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REGIONAL PARTICULATE STRATEGIES

Draft Report

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ACRONYMS AND ABBREVIATIONS

acfm	actual cubic feet per minute
ADEQ	Arizona Department of Environmental Quality
ADT	average daily traffic
API	American Petroleum Institute
BACM	Best Available Control Measures
CAA	Clean Air Act
CAAA	Clean Air Act Amendments of 1990
CARB	California Air Resources Board
CI	compression ignition
CO	carbon monoxide
CRC	Coordinating Research Council
DEQ	Department of Environmental Quality
DOT	U.S. Department of Transportation
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
ERCAM	Emission Reduction and Cost Analysis Model
ESPs	electrostatic precipitators
FCC	fluidized catalytic cracker
FGD	flue gas desulfurization
FHA	Federal Highway Administration
FIRE	Factor Information Retrieval System
gr/acf	grains per actual cubic foot
GVWR	gross vehicle weight rating
HC	hydrocarbon
HDDEs	heavy-duty diesel engines
HDDVs	heavy-duty diesel vehicles
HDVs	heavy-duty vehicles
HFET	Highway Fuel Economy Test
HHDDV	heavy heavy-duty diesel vehicles
I/M	inspection and maintenance
ICI	institutional, commercial, and industrial
kW	kilowatts
LDTs	light-duty trucks
LDVs	light-duty vehicles
LHDDV	light heavy-duty diesel vehicles
MC	motorcycles
MHDDV	medium heavy-duty diesel vehicles
MM-4	Mesoscale Meteorological Model - Version 4
NAAQS	National Ambient Air Quality Standard
NAPAP	National Acid Precipitation Assessment Program
NGR	natural gas reburn
NO_x	oxides of nitrogen
NPRA	National Petroleum Refiners Association
NPRM	Notice of Proposed Rulemaking
NSPS	New Source Performance Standards

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ACRONYMS AND ABBREVIATIONS (continued)

O&M	operation and maintenance
OAQPS	Office of Air Quality Planning and Standards
OPPE	Office of Policy, Planning and Evaluation
OPPIES	OPPE Particulate Programs Implementation Evaluation System
PAE	public awareness and education
PM	particulate matter
PM_{10}	particulate matter of 10 microns or less
$PM_{2.5}$	particles less than or equal to 2.5 microns in diameter
ppm	parts per million
RIAs	Regulatory Impact Analyses
RWC	Residential Wood Combustion
SCAQMD	South Coast Air Quality Management District
SCC	Source Classification Code
SCR	selective catalytic reduction
SET	Sulfate Emission Test
SI	spark ignition
SIP	State Implementation Plan
SJVAQS	San Joaquin Valley Air Quality Study
SJVUAPCD	San Joaquin Valley Unified Air Pollution Control District
SNCR	selective non-catalytic reduction
SO_2	sulfur dioxide
TPY	tons per year
UCD	University of California at Davis
USFS	U.S. Forest Service
VMT	vehicle miles traveled
VOCs	volatile organic compounds
2BHDDV	class 2B heavy-duty diesel vehicles

CHAPTER I
INTRODUCTION

In 1993, the U.S. Environmental Protection Agency (EPA) Office of Policy, Planning and Evaluation (OPPE) contracted with E.H. Pechan & Associates, Inc. (Pechan) to develop a comprehensive system for optimizing national particulate control strategies. Phase I of that effort, which was completed on September 30, 1994, produced the OPPE Particulate Programs Implementation Evaluation System (OPPIES). Phase I study results were provided in a final report entitled, "Development of the OPPE Particulate Programs Implementation Evaluation System" (Pechan, 1994). Development of OPPIES included preparation of national emission estimates for particulate matter (PM) of 10 microns or less (PM_{10}), particles less than or equal to 2.5 microns in diameter ($PM_{2.5}$), and the particulate precursors (sulfur dioxide [SO_2], oxides of nitrogen [NO_x], volatile organic compounds [VOCs], ammonia, and secondary organic aerosols). It also included initial development and testing of a national air quality modeling system, and research into PM control measures and costs.

The objective of this work assignment was to use the Phase I results to upgrade and refine OPPIES to improve its performance as a modeling and control strategy evaluation tool.

This report is organized according to the major task activities performed during the project period. Chapter II describes the improvements made to the national PM emission inventory during this study. Since the development of the PM inventory under OPPIES, new data and models for estimating primary PM and secondary precursor emissions have become available. Significant improvements to the inventory that were performed during this study include:

- Motor vehicle emissions of PM and SO_2 are now estimated using EPA's PART5 model emission factors;
- Motor vehicle ammonia emission factors were updated using emission test results for 3-way catalyst-equipped vehicles from an industry study;
- Ammonia emissions for agricultural sources were revised using the latest emission factors and activity estimates;
- Emission estimates for 11 western States were revised to include data from the Grand Canyon Visibility Transport Commission (GCVTC) Inventory; and
- PM point source emissions were revised to reflect newly developed particle size distributions and PM control efficiencies.

These improvements to the emissions data base are described in Chapter II.

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Chapter III includes the evaluations of control effectiveness and cost for PM and PM precursor emission control measures that have been performed for the subject work assignment. The overall objective of the control measure evaluation was to develop estimates of control effectiveness and costs for the source categories most likely to be candidates for further control if the PM National Ambient Air Quality Standard (NAAQS) is changed.

Chapter IV describes the modeling methods used to estimate what 2007 pollutant emissions are likely to be by area under the provisions of the Clean Air Act Amendments of 1990 (CAAA).

Chapter V describes the Lagrangian Regional Model (LRM) and its application in this study. This model is based on the extensive Mesoscale Meteorological Model - Version 4 (MM-4) data base provided in May 1994 by EPA's Office of Research and Development.

Chapter VI describes the development and testing of the optimization model. This model integrates the products from the other tasks in order to determine optimal control strategies for attaining various hypothetical PM standards.

CHAPTER II
EMISSIONS INVENTORY

A. INTRODUCTION

EPA is considering revisions to the existing PM NAAQS. A national PM emission inventory is needed by EPA to assess the possible impacts of revisions to the NAAQS. EPA's OPPE developed a national inventory under Phase I of the Regional Particulate Study. The inventory developed under this program included emission estimates for PM_{10}, $PM_{2.5}$, and ammonia. Together with the Interim Inventory, a national inventory of VOCs, NO_x, carbon monoxide (CO), and SO_2 developed previously by EPA, emissions data on primary particulates and precursors to secondary particulate formation were needed for assessing the possible impacts of revisions to the PM NAAQS.

Since the development of the PM inventory under OPPIES, new data and models for estimating primary PM and secondary precursor emissions have become available. Listed below are the changes to the inventory that were performed under this study:

- PM (including paved and unpaved road dust) and SO_2 mobile source emissions were revised using emission factors from the PART5 model, recently released by EPA's Office of Mobile Sources (OMS), and ammonia emission factors from motor vehicles were updated;
- Ammonia emissions from agricultural sources were revised using the latest emission factors and activity estimates;
- Emission estimates for 11 western States were revised to include data from the GCVTC Inventory; and
- PM point source emissions were revised to reflect newly developed particle size distributions and PM control efficiencies.

These inventory updates are explained in more detail in the sections that follow. Table II-1 summarizes the emission inventory methods that were applied to develop the National Particulates Inventory for the major source types. Emission estimation methods for source types that are not described in this report are the same as those used in the OPPIES study.

Table II-2 summarizes the total PM_{10} and $PM_{2.5}$ emissions for the United States for 1990 by major source category. Direct PM_{10} emissions are approximately 42 million tons per year, while $PM_{2.5}$ emissions are about 33 percent of this total, at slightly more than 14 million tons. Fugitive dust sources dominate both the PM_{10} and $PM_{2.5}$ totals. Other observations regarding the Table II-2 emission estimates are provided below.

Table II-1
Summary of Emission Modeling Approaches by Major Source Type

Major Source Type	Modeling Approach/Data Sources
Electric Utilities	DOE fuel use data. U.S. EPA AP-42 Emission factors.
Non-Utility Point Sources	1985 NAPAP and BEA Earnings Projections. PM_{10} and $PM_{2.5}$ distribution of TSP completed using updated EPA AP-42 Emission Factors, and FIRE data base.
Fugitive Dust:	
Agricultural Tilling	PM_{10}, $PM_{2.5}$: U.S. Department of Agriculture (USDA) Data. NH_3: Commercial Fertilizers Data Base and emission factors from Netherlands study.
Construction	Census Bureau Construction Expenditures, and PM_{10} Emission Factors for Selected Open Air Sources.
Wind Erosion	1985 NAPAP, National Climatological Data Center (NCDC) data, and USDA farming activity levels.
Unpaved and Paved Roads	EPA PART5 model, NCDC data, Automobile and Truck Fleet data, Federal Highway Administration (FHA) travel data, and silt content data.
Livestock Operations	USDA farming activity levels, EPA PM emission factors, and NH_3 emission factors from Netherlands study.
Other Area Sources	NAPAP and appropriate growth factors.
Mobile Sources	FHA travel data, PM emission factors from PART5, and NH_3 emission factors from Volkswagen study.
Nonroad Sources	Emission Estimates from Emission Inventory Branch (EIB).
Other Combustion:	
Agricultural/Structural Fires	NAPAP and BEA farm income growth factors.
Wildfires	NAPAP. (Grand Canyon Visibility Transport Commission (GCVTC) inventory for 11 western States.)
Prescribed Burning	USDA inventory. (GCVTC inventory for 11 western States.)
Biogenic Sources	1993 study containing emission estimates for 8 land cover types.
SOA	Fractional aerosol coefficients (FACs) from study that estimated potential for certain VOC-emitting source categories to form SOA.
Canadian Sources	NAPAP and Environment Canada growth factors.
Mexican Sources	World Bank 1992 emission report and population growth factors. GCVTC inventory for three major point sources.

Table II-2
National Particulate Emission Summaries

Source Categories	Direct PM_{10} (tons/year)	Direct $PM_{2.5}$ (tons/year)
Fuel Combustion Electric Utilities	284,221	109,608
Fuel Combustion - Industrial	248,974	176,607
Fuel Combustion - Other	601,803	579,142
Chemical & Allied Product Manufacturing	61,537	41,811
Metals Processing	138,096	96,429
Petroleum & Related Industries	29,080	20,797
Other Industrial Processes	409,497	250,790
Solvent Utilization	2,134	1,807
Waste Disposal & Recycling	226,085	197,250
Highway Vehicles	356,738	292,674
Off-Highway	336,343	292,624
Other Combustion	1,166,395	1,028,479
Fugitive Dust - Natural Sources	4,180,983	1,657,704
Fugitive Dust - Agriculture	7,266,172	3,457,629
Fugitive Dust - Other		
Paved Roads	5,967,150	2,517,691
Unpaved Roads	12,325,601	3,249,389
Construction Activities	8,488,983	172,605
Miscellaneous	2,718	442
Not Elsewhere Classified	12	7
Totals	42,156,842	14,169,974

1. Most of the PM emissions for the fuel combustion - other category are from residential wood combustion. Most of PM emissions from this source type are in the less than 2.5 micron range.

2. Apart from their fugitive dust emissions, highway and nonroad engines/vehicles are of about equal importance in their contributions to PM_{10} and $PM_{2.5}$ emissions. Diesel engines are the dominant PM sources in both of these source types.

3. Other combustion includes the emissions from wildfires and prescribed burning. Region X has 70 percent of the wildfire emissions. Region IV has 50 percent of the prescribed burning emissions.

4. Emissions listed as fugitive dust - natural sources are from wind erosion on agricultural land. More than 70 percent of these emissions are in Region VI.

5. Emissions listed as fugitive dust - agriculture are those from agricultural crops (tilling) and agricultural livestock.

6. Paved and unpaved road emissions are 43 percent of PM_{10} and 41 percent of national $PM_{2.5}$ emissions. In non-agricultural areas, paved and unpaved road dust is normally the dominant source of both PM_{10} and $PM_{2.5}$.

7. Construction activity has the biggest difference between PM_{10} and $PM_{2.5}$ emissions. $PM_{2.5}$ emissions are 2 percent of PM_{10} emissions for this source type.

B. 1990 PM_{10}, SO_2, AND AMMONIA EMISSIONS FROM MOTOR VEHICLES

In 1994, EPA released a computer model, with the acronym PART5, that can be used to estimate particulate emission rates from in-use gasoline and diesel-fueled motor vehicles (EPA, 1994). It calculates particle emission factors in grams per mile from on-road automobiles, trucks, and motorcycles, for particle sizes up to 10 microns.

1. Use of the PART5 Model

The EPA's particulate matter emission factor model, PART5, was used to calculate highway vehicle PM_{10} emission factors from vehicle exhaust, brake wear, tire wear, and reentrained road dust from paved and unpaved roads, and SO_2 vehicle exhaust emission factors.

Basic assumptions regarding inputs to PART5 were made that apply to all PART5 model runs. These are listed below:

- The transient speed cycle was used.

- Any county with an existing inspection and maintenance (I/M) program was given I/M credit from PART5, regardless of the details of the I/M program. PART5 gives credit based on the assumption that high emitting vehicles will be forced to make emission reducing repairs and that an existing I/M program will deter tampering. This only affects lead and sulfate emissions from gasoline-powered vehicles.

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- Using the input parameter BUSFLG, bus emission factors for all rural road types, urban interstates, and other freeways and expressways road types were modeled using the PART5 transit bus emission factors, while bus emission factors for all other urban road types were modeled using the PART5 Central Business District bus emission factors.

a. Registration Distribution

The vehicle registration distribution used was also common to all PART5 model runs. PART5 uses the same vehicle classifications as the MOBILE model, except that the MOBILE heavy-duty diesel vehicle (HDDV) class is broken into five subclasses in PART5. Table II-3 lists each vehicle class in PART5 along with its Federal Highway Administration (FHA) class and gross vehicle weight.

To maintain consistency with the 1990 Interim Inventory, the 1990 vehicle registration distribution used in the MOBILE modeling for the 1990 Interim Inventory was adapted for this analysis. This registration distribution was modified by distributing the MOBILE HDDV vehicle class distribution among the five PART5 HDDV subclasses (class 2B heavy-duty diesel vehicles [2BHDDV], light heavy-duty diesel vehicles [LHDDV], medium heavy-duty diesel vehicles [MHDDV], heavy heavy-duty diesel vehicles [HHDDV], and BUSES). This was accomplished using HDDV subclass-specific sales, survival rates, and diesel market shares.

b. HDDV Vehicle Class Weighting

After PART5 emission factors are generated, the PART5 HDDV subclass emission factors (2BHDDV, LHDDV, MHDDV, HHDDV, and BUSES) are weighted together to develop a single HDDV emission factor, to correspond with the vehicle miles traveled (VMT) data already developed for the 1990 Interim Inventory. These weighting factors are based on truck VMT by weight and truck class from the *Truck Inventory and Use Survey* (BOC, 1990) and *Highway Statistics 1990* (FHA, 1990).

c. Emission Factor Mapping

The VMT data developed for the Interim Inventory and used in emission calculations here are at the monthly, county, road type, and vehicle type level. Road type and vehicle type combine to determine the vehicle speed modeled and Source Classification Code (SCC). The speeds modeled by vehicle type and road type are shown in Table II-4. These speeds were developed for use in the MOBILE modeling done for the Interim Inventory. Emission factors were calculated for each combination of State, I/M status, month, vehicle type, and speed. VMT data for each county/month/vehicle type/road type were mapped to the appropriate emission factor.

2. Exhaust PM_{10} Emissions

Monthly, county-level, SCC-specific PM_{10} emissions from highway vehicle exhaust components were calculated by multiplying 1990 monthly county-level, SCC-specific VMT by 1990 State-level, SCC-specific exhaust PM_{10} emission factors generated using PART5. None of the inputs affecting the calculation of the PM_{10} exhaust emission factors vary by month, so only annual PM_{10} exhaust emission factors were calculated. PART5 total

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Table II-3
PART5 Vehicle Classes

	Vehicle Class	FHA Class	Gross Vehicle Weight (lbs)
LDGV	light-duty gasoline vehicles		
LDGT1	light-duty gasoline trucks, I	1	<6,000
LDGT2	light-duty gasoline trucks, II	2A	6,001-8,500
HDGV	heavy-duty gasoline trucks	2B - 8B	>8,500
MC	motorcycles		
LDDV	light-duty diesel vehicles	1	<6,000
LDDT	light-duty diesel trucks	2A	6,001-8,500
2BHDDV	class 2B heavy-duty diesel vehicles	2B	8,501-10,000
LHDDV	light heavy-duty diesel vehicles	3,4,5	10,001-19,500
MHDDV	medium heavy-duty diesel vehicles	6,7,8A	19,501-33,000
HHDDV	heavy heavy-duty diesel vehicles	8B	33,000+
BUSES	buses		

Table II-4
Average Speeds by Road Type and Vehicle Type

	Rural Road Speeds (mph)					
Vehicle Type	**Interstate**	**Principal Arterial**	**Minor Arterial**	**Major Collector**	**Minor Collector**	**Local**
LDV	60	45	40	35	30	30
LDT	55	45	40	35	30	30
HDV	40	35	30	25	25	25
	Urban Road Speeds (mph)					
Vehicle Type	**Interstate**	**Other Freeways & Expressways**	**Principal Arterial**	**Minor Arterial**	**Collector**	**Local**
LDV	45	45	20	20	20	20
LDT	45	45	20	20	20	20
HDV	35	35	15	15	15	15

NOTES: LDV = Light-duty vehicle.
LDT = Light-duty truck.
HDV = Heavy-duty vehicle.

exhaust emission factors are the sum of lead, soluble organic fraction, remaining carbon portion, and direct SO_4 (sulfate) emission factors.

3. Exhaust SO_2 Emissions

National annual SO_2 highway vehicle exhaust emission factors by vehicle type and speed were calculated using PART5. These emission factors calculated within PART5 vary according to fuel density, the weight percent of sulfur in the fuel, and the fuel economy of the vehicle (which varies by speed). None of these parameters vary by month or State. Monthly/county/SCC-specific SO_2 emissions were then calculated by multiplying each county's monthly VMT at the road type and vehicle type level by the SO_2 emission factor (calculated for each vehicle type and speed) that corresponds with the vehicle type and road type.

4. PM_{10} Brake Wear Emissions

The PART5 PM_{10} emission factor for brake wear is 0.013 grams per mile. This value was applied to estimate brake wear emissions for all vehicle types.

5. PM_{10} Tire Wear Emissions

PART5 emission factors for tire wear are proportional to the average number of wheels per vehicle. The emission factor is 0.002 grams per mile per wheel. Therefore, separate tire wear emission factors were calculated for each vehicle type. Estimates of the average number of wheels per vehicle by vehicle class were developed using information from the *Truck Inventory and Use Survey* (BOC, 1990). Tire wear PM_{10} emissions were then calculated at the monthly/county/SCC level by multiplying the monthly/county/SCC level VMT by the tire wear emission factor for the appropriate vehicle type.

