted. The mean and probability distribution of the emission factors were calculated (number of entries per pollutant 5-8). The RSD values were 27%, 41%, and 72 % for CO, CH_4 and $PM_{2.5}$, respectively. Thus, on average, in 68% of the cases one could expect the actual fire size to be within plus or minus 50% of the reported value (Table 7.1).

The uncertainties in each of the parameters can be combined in a low and a high estimate for total emissions (Table 7.1). This analysis shows that combining these three sources of uncertainty could lead to emissions estimates between 15 and 300% of the reported average emissions, based on a range of one RSD for each parameter. However, when interpreting these results one has to keep in mind that each of these parameters has its own probability distribution, and that these distributions can be considered to be independent of each other. For example, just considering one parameter, the probability of a value on the extreme end of one standard deviation (high or low) is ~16% (or 0.16). When all three parameters are combined the probability that all parameters are high or low equals $(0.16)^3$, a probability of only ~0.4%.

Table 7.1: Uncertainty Estimates

Summary of uncertainty estimates of pollutant emissions from wildfires using the 1996 inventory. Shown are the relative standard deviations for each source of uncertainty, and their minimum and maximum based on one relative standard deviation (RSD). The baseline $PM_{2.5}$ emissions for the 1996 wildfires were approximately 648,000 tons.

Source of Uncertainty	Relative Standard Deviation %	Uncertainty Rratio (1 RSD)		$PM_{2.5}$ Emission Estimate for Wildfire 1996, tons $*10^3$ (1 RSD)	
		Minimum	Maximum	Minimum	Maximum
Fire size	25	0.75	1.25	486	810
Fuel loading	60	0.40	1.60	259	1037
Emission factor	50	0.50	1.50	324	972
ALL	n/a	0.15	3.00	97	1944

SECTION 8

SMOKE MODELING FILES

8.1 Format of the SMOKE Modeling Input Files

The PTINV file contains the locations of all the fires in the inventory, expressed as the latitude and longitude (in decimal degrees). The file has five header lines showing a model input ID, county, year, file description, and the data contained in the file. Each subsequent line represents a separate fire, with the following information: state FIP, county FIP, fire name (up to 14 characters), fire name (full), and latitude (degrees), and longitude (degrees). These variables are interspersed with several fixed values and blank spaces as placeholders. Each of the variables and placeholders has a unique column width, indicated in the column next to the variable name. The SMOKE file data elements are detailed in Table 8.1. The file will have as many lines as there are individual fires in the inventory, i.e., 1,348 in the case of the 1996 wildfire emission inventory.

The PTHOUR file contains the plume height data for all the fire days in the inventory. The header of the PTHOUR consists of a model input ID, county, year, file description, and the data contained in the file. All fire days are represented in this file. Thus, if a fire burns over a 3-day period, three separate fire days will be entered into the data file. For each fire day, three lines of codes are entered: one for the proportion of the plume entrained in the lower atmospheric layer (<100 m; variable name LAYF1), one for the bottom of the plume (in m; PBOT), and one for the top of the plume (in m; PTOP). For wildfires these three parameters are scaled to the virtual fire size for each day. The information included in the file is as follows: state FIP, county FIP, fire name (up to 14 characters), date (day / month / year), time zone, and 24 hourly values for each of the three parameters described above. Similarly to the PTINV file, these variables are interspersed with several fixed values and blank spaces as placeholders with unique column widths. Since each fire day gets three lines of code in the PTHOUR file, the total number of input lines in the 1996 wildfire emission inventory is 15,933 lines (5,311 fire days times 3 lines per fire day).

The PTDAY file contains daily total emissions of eight pollutants for all the fire days in the inventory. Similarly to the other files, the header of the PTDAY file consists of a model input ID, county, year, file description, and the data contained in the file. All fire days are represented in this file. Thus, if a fire burns over a 3-day period, three separate fire days will be entered into the data file. For each fire day, eight lines of code are entered, one for each pollutant. The pollutants included in the file are PM_{10}, $PM_{2.5}$, volatile organic hydrocarbons (VOC), ammonia (NH_3), nitrogen oxides (NO_x), carbon monoxide (CO), sulfur dioxide (SO_2) and PM-coarse. The information in the file is as follows: state FIP, county FIP, fire name (up to 14 characters), pollutant name, date (day / month / year), time zone, and the daily total emissions. Similarly to the PTINV file, these variables are interspersed with several fixed values and blank spaces as placeholders with unique column widths. Since each fire day gets eight lines of code in the

PTHOUR file, the total number of input lines in the 1996 wildfire emission inventory is 42,488 lines (5,311 fire days times 8 lines per fire day).

8.2 Data Extraction Procedures

The procedure to extract the data for the modeling input files from the data processing spreadsheets consisted of several steps. The processing spreadsheets for wildfire have one or two sheets with the output data to the modeling files. To create the modeling files, all data from these sheets were copied over to new Excel workbooks, and pasted as values. These data were then edited to insert the necessary placeholders (Section 8.1), and copied to a template file. The modeling input files were then created using a macro to extract the data from the workbook to a new "prn" file

The prescribed fire emission inventory was exported in a similar fashion but using ArcView GIS software. For each type of SMOKE file, ArcView scripts were programmed to iterate through each activity record and print out the appropriate information. The data order, format, and width as specified by the modeling forum were observed. As with the wildfire "prn" files, emission inventory export files were compared with example files supplied by the Modeling Forum.

Table 8.1: File Format of SMOKE Input Files Extracted from the Excel Emissions Spreadsheet.

PTINV-file		PTHOUR-file		PTDAY-file	
Variable Name	Column Width	Variable Name	Column Width	Variable Name	Column Width
State FIP	2	State FIP	2	State FIP	2
County FIP	3	County FIP	3	County FIP	3
Fire name (short)	15	Fire name (short)	15	Fire name (short)	15
"0" value	15	"0" value	12	"0" value	12
"1" value	12	"1" value	12	"1" value	12
Blank space	14	Blank space	12	Blank space	12
Fire Name (full)	40	Variable Name (3 lines per fire)	5	Pollutant Name (8 line per fire)	5
"2810001000"	10	Date (dd/mm/yy)	8	Date (dd/mm/yy)	8
Blank space	19	Time zone	3	Time zone	3
"72." value	3	Value hour 0	7	Daily emissions	18
Blank space	93	To…	…	"2810001000"	11
"0010" value	4	Value hour 23	7		
Latitude (deg)	9	Blank space	9		
Longitude (deg)	9	"2810001000"	10		

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CD-ROM

This final report for the FEJF 1996 Fire Emission Inventory includes a data CD-ROM. The CD contains:

- The emission inventory SMOKE files as delivered to the Modeling Forum;
- Wildfire emission inventory Excel spreadsheet including calculations, results, and look-up tables;
- Prescribed fire emission inventory as an Excel workbook including emission inventory flat file, metadata descriptions, and look-up tables; and
- This final report as an electronic document.