6. PM_{10} Emissions from Reentrained Road Dust from Unpaved Roads

Estimates of PM_{10} emissions from reentrained road dust on unpaved roads were developed for each county. PART5 reentrained road dust emission factors depend on the average weight, speed, and number of wheels of the vehicles traveling on the unpaved roadways, the silt content of the roadway surface material, and the percentage of days in the year with minimal (less than 0.01 inches) or no precipitation. Emissions were calculated by month at the State/road type level for the average vehicle fleet and then allocated to the county/road type level by land area. The activity factor for calculating reentrained road dust emissions on unpaved roads is the VMT accumulated on these roads. The specifics of the emission estimates for reentrained road dust from unpaved roads are discussed in more detail below.

a. PM_{10} Emission Factor Calculation

The equation used in PART5 to calculate PM_{10} emission factors from reentrained road dust on unpaved roads is based on an empirical formula from AP-42. This equation is shown below (EPA, 1993a):

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$$UNPVD - PSUNP_{10} * 5.9 * (SILT/12) * (SPD/30) * (WEIGHT/3)^{0.7} * (WHEELS/4)^{0.5} * (365-IPDAYS)/365 * 453.392$$

where:

UNPVD	=	unpaved road dust emission factor for all vehicle classes combined (grams per mile)
$PSUNP_{10}$	=	fraction of particles less than 10 microns from unpaved road dust (0.36)
SILT	=	percentage silt content of the surface material
SPD	=	average speed of all vehicle types combined (miles per hour [mph])
WEIGHT	=	average weight of all vehicle types combined (tons)
WHEELS	=	average number of wheels per vehicle for all vehicle types combined
IPDAYS	=	number of precipitation days per year with greater than 0.01 inches of rain
493.592	=	number of grams per pound

The above equation is based on roadside measurements of ambient particulate matter, and, therefore, is representative of a fleet average emission factor rather than a vehicle-specific emission factor. In addition, because this equation is based on ambient measurements, it includes particulate matter from tailpipe exhaust, brake wear, tire wear, and ambient background particulate concentrations. Therefore, the PART5 fleet average PM_{10} emission factors for the tailpipe, tire wear, and brake wear components were subtracted from the unpaved road fugitive dust emission factors before calculating emissions from reentrained road dust on unpaved roads.

i. Silt Content Inputs

Average State-level, unpaved road silt content values developed as part of the 1985 National Acid Precipitation Assessment Program (NAPAP) Inventory, were obtained from the Illinois State Water Survey (Stensland, 1989). Silt contents of over 200 unpaved roads from over 30 States were obtained. Average silt contents of unpaved roads were calculated for each State that had three or more samples for that State. For States that did not have three or more samples, the average for all samples from all States was substituted.

ii. Precipitation Inputs

Rain data input to the emission factor equation above is in the form of the total number of rain days in the year. However, the equation uses the number of days simply to calculate a percentage of rain days. Therefore, to calculate unpaved road dust emission factors that represent monthly conditions, data from the National Climatic Data Center showing the number of days per month with more than 0.01 inches of rain were used (NCDC, 1990). These monthly rain data were multiplied by 12 before being input to PART5 so that the inputs would represent an annual number of rain days, as required by the equation. Precipitation event accumulation data were collected for several meteorological stations within each State.

iii. Vehicle Wheel, Weight, and Speed Inputs

The speeds shown in Table II-4 for light-duty vehicles (LDVs) and trucks were also assumed to be the average unpaved road speeds for the corresponding unpaved road classification. However, because the fugitive dust emission factors are representative of the entire vehicle fleet, these speeds for each road type were weighted by vehicle-specific VMT to obtain road type-specific speeds. These speeds are shown in Table II-5. Estimates of average vehicle weight and average number of wheels per vehicle over the entire vehicle fleet were based on data provided in the *Truck Inventory and Use Survey* (BOC,1990), *MVMA Motor Vehicle Facts and Figures '91* (MVMA, 1991), and the *1991 Market Data Book* (Automotive News, 1991). Using these data sources, a fleet average vehicle weight of 6,358 pounds was modeled with a fleet average number of wheels per vehicle of 5.

Table II-5
Speeds Modeled for Unpaved Roads

Rural Roads	Speed (mph)	Urban Roads	Speed (mph)
Minor Arterial	39	Other Principal Arterial	20
Major Collector	34	Minor Arterial	20
Minor Collector	30	Collector	20
Local	30	Local	20

b. Unpaved Road VMT

The calculation of unpaved road VMT was performed in two parts. Separate calculations were performed for county and noncounty (State or Federally) maintained roadways.

The equation used to calculate unpaved road VMT is:

$$VMTUP = ADTV * FSRM * DPY$$

where:

VMTUP = VMT on unpaved roads (miles/year)
ADTV = average daily traffic volume (vehicles/day/mile)
FSRM = functional system roadway mileage (miles)
DPY = number of days in a year

i. Estimating Local Unpaved VMT

Unpaved roadway mileage estimates were retrieved from the Federal Highway Administration's annual *Highway Statistics* report (FHA, 1990). State-level, county-maintained roadway mileage estimates are organized by surface type, traffic volume, and population category. From this data, State-level unpaved roadway mileage estimates were derived for the volume and population categories listed in Table II-6. This was done by first assigning an average daily traffic volume (ADTV) to each volume category, as shown in Table II-6.

Table II-6
Assumed Values for Average Daily Traffic Volume by Volume Group

	Vehicles Per Day Per Mile			
Volume Category for Rural Roads	**Less than 50**	**50 - 199**	**200 - 499**	**500 and over**
Assumed ADTV Value for Rural Roads	5*	125**	350**	550***
Volume Category for Urban Roads	**Less than 200**	**200 - 499**	**500 - 1999**	**2000 and over**
Assumed ADTV Value for Urban Roads	20*	350**	1250**	2200***

NOTES: *10% of volume group's maximum range endpoint.
**Average of volume group's range endpoints.
***110% of volume group's minimum.

The above equation was then used to calculate State-level unpaved road VMT estimates for the volume and population categories listed in Table II-6. These detailed VMT data were then summed to develop State-level, county-maintained unpaved roadway VMT.

ii. Estimation of Federal and State-Maintained Unpaved Roadway VMT

The calculation of noncounty (State or Federally) maintained unpaved road VMT differed from the calculation of county-maintained unpaved road VMT. This was required since noncounty unpaved road mileage was categorized by arterial classification, not roadway traffic volume.

To calculate noncounty, unpaved road VMT, State-level ADTV values for urban and rural roads were multiplied by State-level, rural and urban roadway mileage estimates. Assuming the ADTV does not vary by roadway maintenance responsibility, the county-maintained ADTV values were assumed to apply to noncounty-maintained roadways as well. To develop noncounty unpaved road ADTV estimates, county-maintained roadway VMT was divided by county-maintained roadway mileage estimates, as shown in the following equation:

$$ADTV - VMT / MILEAGE$$

where:

ADTV	=	average daily traffic volume for State and Federally maintained roadways
VMT	=	VMT on county-maintained roadways (miles/year)
MILEAGE	=	State-level roadway mileage of county-maintained roadways (miles)

Federal and State-maintained roadway VMT was calculated by multiplying the State-level roadway mileage of Federal and State-maintained unpaved roads (FHA, 1990) by the State-level ADTV values calculated as discussed above for locally-maintained roadways. The following equation illustrates:

$$VMT = ADTV * RM * 365\ days\ per\ year$$

where:

VMT	=	VMT at the State level for Federally and State-maintained unpaved roadways (miles/year)
ADTV	=	average daily traffic volume derived from local roadway data
RM	=	State-level Federally and State-maintained roadway mileage (mi)

iii. Calculation of State-level Emissions

The State and Federally maintained unpaved road VMT were added to the county-maintained VMT for each State and road type to determine each State's total unpaved road VMT by road type. The State-level unpaved road VMT by road type were then temporally allocated by month using the same NAPAP temporal allocation factors used to allocate total VMT. These monthly State-level, road type-specific VMT were then multiplied by the corresponding monthly, State-level, road type-specific emission factors developed as discussed above. These State-level emission values were then allocated to the county level using the procedure discussed below.

iv. Allocation of State-Level Emissions to Counties

The State/road type-level unpaved road PM_{10} emission estimates were then allocated to each county in the State using estimates of county rural and urban land area from the U.S. Bureau of the Census (BOC, 1992b). The following formula was used for this allocation:

$$PM10_{X,Y} = (CNTYLAND_{URB,X}/STATLAND_{URB}) * PM10_{ST,URB,Y} + (CNTYLAND_{RUR,X}/STATLAND_{RUR}) * PM10_{ST,RUR,Y}$$

where:

$PM_{10x,y}$	=	unpaved road PM_{10} emissions (tons) for county x and road type y
$CNTYLAND_{URB,X}$	=	urban land area in county x
$STATLAND_{URB}$	=	urban land area in entire State
$PM_{10ST,URB,Y}$	=	unpaved road PM_{10} emissions in entire State for urban road type y
$CNTYLAND_{RUR,X}$	=	rural land area in county x
$STATLAND_{RUR}$	=	rural land area in entire State
$PM_{10ST,RUR,Y}$	=	unpaved road PM_{10} emissions in entire State for rural road type y

7. PM_{10} Emissions from Reentrained Road Dust from Paved Roads

Estimates of PM_{10} emissions from reentrained road dust on paved roads were developed at the county level in a manner similar to that for unpaved roads. PART5 reentrained road dust emission factors for paved roads depend on the road surface silt loading and the average weight of all of the vehicles traveling on the paved roadways. The equation used in PART5 to calculate PM-10 emission factors from reentrained road dust on paved roads is a generic paved road dust calculation formula from AP-42. This equation is shown below (EPA, 1994a):

$$PAVED = PSDPVD_{10} * (PVSILT/2)^{0.65} * (WEIGHT/3)^{1.5}$$

where:

PAVED	=	paved road dust emission factor for all vehicle classes combined (grams per mile)
$PSDPVD_{10}$	=	base emission factor for particles of less than 10 microns in diameter from paved road dust (7.3 g/mi)
PVSILT	=	road surface silt loading (g/m^2)
WEIGHT	=	average weight of all vehicle types combined (tons)

An empirical model was used to develop silt loading values by State and road type based on traffic volume (MRI, 1984). The value of average vehicle weight for the entire vehicle fleet used in the calculation of unpaved road emissions was used here as well.

As with the PART5 emission factor equation for unpaved roads, the above PM-10 emission factor equation for paved roads is representative of a fleet average emission factor rather than a vehicle-specific emission factor and it includes particulate matter from tailpipe exhaust, brake wear, tire wear, and ambient background particulate concentrations. Therefore, the PART5 fleet average PM-10 emission factors for the tailpipe, tire wear, and brake wear components were subtracted from the paved road fugitive dust emission factors before calculating emissions from reentrained road dust on paved roads.

The emission factors obtained from PART5 were modified to account for the number of days with a sufficient amount of precipitation to prevent road dust resuspension. The PART5 emission factors were multiplied by the fraction of days in a month with less than 0.01 inches of precipitation. This was done by subtracting the number of days per month with more than 0.01 inches of precipitation from the number of days in each month and dividing by the total number of days in the month. Precipitation data used in this calculation were obtained from the National Climatic Data Center (NCDC, 1990). These emission factors were developed by month at the State and road type level for the average vehicle fleet.

VMT from paved roads was calculated at the State/road type level by subtracting the State/road type-level unpaved road VMT from total State/road type-level VMT. The paved road VMT were then temporally allocated by month using the NAPAP temporal allocation factors for VMT. These monthly/State/road type-level VMT were then multiplied by the corresponding paved road emission factors developed at the same level.

These paved road emissions were allocated to the county level according to the fraction of total VMT in each county for the specific road type. The following formula illustrates this allocation:

$$PVDEMIS_{X,Y} = PVDEMIS_{ST,Y} * VMT_{X,Y}/VMT_{ST,Y}$$

where:

$PVDEMIS_{X,Y}$	=	paved road PM_{10} emissions (tons) for county x and road type y
$PVDEMIS_{ST,Y}$	=	paved road PM_{10} emissions (tons) for the entire State for road type y
$VMT_{X,Y}$	=	total VMT (million miles) in county x and road type y
$VMT_{ST,Y}$	=	total VMT (million miles) in entire State for road type y

8. Ammonia Emissions

Little research has been done to date on ammonia emission factors from motor vehicles. The most comprehensive vehicle testing including ammonia emission factors available for use in this analysis is summarized in a report by Volkswagen AG (Volkswagen, 1989). In the testing program described in this report, 18 different Volkswagen/Audi vehicles from the 1978 through 1986 model years were tested. The vehicles were selected to represent a cross-section of the Volkswagen/Audi passenger car production program. The vehicles all had either 4 or 5 cylinder gasoline or diesel engines. Seven of the gasoline vehicles were equipped with 3-way catalysts with oxygen sensors, seven of the vehicles were diesel-fueled, and the remaining four vehicles were gasoline vehicles with no catalysts.

Emissions from each of these vehicles were measured using a chassis dynamometer over three different test procedures: the U.S. Federal Test Procedure (FTP), the U.S. Sulfate Emission Test (SET), and the U.S. Highway Driving Test. The FTP includes both cold and hot engine starts with a cumulative mileage of 11.1 miles over 505 seconds. The SET simulates 13.5 miles of travel on a freeway in Los Angeles with heavy traffic over a time of 1,398 seconds. The Highway Driving Test, also known as the Highway Fuel Economy Test (HFET), results in an average speed of 48.1 mph over 10.2 miles with a maximum speed of 59.9 mph. Both the SET and the HFET are hot start tests (no cold starts are included). Each vehicle was tested on all three test cycles on the same day, with three to five repeated measurements carried out for each vehicle on consecutive days.

The mean results of Volkswagen's emission testing program were reported for each of the 18 vehicles tested and for each of the test cycles. The report also shows the total mean value over all three tests by engine type (gasoline with catalyst, gasoline without catalyst, and diesel). These values accounting for all three test cycles were used in our analysis to calculate ammonia emissions since most types of driving would be included in one of the three test cycles (i.e., urban driving would be represented by the FTP; stop and go driving on expressways would be represented by the SET; and freeway driving would be represented by the HFET). These mean emission factors are shown in Table II-7.

Table II-7
Ammonia Emission Factors by Engine Type

Engine Type	Mean Ammonia Emission Factor (grams/mile)
Gasoline Engine without Catalyst	0.00352
Gasoline Engine with 3-Way Catalyst	0.13743
Diesel Engine	0.00188

Using the ammonia emission factors from Table II-7 above, data from MOBILE5a regarding the fraction of vehicles with 3-way catalysts and 1990 travel fractions by vehicle type and model year, ammonia emission factors representing the 1990 composite fleet by vehicle type were calculated. Table II-8 shows the spreadsheet used to calculate the 1990 light-duty gasoline vehicle (LDGV) ammonia emission factor. Similar spreadsheets were used for calculating the light-duty gasoline truck 1 (LDGT1), light-duty gasoline vehicle 2 (LDGT2), and heavy-duty gasoline vehicle (HDGV) emission factors. For this analysis, motorcycles (MC) were assigned the non-catalyst gasoline engine emission factor while all diesel vehicle types were assigned the diesel engine emission factor from the Volkswagen report. Table II-9 summarizes the 1990 ammonia emission factors used by vehicle type.

Emissions were calculated by multiplying the vehicle specific emission factors from Table II-9 by the corresponding vehicle-specific VMT for each county and road type combination and converting the resulting values from grams to tons.

C. AMMONIA EMISSIONS FROM AGRICULTURAL SOURCES

Agricultural sources (i.e., livestock operations and fertilizer application) constitute approximately 90 percent of ammonia emissions in current inventories. This report section describes the methods that were used to estimate ammonia emissions from livestock operations and fertilizer application.

1. Livestock Operations

The activity data used for this analysis were taken from the 1992 Census of Agriculture (BOC, 1992a). The Census of Agriculture has county-level estimates of number of head for the following livestock: cattle and calves, hogs and pigs, poultry, sheep, horses, goats, and minks.

Emission factors were taken from a study of ammonia emissions conducted in the Netherlands (Asman, 1992). These emission factors were recommended for use in a 1994 EPA-AREAL sponsored report on ammonia emission factors (Battye et al., 1994). The livestock operation emission factors are shown in Table II-10.

Table II-8
Calculation of 1990 Composite Ammonia Emission Factor for LDGVs

Model Year	Fraction of LDGVs with 3-Way Catalysts	Fraction of LDGVs w/o 3-Way Catalysts	Ammonia Emission Factor for LDGVs with Catalysts (g/mi)	Ammonia Emission Factor for LDGVs without Catalysts (g/mi)	Weighted LDGV Emission Factor (g/mi)	LDGV Travel Fraction	Composite LDGV Ammonia Emission Factor (g/mi)
1990	1	0	0.13743	0.00352	0.137	0.024	0.003285
1989	1	0	0.13743	0.00352	0.137	0.114	0.015640
1988	1	0	0.13743	0.00352	0.137	0.113	0.015543
1987	1	0	0.13743	0.00352	0.137	0.105	0.014485
1986	1	0	0.13743	0.00352	0.137	0.102	0.014045
1985	1	0	0.13743	0.00352	0.137	0.093	0.012726
1984	1	0	0.13743	0.00352	0.137	0.083	0.011352
1983	0.88	0.12	0.13743	0.00352	0.121	0.057	0.006869
1982	0.86	0.14	0.13743	0.00352	0.119	0.047	0.005519
1981	0.07	0.93	0.13743	0.00352	0.013	0.044	0.000571
1980	0.07	0.93	0.13743	0.00352	0.013	0.042	0.000539
1979	0	1	0.13743	0.00352	0.004	0.044	0.000154
1978	0	1	0.13743	0.00352	0.004	0.036	0.000128
1977	0	1	0.13743	0.00352	0.004	0.027	0.000096
1976	0	1	0.13743	0.00352	0.004	0.017	0.000059
1975	0	1	0.13743	0.00352	0.004	0.013	0.000044
1974	0	1	0.13743	0.00352	0.004	0.009	0.000031
1973	0	1	0.13743	0.00352	0.004	0.009	0.000031
1972	0	1	0.13743	0.00352	0.004	0.006	0.000021
1971	0	1	0.13743	0.00352	0.004	0.004	0.000015
1970	0	1	0.13743	0.00352	0.004	0.003	0.000011
1969	0	1	0.13743	0.00352	0.004	0.002	0.000008
1968	0	1	0.13743	0.00352	0.004	0.002	0.000006
1967	0	1	0.13743	0.00352	0.004	0.001	0.000005
1966	0	1	0.13743	0.00352	0.004	0.004	0.000014
Composite Factor							0.1012

SOURCES: Volkswagen, 1989; EPA, 1994a.

Table II-9
1990 Ammonia Emission Factors by Vehicle Type

Vehicle Type	1990 Ammonia Emission Factors (g/mi)
LDGV	0.10120
LDGT1	0.07020
LDGT2	0.05032
HDGV	0.00865
LDDV	0.00188
LDDT	0.00188
HDDV	0.00188
MC	0.00352

Table II-10
Livestock Operation Ammonia Emission Factors

Category	AMS SCC	Emission Factor (lb NH_3/Head)
Cattle and Calves	2805020000	50.5
Pigs and Hogs	2805025000	20.3
Poultry	2805030000	0.394
Sheep	2805040000	7.43
Horses	2710020030	26.9
Goats	2805045001	14.1
Mink	2205045002	1.28

2. Fertilizer Application

The activity data used to estimate emissions are from the Commercial Fertilizers Data Base compiled by the Tennessee Valley Authority (TVA, 1990) and now maintained by Association of American Plant Food Control Officials. This data base includes county-level usage of over 100 different types of fertilizers, including those that emit ammonia.

The emission factors to be used for fertilizer application come from the same source as the livestock operations emission factors (i.e., the 1992 Netherlands study recommended in the AREAL report). This source provides emission factors for the 10 different types of fertilizers listed below:

- Anhydrous ammonia;
- Aqua ammonia;
- Nitrogen solutions;
- Urea;
- Ammonium nitrate;
- Ammonium sulfate;
- Ammonium thiosulfate;
- Other straight nitrogen;
- Ammonium phosphates; and
- N-P-K.

D. GRAND CANYON INVENTORY DATA

The GCVTC Inventory includes emissions data for 12 States: Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Texas, Utah, Washington, and Wyoming (Radian, 1995). This inventory was developed by compiling and merging existing inventory data bases. The primary data sources used were State-compiled inventories for California and Oregon, AIRS-AFS for point source data for the other 10 States, the 1990 Interim Inventory for area and mobile source data for the other 10 States, the 1985 NAPAP Inventory for ammonia and total suspended particulate (TSP) data, and county-level biogenics data from Washington State University (Radian, 1995). In addition to this existing data, the GCVTC Inventory includes newly developed emission estimates for forest wildfires and prescribed burning.

After an analysis of the different components of the GCVTC Inventory, Pechan incorporated the following portions of the GCVTC Inventory into the PM Inventory:

- Complete point and area source emissions data for California;
- Complete point and area source emissions data for Oregon;
- Forest wildfire data for the 12-State region (except Texas); and
- Prescribed burning data for the 12-State region (except Texas).

Pechan incorporated the State data from California and Oregon because these were complete inventories developed recently by those States. The wildfire data in the GCVTC Inventory represents a detailed survey of forest fires in the study area and is clearly more accurate than the wildfire data in the Phase I Study PM Inventory. The prescribed burning emission estimates in the GCVTC Inventory are the same as those in the PM Inventory at the State level, but contain more detailed county-level data. Further information about the GCVTC emissions data for the prescribed burning and wildfire emission sources is provided below.

1. Prescribed Burning Emission Estimates

Prescribed, or hazard reduction, burning is a frequently used technique for reducing wildfire occurrence. This type of managed burn combusts litter and underbrush to prevent buildup on the forest floor, and reduces wildfire danger. The GCVTC prescribed burning emission estimates were developed by the Forest Service (Lahm, 1994). Acres burned, fuel loading, and fuel consumption were taken from a recent Forest Service study focusing on PM and air toxics emissions (Peterson and Ward, 1993). This data set was developed through surveys and represents 1989 conditions. The emission estimates cover prescribed fires occurring on private, State, and Federal lands. Pollutants covered include direct PM and organics.

Peterson and Ward estimate that their data base captures 80 percent of the prescribed fire activity during 1989.

2. Wildfire Emission Estimates

The GCVTC wildfire emission estimates were developed by the Forest Service, with support from Radian Corporation. Acres burned, fuel loading, and fuel consumption for the emission calculations were obtained from the land managers in the western States. As with prescribed burning, the wildfire emission estimates include fires occurring on private, State, and Federal lands. The GCVTC Inventory contains information on each unique wildfire that occurred from 1986 to 1992. For each fire, the following information was generally available: discovery and containment time and date, location, and an emission estimate.

For this project, Pechan searched the GCVTC wildfire data base and summed the emission estimates for all fires that occurred in 1990. Annual and seasonal (quarterly) emission estimates were stored in the National Particulates Inventory. Seasonal breakdowns were according to the fire start date (by month).

E. DEVELOPMENT OF NEW PM PARTICLE SIZE MULTIPLIERS AND CONTROL EFFICIENCIES

This section describes Pechan's efforts to: 1) update uncontrolled size-specific emission factors using all available size-specific data in EPA's data bases; and 2) update size-specific control efficiencies using the information developed for the first purpose with all available controlled size-specific data in EPA's air pollution reference materials. The general intent of this effort was to use all available control-specific and source-specific data; only in cases where such specific data was unavailable were more general data and methods applied. For both controlled and uncontrolled sources, curves were fit to each individual data series to assure that size-specific data would always be available for $PM_{2.5}$ and PM_{10}, even when data for these diameters were not found in the referenced sources. In addition, this method provided the richest possible data set, given the uncertainty of future PM NAAQS standards.

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The data collection effort utilized information from several sources. Initially, a thorough review was performed of existing size-specific, controlled and uncontrolled emission factor data in AP-42. The data were obtained by SCC from the Fourth Edition, supplements to the Fourth Edition, or the Fifth Edition of AP-42. Controlled emission factors were taken from the above sources and designated according to the Aerometric Information Retrieval System (AIRS) control codes. These AIRS Facility Subsystem control equipment codes are shown in Table II-11. In some cases, the AIRS control codes differ depending on the efficiency of the control. In these cases, control codes were assigned based on the control efficiency stated in AP-42. If AP-42 did not specify the control efficiency, it was calculated from the uncontrolled and controlled TSP emission factors.

AP-42 did not yield size-specific emission factors for all SCC-control equipment combinations in the Inventory. For those uncontrolled sources having only TSP factors in AP-42, SCC-specific particle size distributions were applied to the TSP emission factor to generate size-specific emission factors. (Engineering Science, Inc., under subcontract to Pechan in a previous assignment, developed these uncontrolled particle size distributions for all SCCs. These particle size distributions were estimated based on available field data and engineering judgement.) For those SCCs having only PM_{10} and TSP factors in AP-42, the PM_{10} factors were superseded in those cases where applying the particle size distribution to the TSP factor yielded a different PM_{10} factor. The size distribution data was given preference in this case because it provided three data points on which to fit a curve.

For those SCCs having no uncontrolled emission factor data in AP-42, several other resources were checked. The Factor Information Retrieval System (FIRE) data base had TSP emission factors for some of these SCCs. The FIRE data base incorporates emission factor data from the report, *AIRS Facility Subsystem SCC and Emission Factor Listing for Criteria Air Pollutants* (EPA, 1990a), in addition to that in AP-42. The SCC-specific particle size distributions developed by Engineering Science were applied to the FIRE emission factors to yield size-specific uncontrolled factors.

Some retired SCCs in the inventory were not covered by either AP-42 or FIRE. Each of these SCCs were mapped to one of the nine generalized particle size distributions and these distributions were applied to TSP factors from the old inventory to obtain size-specific data series.

For those controlled sources in the inventory for which size-specific emission factors could not be developed, default control efficiencies developed for specific controls were applied to the uncontrolled, size-specific emission factors. These default control efficiencies were taken from AP-42, Table C.2-3.

Curves were then fit to the size-specific factors available (or derived as described above). The five different curve forms listed below were fit to the data series for each SCC-control equipment combination (including uncontrolled sources), and the form with the highest R^2 value was accepted:

Table II-11
AIRS Facility Subsystem
Control Equipment Codes

Code	Description
000	No Equipment
001	Wet Scrubber - High Efficiency
002	Wet Scrubber - Medium Efficiency
003	Wet Scrubber - Low Efficiency
004	Gravity Collector - High Efficiency
005	Gravity Collector - Medium Efficiency
006	Gravity Collector - Low Efficiency
007	Centrifugal Collector - High Efficiency
008	Centrifugal Collector - Medium Efficiency
009	Centrifugal Collector - Low Efficiency
010	Electrostatic Precipitator - High Efficiency
011	Electrostatic Precipitator - Medium Efficiency
012	Electrostatic Precipitator - Low Efficiency
013	Gas Scrubber (General, Not Classified)
014	Mist Eliminator - High Velocity i.e. V>250 ft/min
015	Mist Eliminator - Low Velocity i.e. V<250 ft/min
016	Fabric Filter - High Temperature i.e. T>250F
017	Fabric Filter - Medium Temperature i.e. 180F<T<250F
018	Fabric Filter - Low Temperature i.e. T<180F
046	Process Change
049	Liquid Filtration System
050	Packed-Gas Absorption Column
051	Tray-Type Gas Absorption Column
052	Spray Tower
053	Venturi Scrubber
054	Process Enclosed
055	Impingement Plate Scrubber
056	Dynamic Separator (Dry)
057	Dynamic Separator (Wet)
058	Mat or Panel Filter - Mist Collector
059	Metal Fabric Filter Screen (Cotton Gins)
061	Dust Suppression by Water Sprays
062	Dust Suppression by Chemical Stabilizers or Wetting Agents
063	Gravel Bed Filter
064	Annular Ring Filter
071	Fluid Bed Dry Scrubber
075	Single Cyclone
076	Multiple Cyclone w/o Fly Ash Reinjection
077	Multiple Cyclone w/Fly Ash Reinjection
085	Wet Cyclonic Separator
086	Water Curtain

NOTE: For the particulate control devices (wet scrubber, gravity collectors, centrifugal collectors, and electrostatic precipitators), the efficiency ranges correspond to the following percentages:

High:	95 and above.
Medium	80 to 95.
Low:	less than 80.

$$
\begin{aligned}
y &= mx + b \\
y &= m\log_{10}x + b \\
\log_{10}y &= mx + b \\
\log_{10}y &= m\log_{10}x + b \\
y &= TSP * (1\text{-}\exp(mx))
\end{aligned}
$$

where:

x	=	particle diameter
y	=	cumulative emission factor for particle diameter
m	=	slope parameter
TSP	=	TSP emission factor
b	=	intercept

In general, R^2 values were 0.90 or higher. For the few combinations where there was both a high R^2 and a negative intercept (i.e., indicating a factor for smaller diameters would be less than zero), the fifth curve form was evaluated again. This form always passes through the origin and rises asymptotically to the TSP limit (two properties that conform with theoretical considerations). If this curve form yielded a poor fit, efforts to develop a representative curve were abandoned, and $PM_{2.5}$ and PM_{10} factors were developed from the SCC-specific uncontrolled size distributions (from Engineering Science) and TSP emission factors from AP-42.

Only about 10 source categories could not be curve fit. For the source categories for which a reasonable curve fit was achieved, the mass percent of TSP in $PM_{2.5}$ and PM_{10} were calculated from the curve equations and collected TSP data. Control efficiencies for $PM_{2.5}$ and PM_{10} were then calculated based on controlled and uncontrolled size-specific factors. (Note: Due to the recent development of test methods to accurately measure condensible PM, certain sections of AP-42 have been updated to incorporate these data. However, the majority of SCCs only list emission factors corresponding to filterable PM. If AP-42 did not specify what type of PM was being measured, it was assumed to be filterable. To be consistent among SCCs, only the emission factors corresponding to filterable particulate were included in the data base.)

F. 1990 EMISSION SUMMARIES

Tables summarizing the complete emissions data base consistent with the Phase II Study are presented in Appendix A.

Figures II-1 through II-12 are emission density plots. These maps were developed by dividing annual county-level emissions for 1990 by the county area in square miles. The first six figures show the total emissions for all source types for direct PM_{10}, direct $PM_{2.5}$, and the significant secondary PM emitters (ammonia, NO_x, SO_2, and SOA). The last six emission density plots show PM_{10} emissions for selected source types that have significant shares of total national emissions. Observations that can be made from these emission density plots are as follows:

1. The OPPIES report noted that there were significant step changes in emission densities at State boundaries for some pollutants. Figures II-1 and II-11 show that where this still occurs for PM_{10}, these boundary differences largely result

from methods used to estimate unpaved road emissions. Silt content samples are used to determine a representative value for each State. This is the key variable that contributes to emission differences at State boundaries. Within State variations in unpaved road emission densities are a function of differences in unpaved road mileage and estimated VMT on these roads.

2. Having no construction activity PM_{10} emissions reported for Oregon (see Figure II-8) suggests an oversight or mis-classification of these emissions in the State inventory.

3. Figure II-9 shows high PM_{10} emission densities from wildfires in Iowa and Nebraska. These emissions may reflect what occurred in a specific year, and not be representative of long-term averages. Year-specific data is preferred for establishing source-receptor relationships, but not for evaluating future control measures and costs.

Figure II-1
1990 PM10 Emissions Density by County

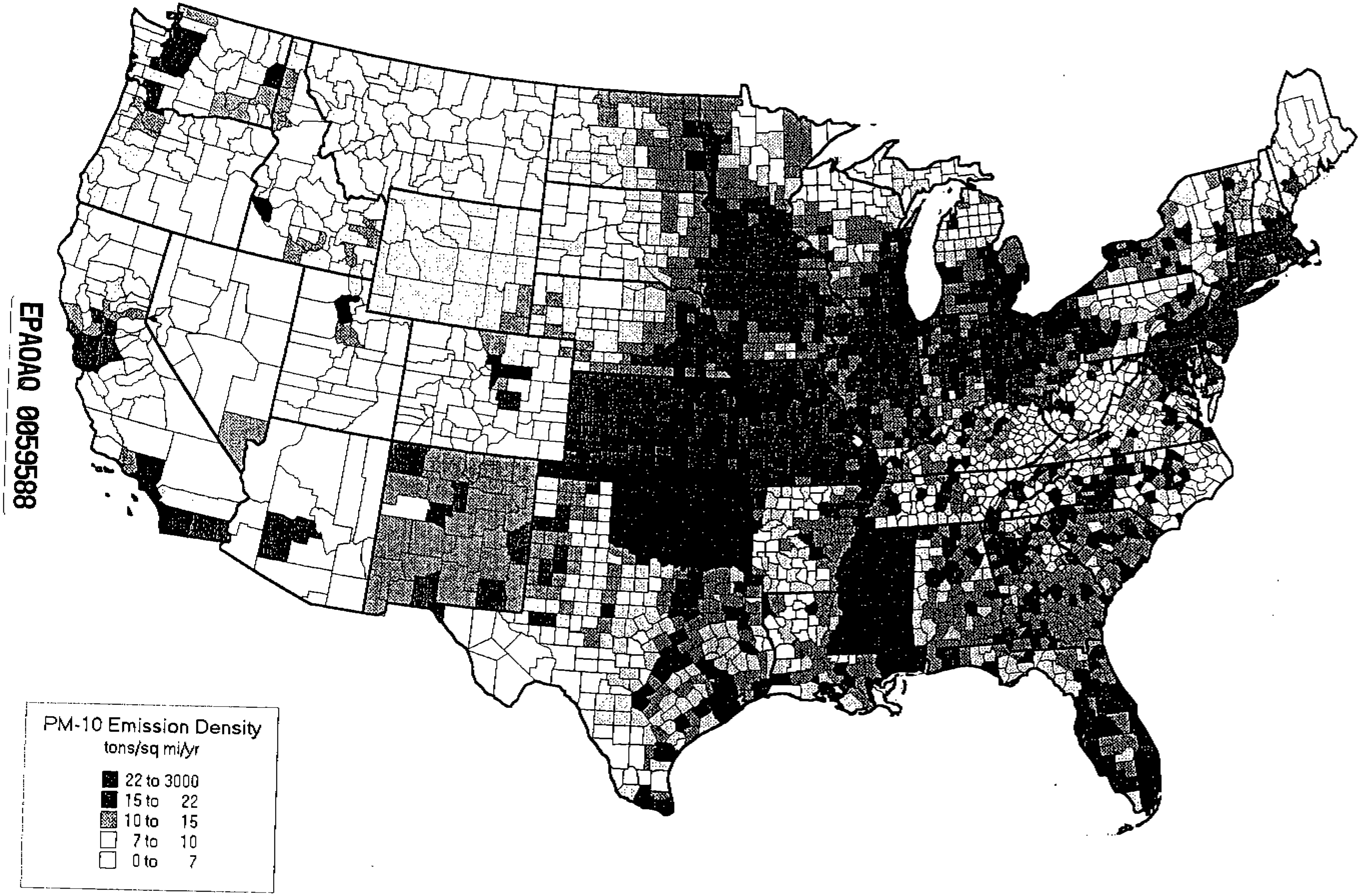

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Figure II-2
1990 PM2.5 Emissions Density by County

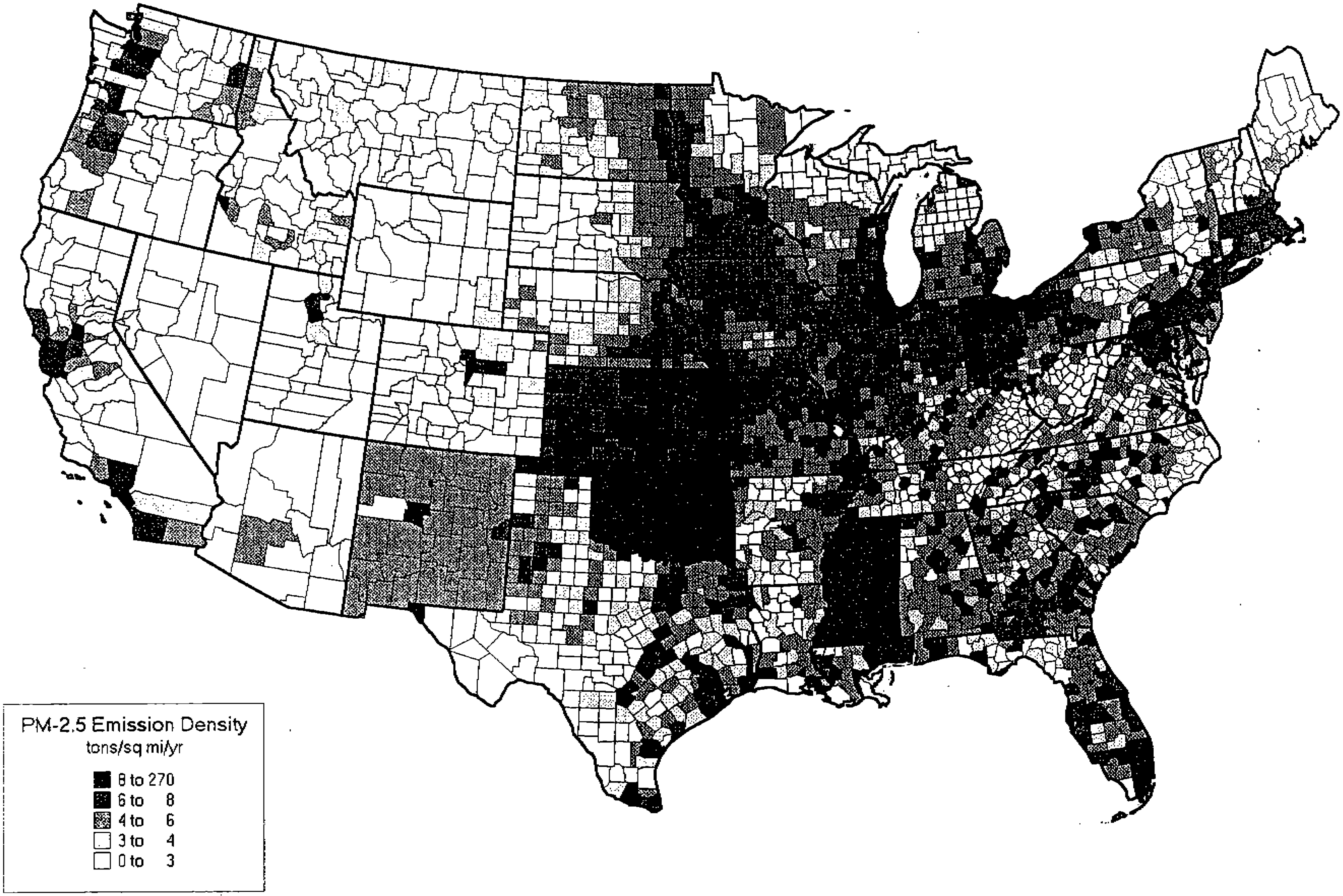


Figure II-3
1990 Ammonia Emissions Density by County

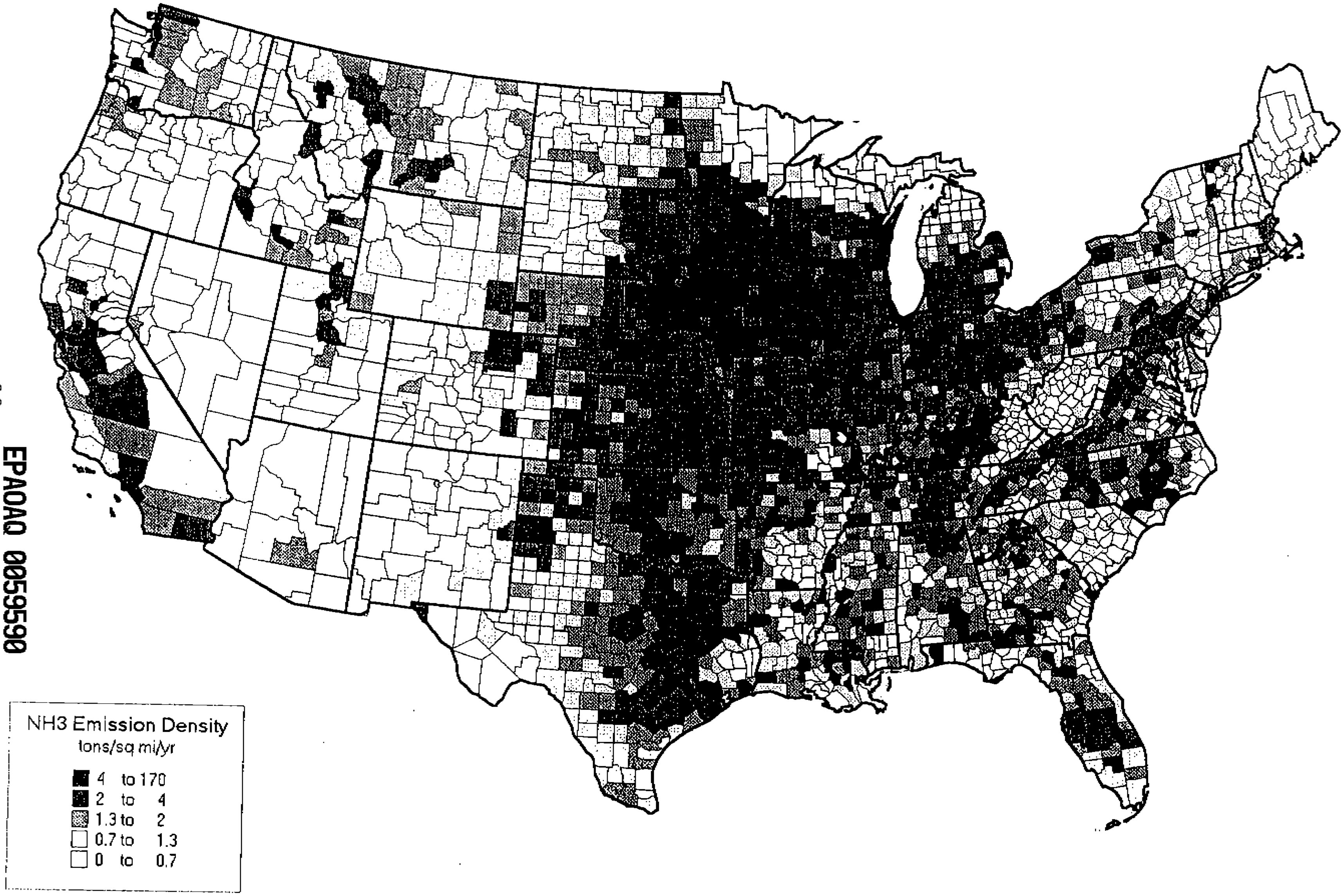


Figure II-4
1990 NOx Emissions Density by County

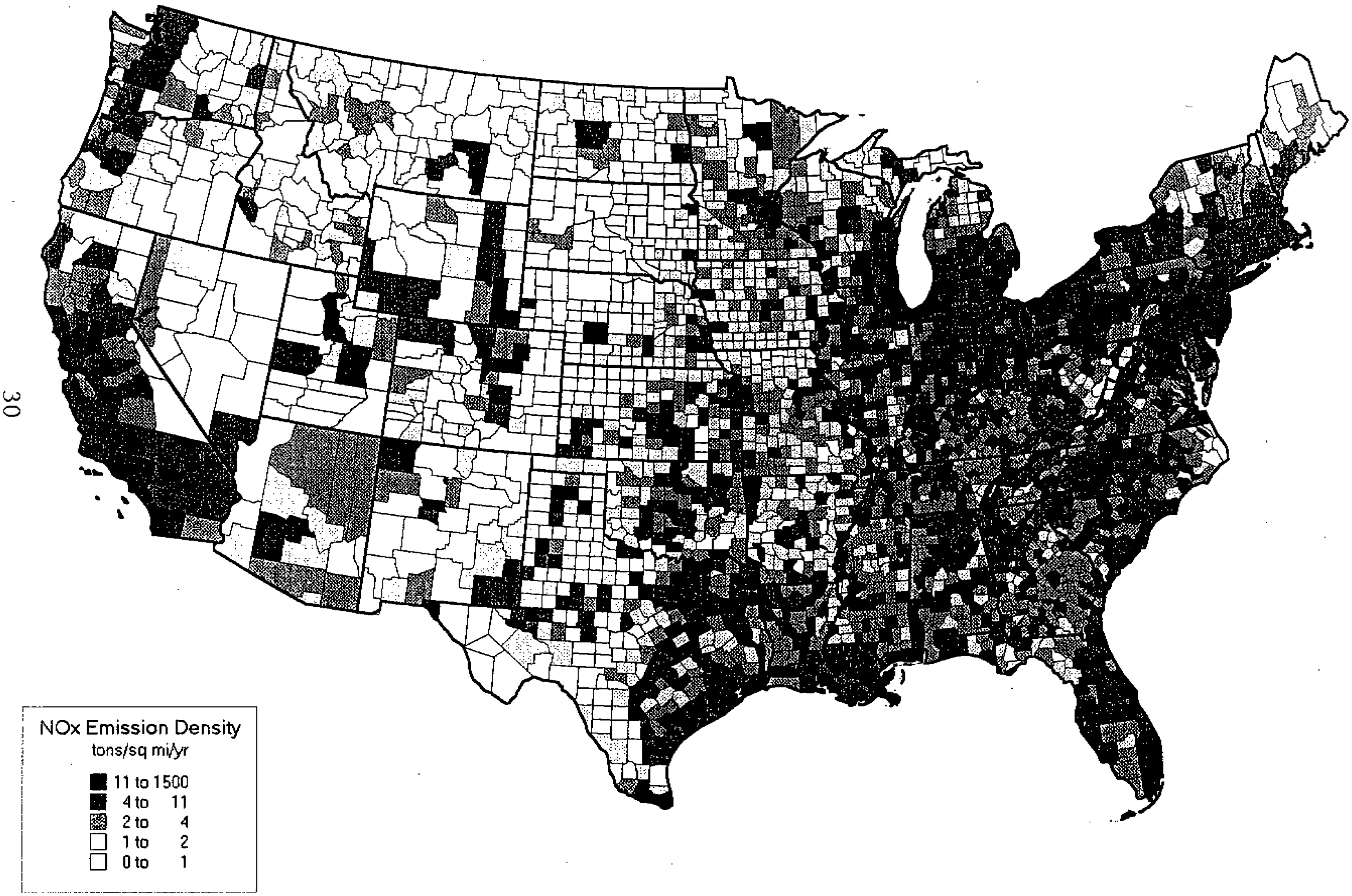


Figure II-5
1990 SO2 Emissions Density by County

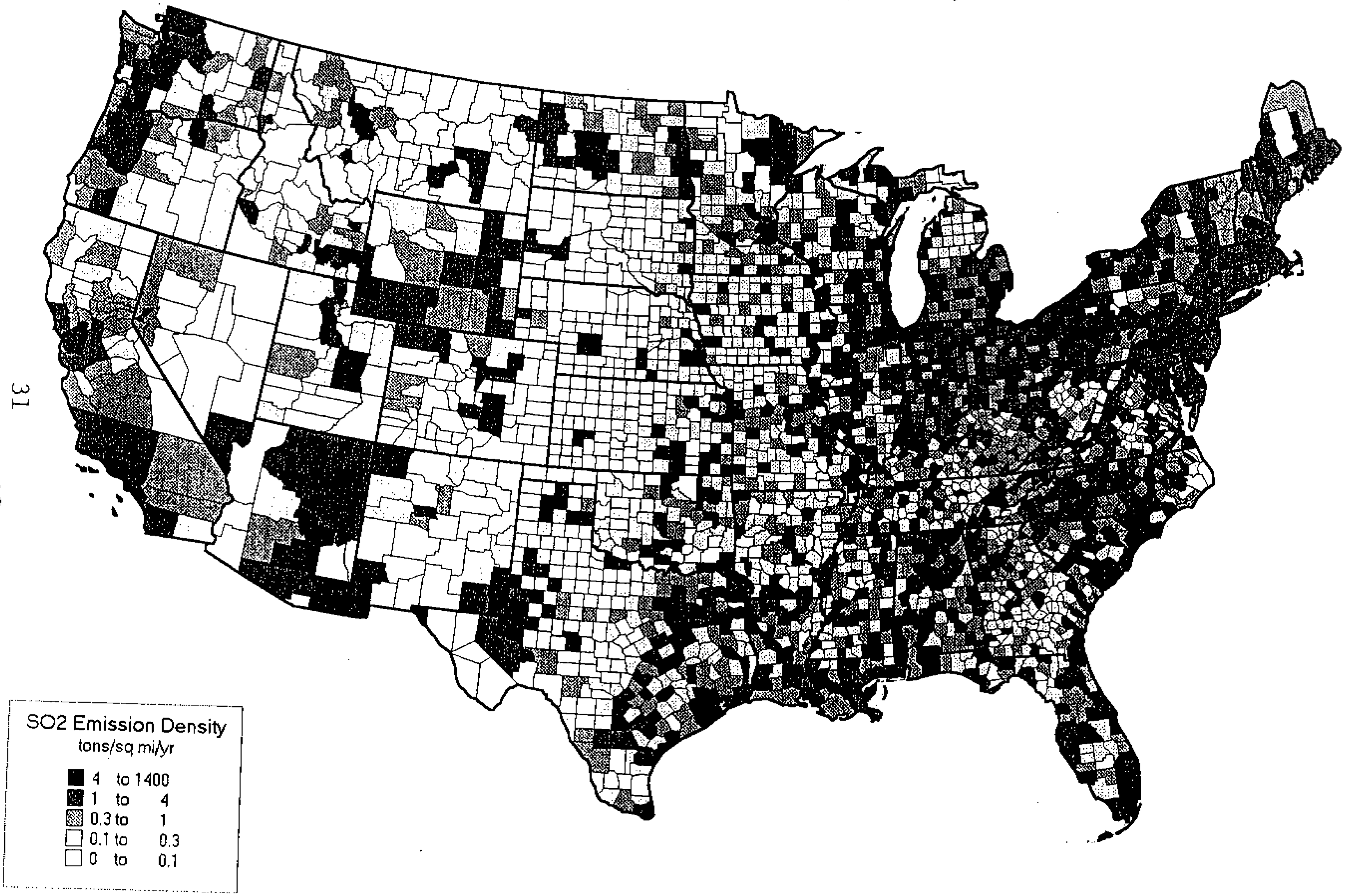


Figure II-6
1990 Secondary Organic Aerosol Emissions Density by County

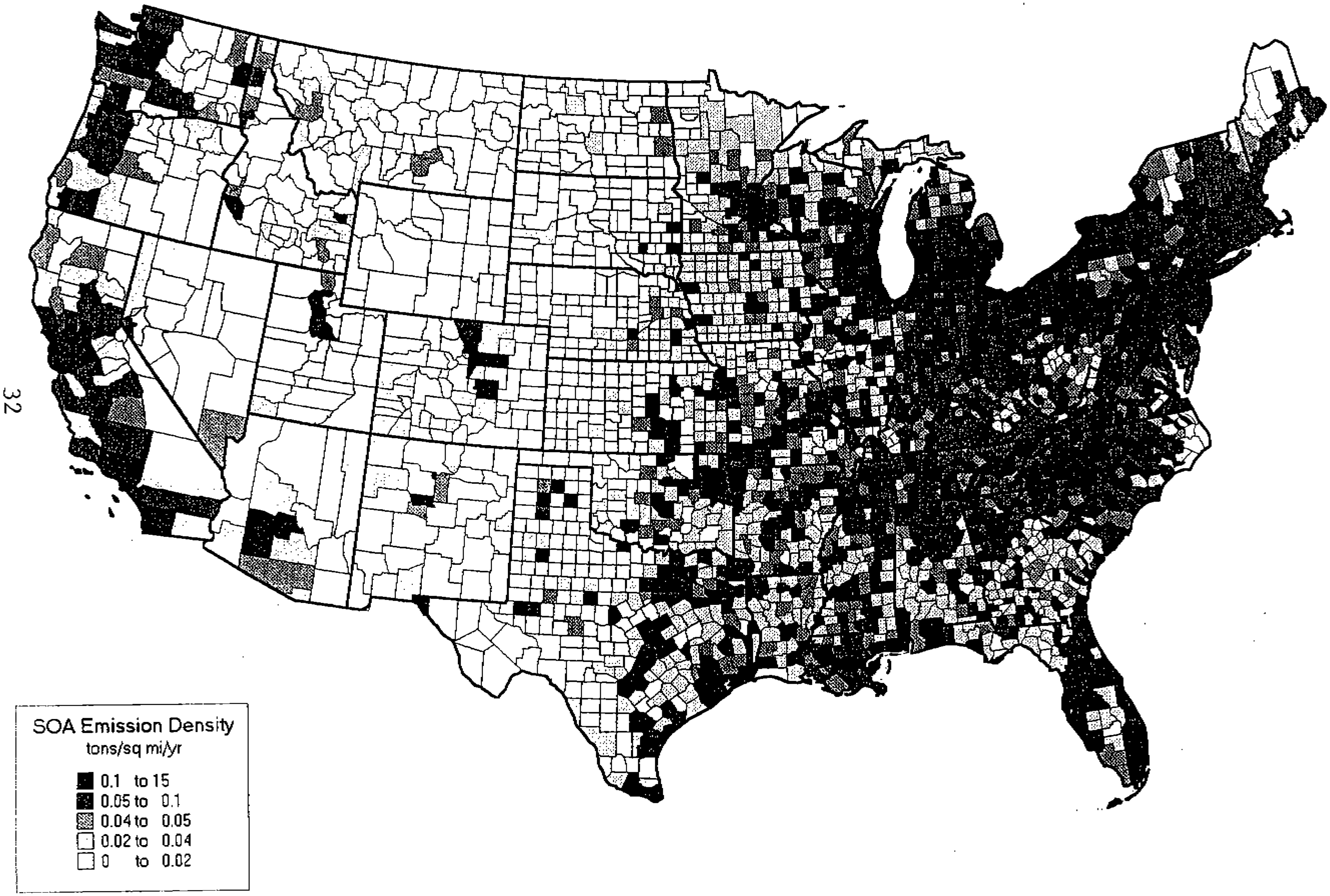


Figure II-7
1990 PM10 Emissions Density for Agricultural Activity

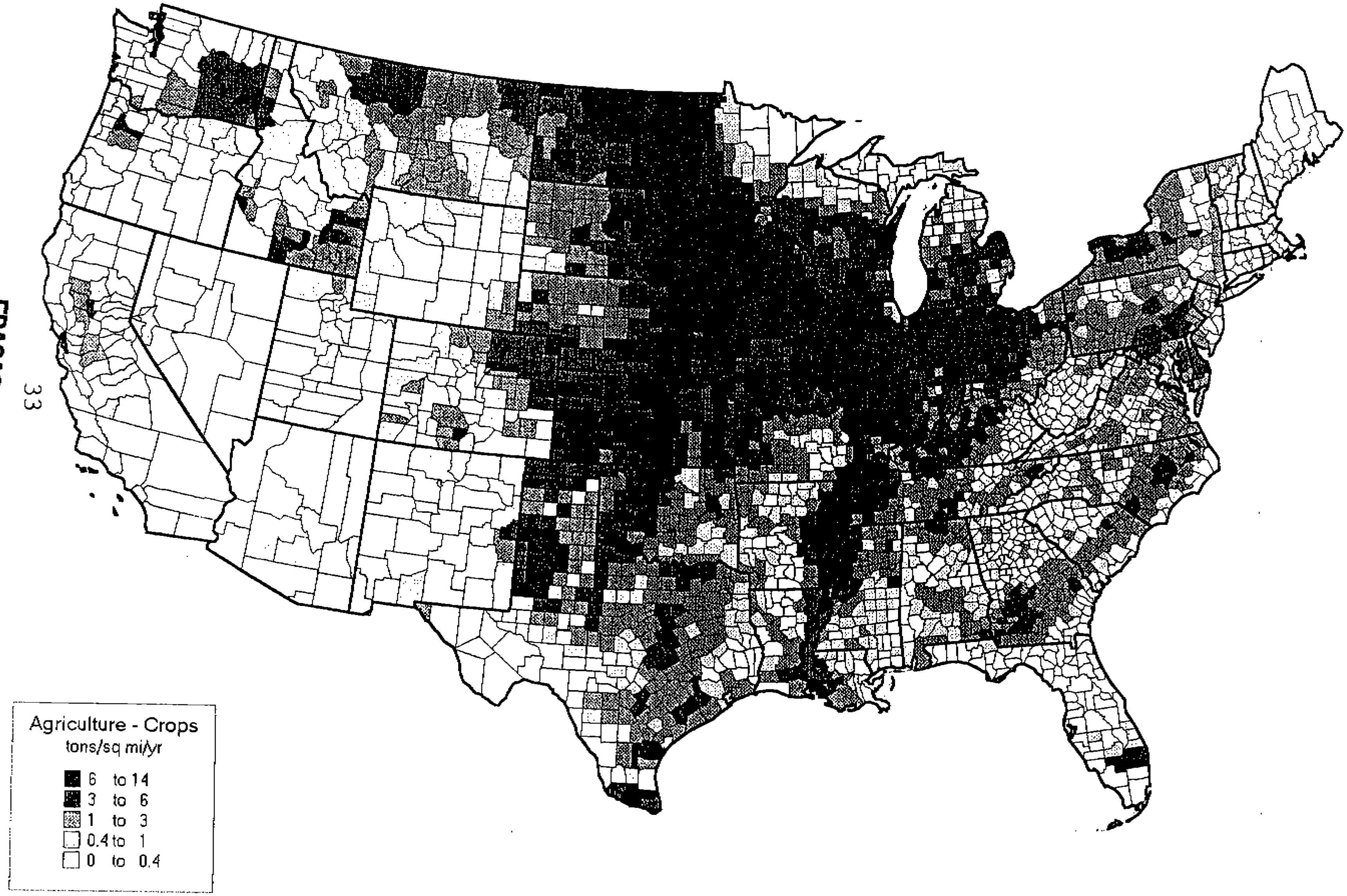


Figure II-8
1990 PM10 Emissions Density for Construction Activity

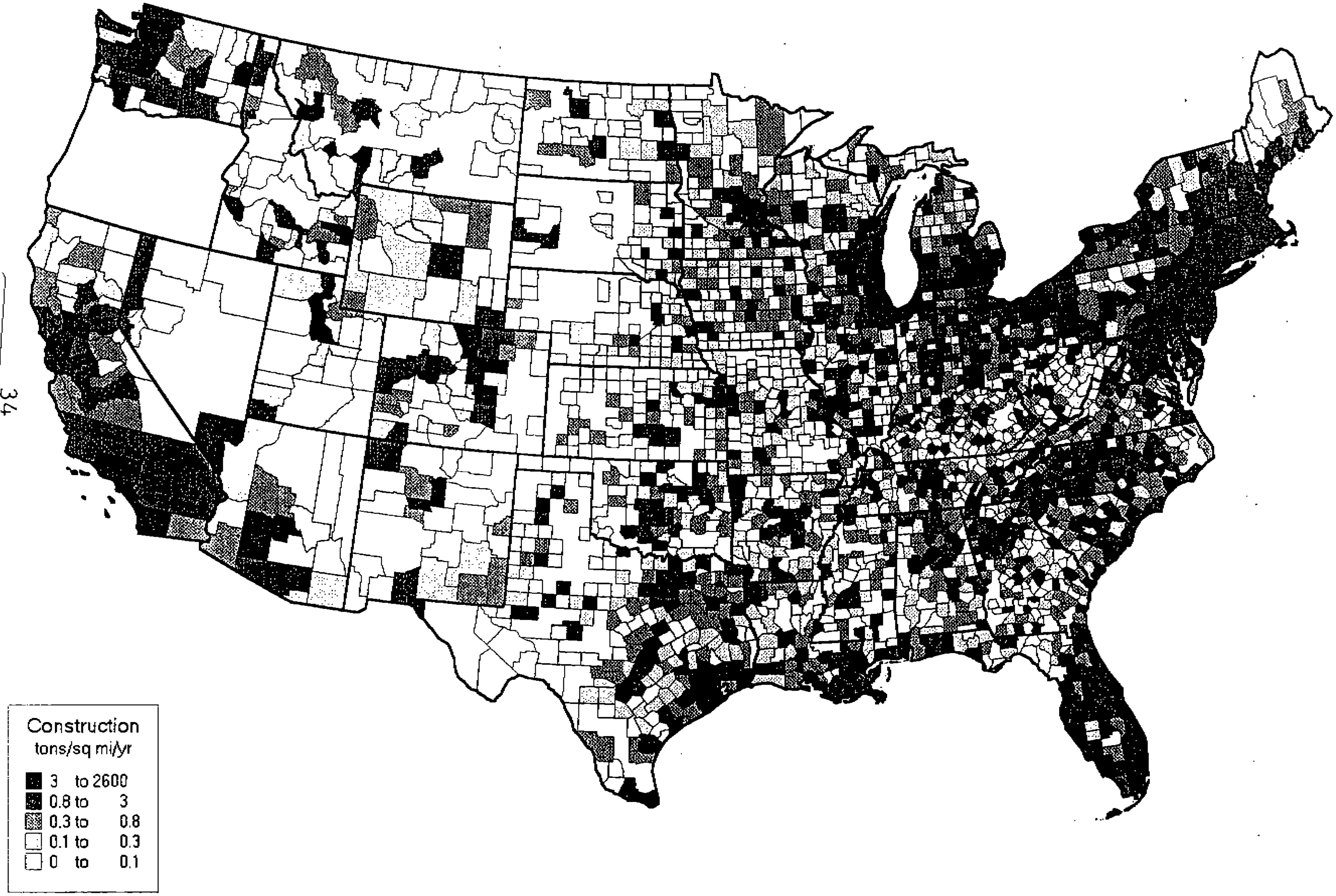


Figure II-9
1990 PM10 Emissions Density for Wildfires

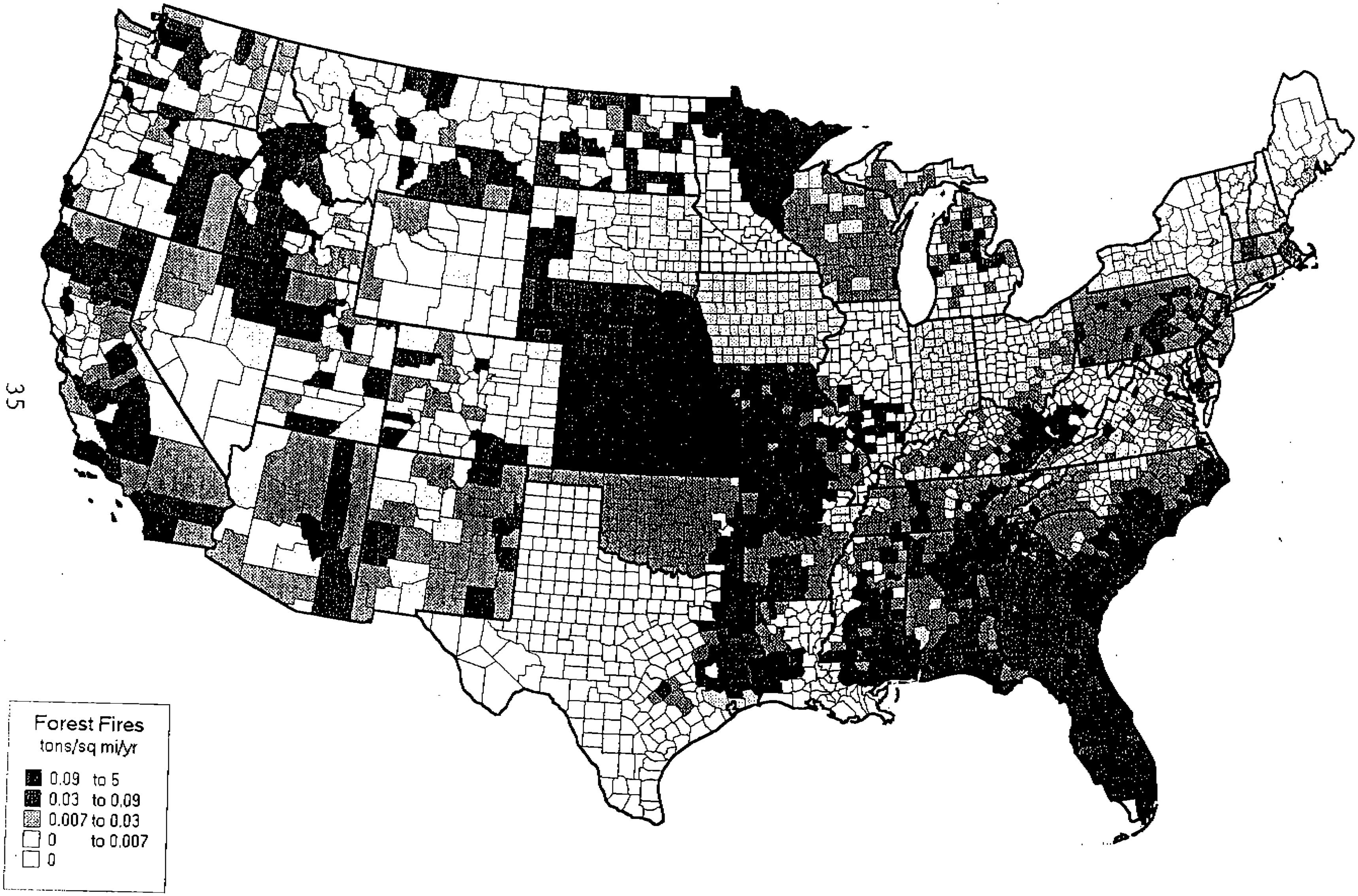


Figure II-10
1990 PM10 Emissions Density for Paved Roads

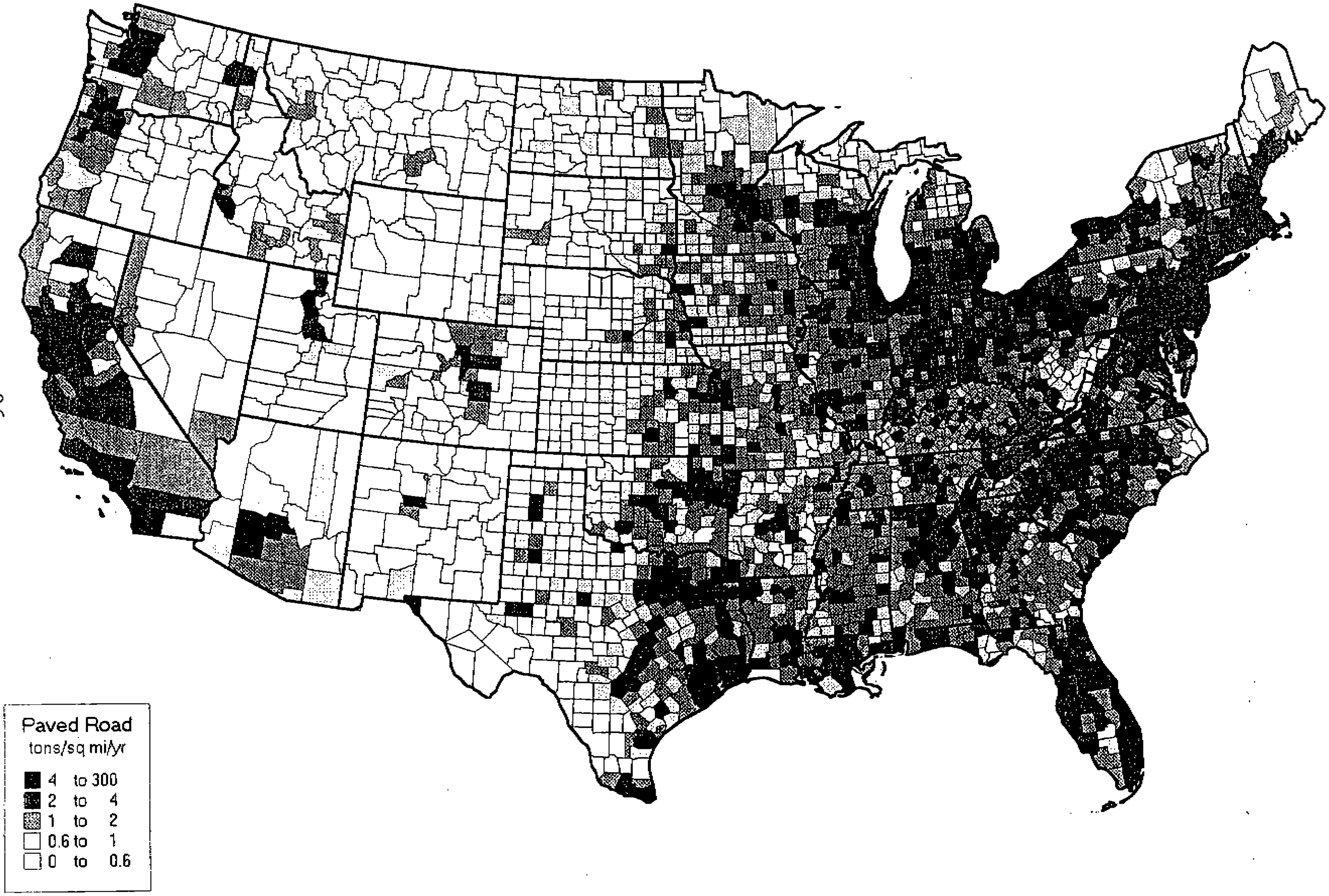


Figure II-11
1990 PM10 Emissions Density for Unpaved Roads

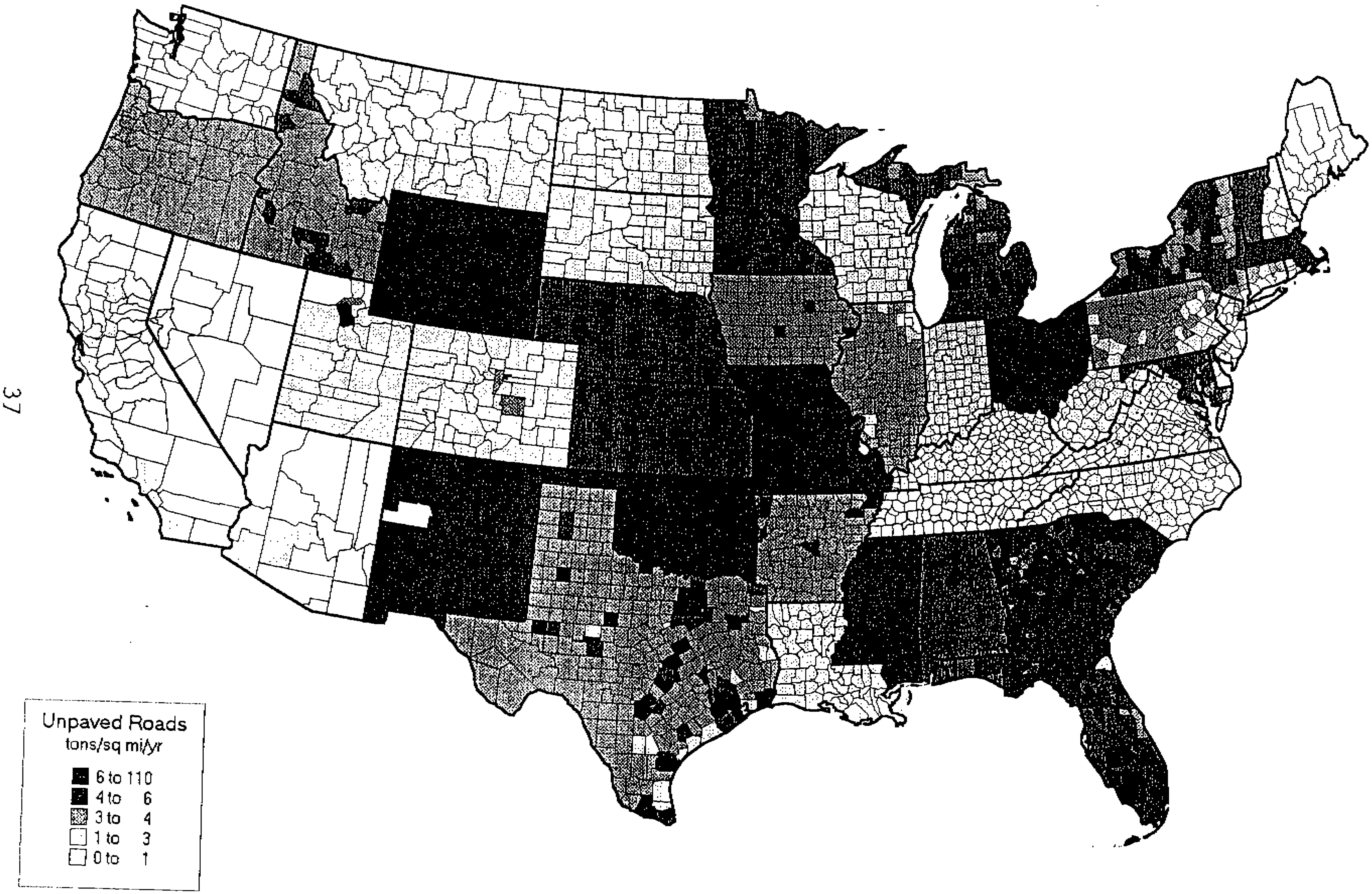
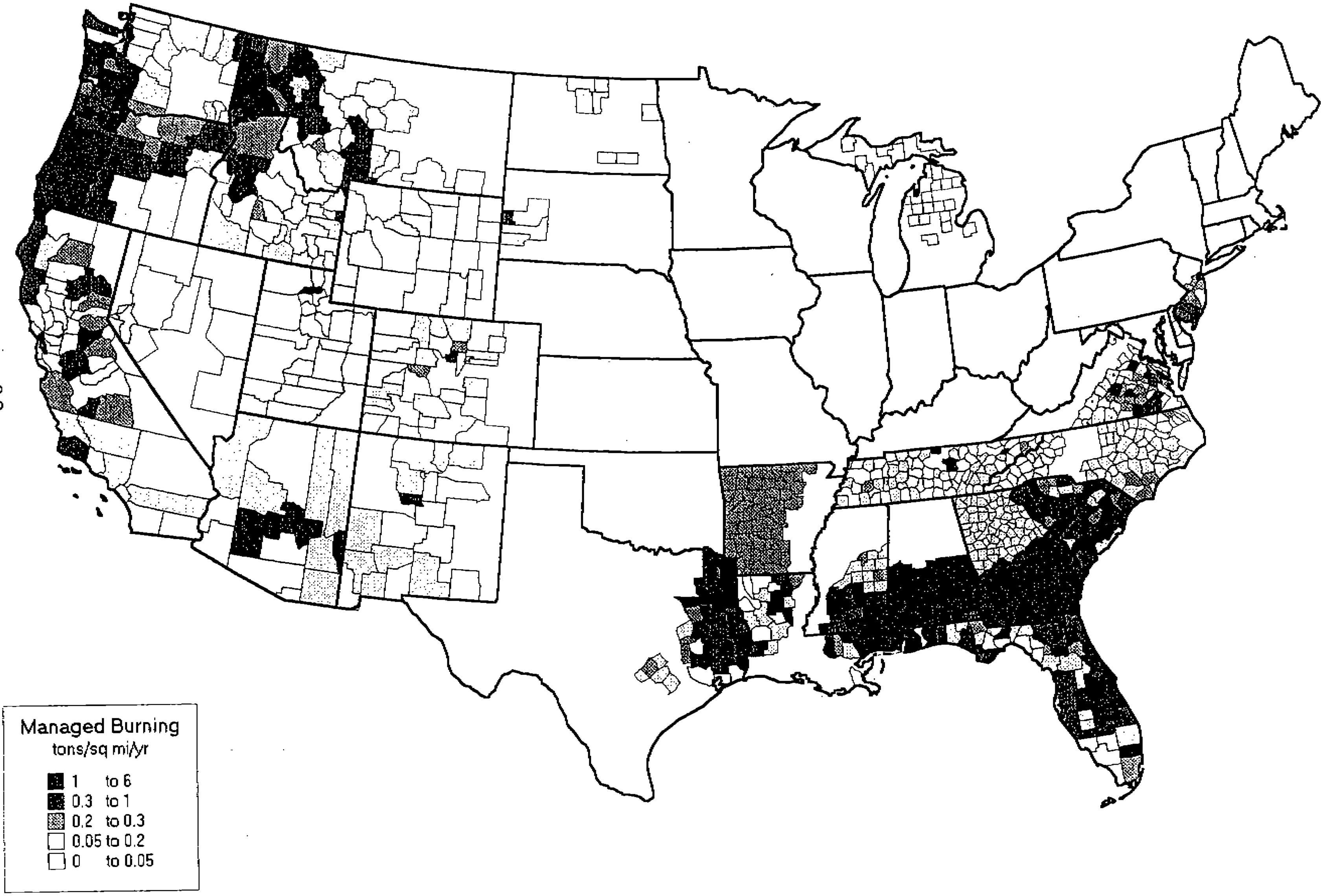


Figure II-12
1990 PM10 Emissions Density for Managed Burning



CHAPTER III
CONTROL MEASURE EVALUATION

A. INTRODUCTION

This section includes the evaluations of control effectiveness and cost for particulate and PM precursor emission control measures that have been performed for the subject work assignment. The overall objective of the control measure evaluation was to develop estimates of control effectiveness and costs for the source categories most likely to be candidates for further control if the PM NAAQS is changed. Because Pechan already prepared some control technique evaluations as part of the Phase I study, and has developed NO_x, VOCs, and SO_2 control cost algorithms for other EPA-sponsored studies, the emphasis in this project is on selected primary PM-emitting source categories. For organizational purposes, the control measure evaluations have been grouped into one of six major sections: area sources, PM point sources, SO_2 point sources, motor vehicles, NO_x control measures, and nonroad engines/vehicles. Where appropriate, the discussion of each source type is clearly divided into background, control measures evaluated, and recommended cost model inputs; cost model inputs are further divided into discussions on measures, control effectiveness, cost equations, and penetration factor.

For many of the source categories, limited information on cost was available, so selection of control techniques for use in modeling was limited. In addition, there are many projects currently underway to examine new and innovative control techniques for many of the sources. Therefore, the control measures selected for modeling do not necessarily represent the optimal or most cost effective technique for that source category and should be viewed more as a representative potential reduction and cost.

Table III-1 presents a comprehensive summary of the control measures used in the incremental control measure evaluations and, ultimately, in the optimization modeling. This table also indicates the models or studies for which this information was developed, including the Emission Reduction and Cost Analysis Model for VOC (ERCAM-VOC), ERCAM for NO_x (ERCAM-NO_x), AIRCOST, or the particulate matter study (the latter are documented in this report).

B. AREA SOURCES

This section discusses area sources that emit PM including: paved roads; unpaved roads; construction activity; agricultural tilling; cattle feedlots; residential wood combustion; prescribed burning; and residential and commercial/industrial natural gas combustion.

Table III-1
Control Measures Included in This Study

Source Category	Control Measure	Pollutants Controlled	Source
Nonroad - Diesel	REFORMULATED DIESEL FUEL	PM, NO_x	PM study
Highway Vehicles - Diesel	REFORMULATED DIESEL	PM, NO_x	PM Study
Paved Roads	VACUUM SWEEPING	PM	PM Study
Unpaved Road - Rural	WATERING	PM	PM Study
Unpaved Road - Urban	HOT ASPHALT PAVING	PM	PM Study
Agricultural Burning	BALE STACK/PROPANE BURNING	PM	PM Study
Agricultural Tilling	WATERING	PM	PM Study
Beef Cattle Feedlots	WATERING	PM	PM Study
Construction Activities	DUST CONTROL PLAN	PM	PM Study
Residential Wood Combustion	CHANGE TO NATURAL GAS	PM	PM Study
ICI Boilers	FABRIC FILTER	PM	PM Study
Utility Boilers	FABRIC FILTER	PM	PM Study
ICI Boilers - SO_2	SCRUBBER	SO_2	PM Study
Utility Boiler - Coal	COAL BLEND	SO_2	AIRCOST
	FGD	SO_2	AIRCOST
Utility Boiler - Oil	OIL BLEND	SO_2	AIRCOST
	FGD	SO_2	AIRCOST
Highway Vehicles - Gasoline	ENHANCED I/M	NO_x, VOC	ERCAM-NO_x
	LOW EMISSION VEHICLES	NO_x, VOC	ERCAM-NO_x
	REFORMULATED GASOLINE	NO_x, VOC	ERCAM-NO_x
Utility Boiler - PC/Wall	LNB	NO_x	ERCAM-NO_x
	SCR	NO_x	ERCAM-NO_x
Utility Boiler - PC/Tangential	LNB + OFA	NO_x	ERCAM-NO_x
	SCR	NO_x	ERCAM-NO_x
Utility Boiler - Stoker	LEA	NO_x	ERCAM-NO_x
	NGR	NO_x	ERCAM-NO_x
	SCR	NO_x	ERCAM-NO_x
Utility Boiler - Oil/Wall	BOOS	NO_x	ERCAM-NO_x
	NGR	NO_x	ERCAM-NO_x
	SCR	NO_x	ERCAM-NO_x
Utility Boiler - Gas/Wall	BOOS	NO_x	ERCAM-NO_x
	SCR	NO_x	ERCAM-NO_x
Utility Boiler - Oil/Tangential	BOOS	NO_x	ERCAM-NO_x
	NGR	NO_x	ERCAM-NO_x
	SCR	NO_x	ERCAM-NO_x
Utility Boiler - Gas/Tangential	BOOS	NO_x	ERCAM-NO_x
	SCR	NO_x	ERCAM-NO_x
Utility Boiler - Cyclone	SCR	NO_x	ERCAM-NO_x
	SCR	NO_x	ERCAM-NO_x
Industrial Boiler - Cyclone	NGR	NO_x	ERCAM-NO_x
	SCR	NO_x	ERCAM-NO_x
Industrial Boiler - PC	LNB	NO_x	ERCAM-NO_x
	SNCR	NO_x	ERCAM-NO_x
	SCR	NO_x	ERCAM-NO_x
Industrial Boiler - Stoker	SNCR	NO_x	ERCAM-NO_x
	SCR	NO_x	ERCAM-NO_x
Industrial Boiler - Residual Oil	LNB	NO_x	ERCAM-NO_x
	LNB + FGR	NO_x	ERCAM-NO_x
	SCR	NO_x	ERCAM-NO_x

Table III-1 (continued)

Source Category	Control Measure	Pollutants Controlled	Source
Industrial Boiler - Distillate Oil	LNB	NO_x	ERCAM-NO_x
	LNB + FGR	NO_x	ERCAM-NO_x
	SCR	NO_x	ERCAM-NO_x
Industrial Boiler - Natural Gas	LNB	NO_x	ERCAM-NO_x
	LNB + FGR	NO_x	ERCAM-NO_x
	SCR	NO_x	ERCAM-NO_x
IC Engines - Natural Gas	AF + IR	NO_x	ERCAM-NO_x
	NSCR	NO_x	ERCAM-NO_x
IC Engines - Oil	IR	NO_x	ERCAM-NO_x
	SCR	NO_x	ERCAM-NO_x
Gas Turbines - Natural Gas	LNB	NO_x	ERCAM-NO_x
	SCR + STEAM INJECTION	NO_x	ERCAM-NO_x
Gas Turbines - Oil	WATER INJECTION	NO_x	ERCAM-NO_x
	SCR + WATER INJECTION	NO_x	ERCAM-NO_x
Process Heaters - Natural Gas	ULNB	NO_x	ERCAM-NO_x
	LNB + SCR	NO_x	ERCAM-NO_x
Process Heaters - Distillate Oil	ULNB	NO_x	ERCAM-NO_x
	LNB + SNCR	NO_x	ERCAM-NO_x
	LNB + SCR	NO_x	ERCAM-NO_x
Process Heaters - Residual Oil	ULNB	NO_x	ERCAM-NO_x
	LNB + SNCR	NO_x	ERCAM-NO_x
	LNB + SCR	NO_x	ERCAM-NO_x
Adipic Acid Manufacturing Plant	THERMAL REDUCTION	NO_x	ERCAM-NO_x
Nitric Acid Manufacturing Plant	EXTENDED ABSORPTION	NO_x	ERCAM-NO_x
	SCR	NO_x	ERCAM-NO_x
	NSCR	NO_x	ERCAM-NO_x
Area Source Industrial Coal Comb	RACT TO SMALL SOURCES	NO_x	ERCAM-NO_x
Area Source Industrial Oil Comb	RACT TO SMALL SOURCES	NO_x	ERCAM-NO_x
Area Source Industrial NG Comb	RACT TO SMALL SOURCES	NO_x	ERCAM-NO_x
Residential NG Consumption	WATER HEATER REPLACEMENT	NO_x	ERCAM-NO_x
	LNB SPACE HEATERS	NO_x	ERCAM-NO_x
Open Burning	EPISODIC BAN	NO_x	ERCAM-NO_x
Nonroad Diesels	CARB STDS FOR > 175 HP	NO_x	ERCAM-NO_x
Commercial Marine Vessels	EMISSION FEES	NO_x	ERCAM-NO_x
Locomotives	POTENTIAL FEDERAL STANDARDS	NO_x	ERCAM-NO_x
Locomotives	POTENTIAL CARB STANDARDS	NO_x	ERCAM-NO_x
Process Heaters - Other	ULNB	NO_x	ERCAM-NO_x
	LNB + SNCR	NO_x	ERCAM-NO_x
	LNB + SCR	NO_x	ERCAM-NO_x
Industrial Boiler - Other	LNB	NO_x	ERCAM-NO_x
	LNB + FGR	NO_x	ERCAM-NO_x
	SCR	NO_x	ERCAM-NO_x
Cogeneration - Coal	LNB	NO_x	ERCAM-NO_x
	SNCR	NO_x	ERCAM-NO_x
	SCR	NO_x	ERCAM-NO_x
Cogeneration - Natural Gas Turbines	LNB	NO_x	ERCAM-NO_x
	SCR + STEAM INJECTION	NO_x	ERCAM-NO_x
Industrial Cogeneration - Nat. Gas	LNB + FGR	NO_x	ERCAM-NO_x
	SCR	NO_x	ERCAM-NO_x
Glass Manufacturing	LNB	NO_x	ERCAM-NO_x
	SCR	NO_x	ERCAM-NO_x
	OXY-FIRING	NO_x	ERCAM-NO_x

Table III-1 (continued)

Source Category	Control Measure	Pollutants Controlled	Source
Cement Manufacturing - Dry	LNB	NO_x	ERCAM-NO_x
	SNCR - UREA BASED	NO_x	ERCAM-NO_x
	SCR	NO_x	ERCAM-NO_x
Cement Manufacturing - Wet	LNB	NO_x	ERCAM-NO_x
	SCR	NO_x	ERCAM-NO_x
Iron & Steel Mills - Reheating	LNB	NO_x	ERCAM-NO_x
	LNB + FGR	NO_x	ERCAM-NO_x
Iron & Steel Mills - Annealing	LNB	NO_x	ERCAM-NO_x
	LNB + SNCR	NO_x	ERCAM-NO_x
	LNB + SCR	NO_x	ERCAM-NO_x
Iron & Steel Mills - Galvanizing	LNB	NO_x	ERCAM-NO_x
	LNB + FGR	NO_x	ERCAM-NO_x
Open Burning	EPISODIC/SEASONAL BAN	NO_x	ERCAM-NO_x
Municipal Waste Combustors	SNCR	NO_x	ERCAM-NO_x
Medical Waste Incinerators	SNCR	NO_x	ERCAM-NO_x
Bulk Terminals	RACT	NO_x	ERCAM-NO_x
Metal Product Surface Coating	VOC content limits & improved	VOC	ERCAM-VOC
Wood Product Surface Coating	Reformulation	VOC	ERCAM-VOC
Wood Furniture Surface Coating	Reformulation	VOC	ERCAM-VOC
Adhesives - Industrial	RACT	VOC	ERCAM-VOC
Paper Surface Coating	Add-on control (incineration)	VOC	ERCAM-VOC
Miscellaneous Surface Coating	Add-on control (incineration)	VOC	ERCAM-VOC
Automobile Refinishing	CARB BARCT limits	VOC	ERCAM-VOC
	FIP Rule (VOC Content & TE)	VOC	ERCAM-VOC
Miscellaneous Surface Coating	MACT level of control	VOC	ERCAM-VOC
Aerosols	CARB Tier 2 Standards - Reform	VOC	ERCAM-VOC
	SCAQMD Standards - Reformulation	VOC	ERCAM-VOC
Aircraft Surface Coating	Add-on control levels	VOC	ERCAM-VOC
Marine Surface Coating	Add-on control levels	VOC	ERCAM-VOC
SOCMI Batch Reactor Processes	New CTG	VOC	ERCAM-VOC
Open Burning	Seasonal/episodic ban	VOC	ERCAM-VOC
Cutback Asphalt	Switch to emulsified asphalts	VOC	ERCAM-VOC
SOCMI Fugitives	RACT	VOC	ERCAM-VOC
Petroleum Refinery Fugitives	RACT	VOC	ERCAM-VOC
Pharmaceutical Manufacture	RACT	VOC	ERCAM-VOC
Synthetic Fiber Manufacture	RACT (adsorber)	VOC	ERCAM-VOC
Oil/NG Production Fields	RACT (equipment/maintenance)	VOC	ERCAM-VOC
Service Stations - Stage I	Vapor balance & P-V valves	VOC	ERCAM-VOC
Web Offset Lithography	New CTG (carbon adsorber)	VOC	ERCAM-VOC
Pesticide Application	Reformulation - FIP rule	VOC	ERCAM-VOC
Recreational Vehicles	CARB standards	VOC	ERCAM-VOC
Nonroad Gasoline	Reformulated gasoline	VOC	ERCAM-VOC

1. Paved Road Resuspension

a. Background

Paved road resuspension refers to emissions of PM generated by mobile sources passing over dust that has settled, or otherwise been placed, on the paved surface. The applicable area source SCC is 2294000000.

b. Control Measures Evaluated

Paved road resuspension emissions can be controlled by using either preventive or mitigative measures. Preventive measures include the reduction or substitution of applied sand or other traction controls, and the reduction of carryout from unpaved areas. Mitigative measures include broom sweeping, vacuum sweeping, and water flushing. Mitigative measures were selected as the best options for cost modeling, since they could be used for a wide range of roadway dust sources (e.g., unpaved area carryout, traction controls, and ambient settling). Therefore, these measures could be applied to any geographic region.

c. Recommended Cost Model Inputs

1. Measures

Vacuum street sweeping was selected as the mitigative measure for control cost modeling. A new generation of vacuum street sweepers that has been specifically designed for cleaning roads as a fugitive dust control is now commercially available. The new sweepers have high vacuum heads and ventilation systems that filter the sweep air prior to it being exhausted to the atmosphere. Older generation broom and vacuum sweepers use a fine water spray to knock down dust during the sweeping process. This water spray also tends to cause the fine dust to become imbedded in the roadway, preventing removal. After the imbedded dust dries out, it is available for resuspension. The newer equipment does not use a water spray, but instead uses a filtration system to remove dust from the sweep air. Filtering systems are available at either a standard 4 micron pore size or a new 2 micron pore size (Winter, 1995).

ii. Control Effectiveness

The control effectiveness of this option was estimated by EPA to be approximately 34 percent (EPA, 1988b). The new generation sweepers exceed this figure, based on the improved ability to pick up fine particles (Ono, 1995; Taylor, 1995; Winter, 1995). Recent testing has shown that the new generation sweepers can achieve a control efficiency of 79 percent for particulate matter (Sutherland, 1995).

iii. Cost Equation

Cost estimates for vacuum street sweeping are presented later in this chapter (see Table III-5) on a dollars per VMT basis. The cost effectiveness is dependent on the characteristics of the roadway to be controlled, including average daily traffic (ADT) and road width. Therefore, cost effectiveness was determined for several roadway functional classes as established by the U.S. Department of Transportation (DOT), FHA (DOT, 1990). Examples include rural interstate highways, urban collectors, and urban principal arterials. Table III-2 provides a listing of the different functional classes considered, as well as assumed configurations for each. Each configuration includes the number of lanes and lane widths of 12 feet, which are typical of the lane data provided for each functional class and reported by DOT (DOT, 1990). The total number of shoulders (i.e., whether or not the roadway is divided) and the paved shoulder widths are assumed. The total width of the roadway is derived by summing the width of all lanes and shoulders.

Data on the cost and performance of a new generation vacuum sweeper were obtained from an equipment vendor (Winter, 1995). This information is summarized in Table III-3. According to the vendor, the vacuum sweeper can clean a section of roadway in a single pass at 5 miles per hour. The frequency of sweepings can vary widely depending on the area and the source of roadway dust. For example, the town of Mammoth Lakes, California may sweep up cinders placed on the road for traction control up to 20 or 30 times per season depending on the number of snow storms (Taylor, 1995).

For the purposes of this assessment, it was assumed that the frequency of vacuum sweeping is two times per month in order to achieve the 79 percent control efficiency. In addition, it was assumed that the equipment would be operated 8 hours per day and 5 days per week. In order to determine the number of roadway miles that are maintained, the hours per day spent sweeping were used. It is estimated that the actual sweeping time will be 6 hours per day. This value accounts for travel and dumping time. The annual hours are equated as 1,500 hours/year by running the sweeper for 6 hours a day, 5 days a week, for 50 weeks a year.

Example - Urban Collector =>
(5 miles/hour) (1,500 hours/year) (9 foot sweep span/30 foot road) (1 year/24 frequency) = 94 miles

Total annualized costs were determined using the data presented in Table III-3. The interest rate was assumed to be 7 percent. Total annualized costs were estimated to be $85,600 per sweeper. To estimate cost inputs for each roadway functional class, the annualized costs were divided by the product of the number of miles of road maintained per year and the weighted ADT for each functional class.

Table III-4 shows how the national weighted ADT were derived for each functional class. For each functional class, a midpoint was selected or assumed for each volume group (e.g., <500 vehicles per day, 500-2500 vehicles per day). Midpoints that had to be assumed were those for the highest volume groups (e.g., > 20,000 vehicles per day). For these groups, a midpoint was assumed based on the size of the other volume groups within the functional class. Cost estimates are provided in Table III-5.

iv. Penetration Factor

For paved road resuspension, the penetration factor for street sweeping is expected to vary by roadway functional classification, ADT, and season. Assumed penetration factors by roadway functional class are listed in Table III-5. It was assumed that specific roadways in both urban and rural settings would be targeted for control such that the highest penetration factor is 90 percent for any given functional classification. Specific

Table III-2
Roadway Characterization

Functional Class	Number of Lanes[1]	Number of Shoulders[2]	Shoulder Width[2] (feet)	Total Width (feet)
Rural Interstate	4	4	6	72
Urban Interstate	6	4	6	96
Other Urban Freeways	6	4	6	96
Other Principal Rural Arterial	2	2	3	30
Other Principal Urban Arterial	4	4	3	54
Minor Rural Arterial	2	2	3	30
Minor Urban Arterial	2	2	3	30
Major Rural Collector	2	0	na	24
Urban Collector	2	2	3	30
Minor Rural Collector	2	0	na	24

NOTES: [1]All lanes are assumed to be 12 feet wide based on data provided by DOT (1990).
[2]Assumed values.

Table III-3
Cost and Performance Data for New Generation Vacuum Sweeper

Cost/Performance Data	Value	Reference
Operating Speed	5 miles/hour	Winter, 1995
Sweep Width	9 feet	Winter, 1995
Sweep Frequency to Achieve 79% Control	2 times/month	Assumed
Capital Cost	$210,000	Winter, 1995
Equipment Life	10 years	Hines, 1995
Interest Rate	7 percent	Assumed
Operating Labor[1]	$45/hour operation	Hines, 1995
Diesel Fuel	$12/hour operation	Hines, 1995
Maintenance Labor and Parts	$4/hour operation	Hines, 1995

NOTE: [1]Includes driver and flagman.

Table III-4
Determination of Weighted ADT by Roadway Functional Class

Functional Class	Rural: Midpoint of ADT Range	Rural: Frequency	Rural: Nationally Weighted ADT*	Urban: Midpoint of ADT Range	Urban: Frequency	Urban: Nationally Weighted ADT*
Interstate	3,000	0.162	486	7,500	0.078	585
	8,000	0.187	1,496	25,000	0.261	6,525
	15,000	0.357	5,355	47,500	0.233	11,068
	30,000	0.294	8,820	80,000	0.223	17,840
				125,000	0.205	25,625
		weighted ADT=	16,157			61,643
Other Freeways/Expressways				7,500	0.203	1,523
				25,000	0.344	8,600
				47,500	0.253	12,018
				80,000	0.098	7,840
				125,000	0.002	250
		weighted ADT=				30,230
Other Principal Arterial	500	0.059	30	500	0.005	3
	1,500	0.153	230	1,500	0.032	48
	2,500	0.157	393	2,500	0.059	148
	6,500	0.48	3,120	7,500	0.201	1,508
	12,500	0.078	975	15,000	0.371	5,565
	20,000	0.063	1,260	30,000	0.332	9,960
		weighted ADT=	6,007			17,231
Minor Arterial	500	0.253	127	500	0.045	23
	1,500	0.246	369	1,500	0.171	257
	2,500	0.19	475	2,500	0.16	400
	6,500	0.275	1,788	7,500	0.302	2,265
	12,500	0.024	300	15,000	0.244	3,660
	20,000	0.012	240	30,000	0.076	2,280
		weighted ADT=	3,298			8,884
Major Collector Urban "Collector"	50	0.097	5	500	0.198	99
	250	0.338	85	1,500	0.366	549
	750	0.204	153	4,000	0.187	748
	2,500	0.322	805	7,500	0.181	1,358
	7,500	0.031	233	15,000	0.06	900
	15,000	0.008	120	30,000	0.008	240
		weighted ADT=	1,400			3,894
Minor Collector	50	0.306	15			
	250	0.436	109			
	750	0.138	104			
	2,500	0.113	283			
	7,500	0.004	30			
	15,000	0.001	15			
		weighted ADT=	555			
Local	25	0.158	3.95	100	0.24	24
	100	0.416	42	350	0.2575	90
	350	0.314	110	1,250	0.3865	483
	750	0.112	84	3,000	0.116	348
		weighted ADT=	239			945

NOTES: *Represents the weighted average daily traffic volume for the functional class and ADT range.
Shading indicates controlled functional classes/volumes.

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Table III-5
Cost Inputs for Vacuum Street Sweeping

Functional Class	Weighted ADT[1]	Annual Miles Maintained	Weighted VMT	Annual Cost ($/VMT)[2]	Penetration Factor	Capital Cost ($/VMT)
Urban Interstate	61643	29	2.71E+08	0.00089	0.42	0.000774
Other Urban Freeways	30230	29	6.03E+08	0.00040	0.67	0.000348
Other Principal Urban Arterial	17231	52	4.19E+08	0.00058	0.90	0.000501
Rural Interstate	16157	54	3.18E+08	0.00192	0.55	0.001673
Minor Urban Arterial	8884	94	6.37E+08	0.00038	0.67	0.000330
Other Principal Rural Arterial	6007	94	5.44E+08	0.00044	0.37	0.000386
Urban Collector	3894	94	3.44E+08	0.00070	0.64	0.000610
Minor Rural Arterial	3298	94	2.57E+08	0.00094	0.71	0.000818
Major Rural Collector	1400	117	1.37E+08	0.00176	0.83	0.001534
Minor Rural Collector	555	117	1.19E+08	0.00204	0.59	0.001772
Urban Local	945	117	7.06E+07	0.00342	0.88	0.002973
Rural Local	239	117	3.59E+06	0.06725	0.35	0.058541

NOTES: [1]ADT is a national average weighted by the frequency of occurrence of roadways within given ranges of ADT (DOT, 1990).
[2]Cost inputs are in 1995 dollars. The cost factor for vacuum sweeping is 0.8373 to convert 1995 dollars to 1990 dollars. This factor reflects the Producer Price Indices from Bureau of Labor Statistics for sweepers. Includes annualized capital.

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roadways will likely be targeted for control due to higher dust loadings on certain roads (e.g., roads routinely receiving traction enhancers, roads adjacent to significant sources of track out materials).

It was also assumed that the penetration factor for street sweeping in urban areas would generally be higher than in rural areas due to higher traffic volumes. The higher ADT in urban areas will make street sweeping a more attractive control measure. The penetration factor for interstates and highways is assumed to be low, since there may be difficulties in scheduling sweeping activities around heavy traffic use. Further, it was assumed that the penetration factor for local road types is relatively low, since the relatively low traffic volumes will not provide significant reductions in PM emissions. Penetration is calculated by dividing controlled ADT by the total weighted ADT, where controlled ADT is illustrated in Table III-4 by gray shading.

Example - Rural Minor Collector => (283 + 30 + 15)/55.5 = 5.9

2. Unpaved Roads

a. Background

Fugitive dust emissions from vehicles traveling on unpaved roads are contained in area source SCC 2296000000.

b. Control Measures Evaluated

Following a review of the data previously collected by Pechan in Phase I of the project, several surface improvement and surface treatment control options were analyzed for the control of fugitive dust emissions from unpaved roads.

Surface improvement options included hot asphalt paving, recycled asphalt paving and cold mix asphalt paving. The costs for installing recycled asphalt paving are approximately equivalent to those for hot asphalt paving (Murphy, 1995; Rosenburger, 1995). Cold mix (emulsified mix) asphalt paving is actually more expensive than hot asphalt paving, when compared in terms of equivalent strength and stability, since twice the paving thickness is required (Rosenburger, 1995).

c. Recommended Cost Model Inputs

i. Measures

Hot asphalt paving was selected as the only surface improvement option for developing cost inputs. For surface treatment options, costs were derived for chemical treatment and water treatment.

ii. Control Effectiveness

For hot asphalt paving, close to 100 percent control effectiveness can initially be achieved following paving of the unpaved surface. However, as ambient dust settles and other sources of dust are deposited on the roadway, the efficiency will decrease. An average efficiency of 96 percent was derived from two estimates. The first source is the efficiency provided by the South Coast Air Quality Management District (SCAQMD) (SCAQMD, 1994). The second estimate was calculated as the difference between paved road resuspension and unpaved road emission factors utilized in the development of the emission inventory. For both surface treatment options, it is assumed that the treatments are applied in sufficient quantity and at a sufficient frequency to achieve the 75 percent efficiency outlined by EPA (EPA, 1988b).

For cost modeling, hot asphalt paving was selected as the control option in urban areas. In rural areas, water treatment was selected as the control option, based on cost, and the expectation that local governments will have difficulty justifying the higher costs of surface improvement options in rural areas.

The recommended value for PM_{10} control effectiveness for watering is 75 percent, which is consistent with the costing assumptions presented above. Water acts to form cohesive moisture films among the discrete grains of roadway dust, preventing or reducing their initial injection into the atmosphere. These moisture films are likely to be evaporated at different rates on particles of varying sizes due to differences in surface area and the fact that smaller particles are at or close to the air-surface interface. Because of this, it is recommended that the control efficiency for $PM_{2.5}$ be conservatively estimated as 50 percent of the PM_{10} control efficiency. Hence, for unpaved roads, the recommended $PM_{2.5}$ control efficiency is 37 percent.

iii. Cost Equation

For all control options, it was assumed that the unpaved surface was a 24 foot wide two lane roadway. Costs were determined for this configuration in an urban and a rural setting. An ADT of 80 is assumed for rural roadways and an ADT of 400 is assumed for urban roadways in estimated cost effectiveness (Pechan, 1995a).

The annualized cost for the hot asphalt paving option is based on data from the Asphalt Institute (Rosenburger, 1995) and an industry contact (Murphy, 1995). Additional data on hot asphalt paving was obtained from the SCAQMD (SCAQMD, 1994), the Clark County Nevada Health District (CCHD, 1994), and the County of Sacramento, California (Roschen, 1995). The latter data sources indicate capital costs between \$165,000 and \$170,000 per mile of 24 foot roadway surface (1994 dollars). These costs are much higher than those obtained from the Asphalt Institute and industry, which ranged from \$85,000 to \$95,000 per mile (Rosenberger, 1995; Murphy, 1995). The assumed specifications for paving the unpaved road were 3.5 to 4 inch thickness, minimal grading, and minimal additional substrate (i.e., gravel).

The discrepancy in the above capital costs may be attributable to differences in the length of roadway to be paved, the amount of grading or substrate material required, geographic area, and most importantly, traffic volume. Traffic volume determines the thickness of the substrate and asphalt paving required. The thickness of the roadway plays a major role in the overall cost (Roschen, 1995). Capital cost estimates from the Asphalt Institute and industry were selected, since it was known that the values of the variables used to determine these costs (e.g., road thickness, required grading, etc.) were consistent with the assumed specifications.

Operation and maintenance (O&M) costs for paved roads can also vary widely. For the first 3 to 4 years, there may be no maintenance required for the new paved road. After 3 to 4 years, the first phase of maintenance typically starts, which often consists of crack sealing. After 6 to 8 years, a seal coat is often required. More extensive maintenance occurs after 10 to 12 years. Resurfacing is often required where thin layers of hot asphalt paving are applied over the existing roadway. The level of maintenance (and associated cost) after 10 to 12 years is highly variable and is related to the quality of maintenance performed during the early phases of the surface's lifetime (Roschen, 1995).

For the purposes of this analysis, it was assumed that the incremental O&M costs during the first 10 years of the paved road lifetime are no higher than the O&M costs for the unpaved surface (i.e., annual grading, addition of substrate, etc.). This assumption is based on information obtained from Sacramento County (Roschen, 1995; Simmons, 1995). It was also assumed that the road required new surfacing after 12 years in an urban setting and after 17 years in a rural setting. The costs for resurfacing, $40,800 per mile, were obtained from the Asphalt Institute (Rosenburger, 1995). Table III-6 provides a listing of the cost data and assumptions used to develop model inputs.

Table III-6
Cost Data for Hot Asphalt Paving

Cost Data	Value	Reference
Capital Costs	$90,000/mile	Murphy, 1995; Rosenburger, 1995
Resurfacing Costs	$40,800/mile	Rosenburger, 1995
Additional O&M Costs (excluding resurfacing)	$0/mile	assumed
Roadway Life	40 years	assumed
Resurface Interval	12 years (urban) 17 years (rural)	Rosenburger, 1995
Average Daily Traffic	400 (urban) 80 (rural)	Pechan, 1995b

Cost data for chemical suppression were taken directly from SCAQMD (SCAQMD, 1994). SCAQMD provided an annualized estimate of $16,107 per mile.

To develop cost estimates for water treatment, data were taken from EPA (EPA, 1988b). Table III-7 lists the cost data and assumptions used to develop cost estimates. Values for variables such as watering frequency and application intensity were selected to provide the 75 percent control efficiency estimated by EPA (EPA, 1988b). Hourly traffic was conservatively estimated by assuming that the ADT estimates used above for the hot asphalt paving analysis all occurred over an 8-hour period. For example, on a rural road, the 80 vehicles passing over the road each day do so over an 8-hour period. This results in an average of 10 vehicles per hour.

In Table III-7, the evaporation rate was developed from data presented by EPA (EPA, 1988b). This value represents the approximate midpoint of the national annual range, and considerable temporal and spatial variability can be expected in certain regions. At

Table III-7
Cost Data and Assumptions for Water Treatment of Unpaved Roads

Cost Data/Assumption	Value	Reference
Capital Cost of Watering Truck	$17,100 *(1985 dollars)*	EPA, 1988b
Annual O&M Costs	$32,900 *(1985 dollars)*	EPA, 1988b
Hourly Traffic	10 vehicles/hour (rural) 50 vehicles/hour (urban)	assumed
Watering Frequency	every 4 hours (rural) every hour (urban)	assumed
Application Intensity	0.5 liters/square meter 0.6 liters/square meter	assumed
Evaporation Rate	0.37 millimeters/hour	assumed
Truck Speed	5 miles/hour	assumed
Daily Application Duration	6 hours/day	assumed

the regional and national level, higher evaporation rates occur during the summer months. Also, in some areas of the country, such as the Southwest, evaporation rates can be much higher than the midpoint of the national range. Daily application duration refers to the number of hours spent each day by the watering truck applying water. It was assumed that 2 hours out of each 8-hour day would be spent on activities such as traveling to the site and filling the truck.

Control costs for unpaved roads in dollars per VMT are listed in Table III-8. The costs for hot asphalt paving and chemical suppression vary largely between rural and urban locations, as compared to the costs for water treatment. This is due to the fact that costs per mile of roadway for these options are the same in rural and urban locations. Therefore, the differences in cost between rural and urban areas are strictly a function of VMT. For water treatment, however, the control cost per mile changes depending on whether the setting is rural or urban. Higher per mile costs are associated with higher traffic volumes. The overall effect is that there is a narrower cost differential between rural and urban areas for water treatment. Capital costs are estimated at $0.594 per VMT for hot asphalt paving of urban roads, and $0.044 per VMT for water treatment of rural roadways.

iv. Penetration Factor

The penetration factor for hot asphalt paving in urban areas is assumed to be 50 percent (half of the unpaved roadway mileage). It is expected that the high capital costs will make it difficult for many local governments to adopt this control for a more significant portion of the urban unpaved roads in their areas.

For watering in rural areas, the penetration factor is assumed to be 25 percent (25 percent of the unpaved roadway mileage). This value is assumed to cover those roadways with a high enough traffic volume to warrant control.

3. Construction Activity

a. Background

There are a wide range of sources of fugitive dust emissions during construction activities, including land clearing and earth movement, blasting, loading of haul vehicles, handling of storage piles, track out to paved surfaces, and wind erosion of disturbed surfaces. Affected emissions are contained in area source category SCCs 2311000100, 2311010000, 2311020000, and 2311030000.

b. Control Measures Evaluated

Due to the wide range of fugitive dust sources during construction activities, there exists a wide range of potentially applicable control strategies. Typically, one or more of the following options are included in a dust control plan (required for construction activities in many nonattainment areas):

- Chemical suppression;
- Water treatment;
- Installation of wind fencing;

Table III-8
Model Inputs for Controlling Unpaved Road Emissions

Control Category	Control Option	Annualized Costs[1] ($/VMT)		Cost Reference Year	Control Efficiency (%)	Capital Cost $/VMT
		rural	urban			
Surface Improvement	Hot Asphalt Paving[2]	0.31	0.08	1995	96	0.594 Urban
Surface Treatment	Chemical Suppression[3]	0.55	0.11	1994	75	
	Water Treatment[4]	0.15	0.10	1985	75	0.044 Rural

NOTES: [1]Costs for water treatment do not include the costs for water, which may add up to $0.03/VMT in areas with water shortages (Delang, 1995).
[2]Cost inputs for hot asphalt paving are in 1995 dollars. The indices to convert this value to 1990 dollars is 0.9702 and reflects Producer Price Indices from Bureau of Labor Statistics for paving materials (BLS, 1995).
[3]Cost inputs for chemical treatment are in 1994 dollars. The indices to convert this value to 1990 dollars is 1.0131 and reflects Producer Price Indices from Bureau of Labor Statistics for chemicals (BLS, 1995).
[4]Cost inputs for water treatment are in 1985 dollars. The indices to convert this value to 1990 dollars is 1.1333 and reflects Producer Price Indices from Bureau of Labor Statistics for street flushing (BLS, 1995).

- Street cleaning;
- Paving and/or curbing; and
- Revegetation.

c. Recommended Cost Model Inputs

Given the wide range of sources and potential controls, it is difficult to establish control costs for construction in general. Construction activities that are typically targeted in dust control plans are land clearing/earth movement and tracking out of material onto paved surfaces (Glasser, 1995; SCAQMD, 1994). Therefore, control costs were estimated on a dollars per acre basis for implementation of a dust control plan that requires water treatment of disturbed soil and street cleaning of nearby paved areas using a vacuum street sweeper. The data and assumptions presented in Table III-9 were used to develop a control cost estimate. The control efficiency of a dust control plan is often assumed to be 50 percent (EPA, 1988b; SCAQMD, 1990).

Table III-9
Cost Data and Assumptions for Implementation of a Dust Control Plan

Item	Value	Reference
Duration of construction project	6 months	assumed
Contracted cost of water treatment	$600/day	SCAQMD, 1994
Water treatment:		
coverage	24 feet	assumed
speed	5 miles/hour	assumed
hours of operation	8 hours/day	assumed
frequency of application	3 times/day	assumed
Contracted cost of street cleaning	$23.10/mile	SCAQMD, 1994
Street cleaning:		
distance to be swept	0.16 mile/acre (equal to the perimeter of one acre)	assumed
frequency	3 times/day	assumed

For water treatment, it was assumed that the contractor can adjust the amount of water applied to adequately cover a range of meteorological conditions without affecting the amount of area treated per day. Using this assumption and the data in Table III-7, an annualized cost estimate of approximately $3,500 per ton PM_{10} reduced (1994 dollars) was obtained. The indices to convert this value to 1990 dollars is 1.151 and reflects Producer Price Indices from the Bureau of Labor Statistics for street flushing (BLS, 1995). Capital costs for this treatment are estimated to be $996 per ton PM_{10} reduced (1994 dollars). These estimates are recommended for use in cost modeling for construction activities along with the 50 percent control efficiency for PM_{10} and 25 percent for $PM_{2.5}$ emissions discussed above.

The penetration factor is assumed to be 75 percent. This is based on the assumption that 100 percent of the construction projects will be required to adopt a dust control plan such as the one described above, but that only 75 percent of the total PM emissions are being controlled. For example, emissions from building demolition, blasting, and certain other sources are not typically included in a dust control plan.

4. Agricultural Tilling

a. Background

Agricultural tilling is used for soil preparation and maintenance, and generally produces the bulk of fugitive dust emissions from agricultural activities. Tilling includes plowing, harrowing, land leveling, discing, and cultivating. The SCC for agricultural tilling is 2801000003.

b. Control Measures Evaluated

The two most common control methods are process modifications of various tillage operations and tilling prohibitions on high wind days (SCAQMD, 1990). Unfortunately, little work has been done to estimate control efficiencies and costs of either of these options.

A contingency measure that was included by SCAQMD in the Coachella Valley State Implementation Plan (SIP) was the watering of agricultural fields prior to tilling (SCAQMD, 1990). As with the control options mentioned above, cost and control efficiency data were not presented. Therefore, for the purposes of cost modeling, similar methods to those presented above for construction sites were used to develop costs for the watering of agricultural fields prior to tilling.

c. Recommended Cost Model Inputs

As with the emission estimates, it was assumed that there would be three tillage operations for each acre of crop land per year. Another significant assumption used to derive the cost estimate was that the cost to contract water treatment services for agricultural activities is the same as that for construction activities. Using the assumptions presented in Table III-10, a recommended cost estimate of $15.50 per acre was obtained. It is also recommended that the same control efficiencies for construction activities be used for water treatment of agricultural tilling operations (i.e., 50 percent for PM_{10} and 25 percent for $PM_{2.5}$). Capital costs were assumed to be zero.

Table III-10
Cost Data and Assumptions for Implementation of a Dust Control Plan

Item	Value	Reference
Number of tilling operations	3 operations/year	assumed
Contracted cost of water treatment	$600/day	SCAQMD, 1994
Water treatment: coverage speed hours of operation	 24 feet 5 miles/hour 8 hours/day	 assumed assumed assumed

The penetration factor is assumed to be 50 percent. A higher value was not selected since some tilling operations may not allow for water control due to soil conditions, equipment limitations, or other reasons.

Additionally, several contacts were made with organizations involved in the San Joaquin Valley Air Quality Study (SJVAQS) regarding controls. SJVAQS is a long-term research program aimed at producing a better understanding of the contribution of agricultural sources to the ambient PM levels within the San Joaquin Valley. These contacts included: staff of the San Joaquin Valley Unified Air Pollution Control District (SJVUAPCD), the Merced County Farm Bureau, the Nisei Farmers League, the Arizona Department of Environmental Quality (ADEQ), and the University of California at Davis (UCD).

Contacts from the agricultural community were very strong in their opinions that control of PM from agricultural tilling operations is not technically feasible (Cunha, 1995; Wade, 1995). They are especially against any control, such as the use of water application, that would alter the tilling process. A contact at SJVUAPCD feels that controls are feasible; however, the controls that have been considered to this point have been the establishment of Resource Conservation Plans in conjunction with the Soil Conservation Service (Langston, 1995). The only conservation measure mentioned in the SJVUAPCD attainment plan was "moisture control" whereby farmers would time their tilling in order to take advantage of conditions when higher moisture in the soil exists. No estimate of emission reductions was made and no clear delineation was made as to how the conservation plans would be enforced.

A contact at ADEQ forwarded information from a recent study on different tilling techniques and total PM emissions, performed by the University of Arizona (Stevens, 1995). This study compared conventional tilling for cotton crops with four alternative tilling techniques (including equipment and method changes) over a 3-year period. Although some of the alternative tilling techniques showed reductions compared with the conventional method, none of the alternatives showed consistent reductions over the 3-year period and during some years showed higher emissions compared with the conventional methods. Hence, existing data do not provide evidence that alternative tilling techniques can provide significant and consistent emission reductions.

UCD is performing research under the SJVAQS on both emissions, and control of emissions from agricultural practices. Work is scheduled to begin on measurement of tilling emissions this fall (Ashbaugh, 1995). Some work may be performed on control techniques; however, it is unlikely that add-on controls, such as watering, will be studied.

Given the current state of knowledge, it is recommended that the watering control measure be used in modeling. If watering were to become a viable control option, it may not be performed with a watering truck as described in this report. An investigation into the control of almond harvesting emissions showed that a fine water spray (mist) appeared to be effective in knocking the visible particulate out of the air (Langston, 1995). A similar technology could be developed for tilling, although some technical hurdles would have to be negotiated. Since cost data do not exist for this potential control, it is recommended that the existing cost inputs be used.

5. Cattle Feedlots

a. Background

The SCC for emissions of fugitive dust from beef cattle feedlots is 2805001000. Emissions were calculated using national population estimates for cattle; however, large beef cattle feedlots are concentrated in four geographic regions of the United States. These four regions are all located in the midwest and western States (Peters, 1977). Therefore, the need for controlling emissions from beef cattle feedlots is expected only in certain geographic regions.

b. Control Measures Evaluated

Control of fugitive dust emissions from agricultural (cattle) feedlots is most often performed by watering from either stationary sprinklers or from water trucks. In some areas, cattle producers already use stationary sprinklers during warm periods for purposes relative to livestock health. No other viable control options were identified.

c. Recommended Cost Model Inputs

Control costs were estimated by assuming that installation of a stationary sprinkler system is required. Peters (1977) provided estimates of capital and O&M costs. The mid-range capital cost was $6.50 per head and the mid-range O&M cost was $0.30 per head. Both of these figures are in 1975 dollars. Assuming a 10-year life for the sprinkler system, the total annualized costs are $1.32 per head (1975 dollars).

No data were found on the control efficiency of water application to cattle feedlots. Therefore, it is recommended that water application control of agricultural feedlots be assigned an equivalent control efficiency as water application control of construction activities (50 percent). As with construction activities, the recommended control efficiencies are 25 percent for $PM_{2.5}$ and 50 percent PM_{10}.

The penetration factor is assumed to be 100 percent.

6. Residential Wood Combustion

a. Background

Residential wood combustion emissions include those from traditional masonry fireplaces, freestanding fireplaces (metal zero clearance), wood stoves, and furnaces. In many areas of the country with PM_{10} nonattainment designations, residential wood combustion devices account for a large fraction of the PM emissions. PM emissions from residential wood combustion sources mainly lie within the $PM_{2.5}$ range (EPA, 1995a). The applicable area source SCC for residential wood combustion is 2104008000. Note that AP-42 conventional wood stove emission factors were used to estimate representative emission rates for all residential wood burning activity.

b. Control Measures Evaluated

PM emissions from residential wood combustion sources are a result of incomplete combustion. One method of reducing PM emissions is to improve combustion efficiency. This can be accomplished by changing the combustion design or using a catalyst that fosters greater combustion efficiencies at lower temperatures. Other methods used to reduce or eliminate PM emissions from residential stoves include changing the fuel - or characteristics of the fuel consumed.

New Source Performance Standards (NSPS) were promulgated in 1988 for wood heaters. These regulations required all new wood heaters to be EPA certified to meet specific PM emission limits in two phases. For Phase I, new wood heaters manufactured on or after July 1988, or sold after July 1990, were required to meet emission limits of 5.5 grams per hour and 8.5 grams per hour for catalytic and noncatalytic wood heaters, respectively. Phase II of the NSPS required all wood heaters manufactured on or after July 1990, or sold on or after July 1992, to meet stricter limits. Phase II emission limits are 4.1 grams per hour and 7.5 grams per hour for catalytic and noncatalytic wood heaters, respectively.

Control techniques used to achieve the standards include changing the heater design through the addition of baffles that carry air into the combustion chamber, and/or the addition of catalysts that effectively allow for more complete combustion at temperatures typical of residential combustion devises. It should be noted that recent evidence indicates that the catalyst efficiency might decline rapidly after 1 or 2 years of use (McCrillis, 1995). In addition to reductions associated with the NSPS, the following control techniques can be used to further reduce emissions from residential wood combustion:

(i) Public awareness and education (PAE) program;
(ii) Mandatory curtailment during predicted periods of high PM concentrations;
(iii) All new stove installations EPA-certified Phase II stoves or equivalent;
(iv) Alternative fuel use: natural gas;
(v) Alternative fuel use: pellet stoves; and
(vi) Control of wood moisture content.

Information regarding the emission reduction potential and costs associated with these controls is presented in Table III-11. Because these programs are relatively young, ample data does not exist to precisely quantify the cost of controls in terms of dollars per ton of PM reduced (cost-effectiveness) for most Best Available Control Measures (BACM). Emission reduction and cost estimates for these measures were obtained from EPA guidance documents and augmented with quantitative information from control agencies with experience using these measures. The estimates compiled herein represent the best available information.

The annual costs were calculated using the annualized capital costs of the stoves and installation of the stoves. Capital costs were based on estimates from retail vendors (Vendor Sources, 1995). The capital recovery factor was calculated using default interest rate and equipment life of 7 percent and 15 years, respectively. The actual lifetime depends on the make and model of the stove as well as the frequency with which it is used and the operating and maintenance practices (Crouch, 1995). O&M costs were not

Table III-11
Residential Wood Combustion Control Performance and Cost Estimates

Control Technique	Total Emission Reduction (%)	Costs	Cost Effectiveness ($/ton)	Comments/References
Public Awareness Program (PAE)	5	NA	4,600	(1,3)
Mandatory Curtailment	80	$7,500 per year	300	$4,500 for enforcement, $3,000 for forecasting and advisory/ 1994 dollars. Cost effectiveness includes costs for PAE (3,4)
Immediate Change to EPA Phase II-Certified Stoves	45	$1,600 per stove	17,700	(1,2,3)
Change to Natural Gas Stoves	100	$800-$1,200 per stove	6,300	(1,2)
Change to Pellet Stoves	73	$1,600 per stove	11,000	(1,2)
Improve Wood Burning Performance	5	NA	NA	(1)

SOURCES: (1) EPA, 1989.
(2) Vendor Sources, 1995.
(3) Collure, 1995.
(4) Durak, 1995.

determined due to lack of data. Unless otherwise noted, rule penetration and rule effectiveness are assumed to be 80 percent.

i. Public Awareness and Education (PAE)

PAE programs provide instruction in proper wood burning operation and maintenance of a wood stove as well as the dangers of wood stove emissions. EPA estimates the potential emission reductions of a PAE program to be approximately 5 percent. Costs of PAE programs are variable since they are dependent on program parameters and area characteristics. The PAE program budget in Clemet Falls, Oregon is $30,000 a year (Collure, 1995). Using per capita apportionment, the cost effectiveness of this measure on a national basis is estimated to be approximately $4,600 per ton of PM reduced.

ii. Mandatory Curtailment Program

Mandatory curtailment programs are episodic controls designed to reduce emissions when ambient PM concentrations approach the NAAQS. Several PM nonattainment areas implement mandatory curtailment programs. A large component of the mandatory curtailment program is public education and awareness, another large component is the forecasting system.

Oregon implements a mandatory curtailment program in which there are green, yellow, and red advisory days based on a series of meteorological parameters associated with elevated ambient PM concentrations. Green days indicate no residential wood combustion restrictions, but switching to alternate heating methods is encouraged; yellow days indicate that only EPA-certified wood burning devices may operate; and red days indicate that all residential wood combustion activities are prohibited (Durak, 1995). Exemptions are granted under certain circumstances, such as, if the wood stove is the sole heating source. The program is enforced through infrared photography and visual monitoring. The Oregon Department of Environmental Quality (DEQ) recommends a massive public awareness campaign in conjunction with the curtailment program, including consistent use of local media and schools (Collure, 1995; Durak, 1995). The curtailment alerts are disseminated through newspaper advertisements and public service announcements.

Penalties for burning during mandatory curtailment days include issuing letters to residences found in noncompliance. Letters are issued for the first and second violations. For the third violation, home visits are conducted to educate and assist households found in noncompliance. After three violations, a resident may be subjected to fines if they are found in noncompliance.

EPA guidance documentation (EPA, 1989) suggests an emission reduction potential of 50 percent, given the difficulty with enforcement issues. However, higher reductions have been claimed; for example, the Oregon DEQ claims a reduction of 86 percent. This is based on 100 percent control efficiency and an 86 percent rule penetration (Durak, 1995). Eighty percent can be used as a more conservative estimate. Annual costs of the curtailment program are approximately $7,500 per year. These costs are based on enforcement per advisory day, which was estimated to be $450 according to the Jackson County Health and Human Services Department (based on data from 1985 to 1994 in Jackson, Oregon). There are an average of 10 advisory days per year resulting in an annual average enforcement cost of $4,500. Costs for the forecasting system are approximately $3,000 per year. These costs include taking nephelometer readings daily, and using National Weather Service information to determine the day's advisory status and disseminating the advisory. No cost estimates were available for the public education program or for the expenses incurred by the public. Using the available information, a cost of $7,500 per year will be assumed (estimate is in 1994 dollars). The cost of this measure is based on a 100 percent reduction with an 80 percent rule penetration and a 100 percent rule effectiveness. The cost effectiveness is $300 per ton of PM reduced. This estimate includes the cost per ton for the PAE program developed using data from Clemet Falls.

iii. Phase II Certified Stove Installations

This strategy entails the replacement of non-EPA certified wood stoves and fireplaces with EPA-certified Phase II stoves or stoves meeting more stringent standards. Phase II devices are designed to achieve more efficient combustion and lower particulate emissions than conventional devices.

EPA has estimated an emissions reduction potential of 50 percent for Phase II-certified stove replacements (based on the difference in emissions between an NSPS-certified device and a conventional device [EPA, 1989]). The incremental reduction between Phase I and Phase II PM standards is 25 percent. Phase II of the NSPS requires that all new stoves sold after July of 1992 must be EPA certified to Phase II standards. The overall reduction achievable with this measure depends upon the number of existing devices replaced and the rate of performance degradation of catalytic stoves. Assuming a 15-year wood stove life cycle, complete phase-in of the Phase II, EPA-certified wood stoves would occur in the year 2007. Thus, requiring all existing non-EPA certified wood stoves to be replaced promptly with certified wood stoves would result in speedier reductions, but would not affect emissions growth from new devices. The overall reductions achievable through this requirement is a function of the number of existing devices replaced. Capital costs to replace an uncertified device with an EPA Phase II-certified device average approximately $1,600 (Vendor Sources, 1995). The Oregon DEQ spent 1.2 million dollars to replace 743 stoves, which is an average cost of $1,615 per stove (Collure, 1995).

The NSPS requiring all stoves sold to be Phase I began in 1990, mandatory purchase of new, Phase II stoves began in 1992. Rule penetration is developed by estimating the current wood stove population mix. Assuming a yearly turnover rate of 6.6 percent (based on a 15-year equipment life cycle), the current 1995 population mix of wood stoves is assumed to be 13 percent Phase I stoves, 27 percent Phase II stoves, and 60 percent "conventional" stoves. Replacing the old and Phase I stoves with Phase II stoves will result in an emissions reduction of approximately 45 percent.

Assuming a 45 percent reduction, the cost is estimated at approximately $17,700 per ton of PM reduced. Table III-12 presents the assumptions used in the cost effectiveness calculation.

iv. Alternative Fuel Use - Change to Gas Logs

This control measure is based on replacing wood stoves and wood burning fireplaces with gas burning alternatives. Natural gas is the primary fuel alternative to the

Table III-12
PM Cost Effectiveness Calculations

	Per Stove Emissions Reduction	Total Reduction %	Emission Factor	Emissions Reduced	Capital Costs $	Tons wood burned per stove per year	I %	CRF	Total Annual Costs $	Costs Based On	Cost Index to 1990 $	1990 Annual Costs $	Life yr	CE $/ton Reduced
RESIDENTIAL WOOD COMBUSTION			(tons/ton wood burned)	(tons/yr)	per stove									
Change to gas logs	100	100	0.0153	0.021	1,200	1.4	7	0.10979	131.75	1994	1	131.8	15	6,280
Change to pellet stove	73	73	0.0153	0.016	1,600	1.4	7	0.10979	175.67	1994	1	175.7	15	10,980
Change to Phase II stove	45	45	0.0153	0.010	1,615	1.4	7	0.10979	177.32	1994	1	177.3	15	17,730

* Emission reductions associated with changing to pellet stoves depend on the stove type. Reductions by stove type are assumed to be 90% from "conventional," 65% from Phase I, and 40% from Phase II.
** Emission reductions associated with changing to Phase II certified stoves depend on the stove type. Reductions by stove type are assumed to be 50% from "conventional," and 25% from Phase I.
Tons of wood burned per year per stove estimate is based on EPA, 1993b, assuming one wood stove device per household.

Calculation of total annualized cost: Ca = CRF (Cp) + Co

Ca = Annualized cost of controls, $/yr

Calculation of capital recovery factor: CRF = Capital recovery factor, 1/year

Cp = Installed capital costs, $

Co = Direct operating costs, $/yr

Calculation of cost-effectiveness: $\frac{i * (1 + i)^n}{((1 + i)^n) - 1}$

n = number of periods

i = interest rate per period

CE = Cost-effectiveness, $/ton

Ca = Annualized cost of control equipment, $/yr

R = Annual reduction in particulate emissions, tons/yr

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combustion of wood as a residential heating fuel. Wood burning fireplaces can be converted into "gas log" fireplaces that reduce PM emissions completely (EPA, 1989).

Capital costs for converting wood burning fireplaces to gas log fireplaces depend upon several factors, such as the type of existing fireplace (masonry or freestanding), the distance between the fireplace with the natural gas or propane tank, and the type of gas logs chosen (vented or ventless). Wood stoves may also be converted to gas burning stoves. The average price for conversion ranges between $800 to $1,200 according to vendors (Vendor Sources, 1995). Assuming a 15-year phase-in for this measure, the cost effectiveness is approximately $6,280 per ton PM reduced. Table III-12 presents the assumptions used in the cost effectiveness calculation.

Another consideration when determining the cost effectiveness of this measure is the relative costs for wood and natural gas. These costs have been determined to be nearly equivalent, $65.60 per household heating with natural gas, and $72.30 per household heating with wood. These estimates are based on an average wood consumption of 0.557 cords per household per year (EPA, 1993b). The cost for a cord of wood is assumed to be approximately $130 based on vendor sources. This cost is likely to vary between urban and rural areas, the season in which the wood is purchased, and the quality of the wood (Vendor Sources, 1995). The cost of natural gas is estimated to be $5.89 per thousand cubic feet (DOE, 1994).

In most cases, the difference in the costs of the fuels will be negligible. Notwithstanding, many people may receive firewood free of charge, and for these cases, there would be an additional expense associated with changing to a natural gas fired unit. The availability of natural gas may be a limiting factor for this control strategy in some areas of the country.

v. Alternative Fuel Use - Pellet Stoves

Certified pellet stoves have inherently lower emissions than other Residential Wood Combustion (RWC) devices (EPA, 1989). Pellet stoves require specially manufactured wood pellets and depend on electricity to power the fuel feed system and combustion air. Thus, the application of pellet stoves is somewhat limited (EPA, 1989). Pellet stove emissions are approximately one-tenth the emissions of a conventional wood stove, resulting in a 90 percent reduction from conventional wood burning devices (EPA, 1989). Emissions from pellet stoves are lower than those from Phase II EPA-certified stoves by approximately 40 percent, and lower than Phase I stoves by approximately 65 percent. Based on the wood stove profile penetration outlined in the discussion above, the emission reductions that can be expected by replacing all wood-burning stove types with pellet burning stove types, over a 15-year phase-in period is 73 percent.

Capital costs to convert a wood stove to pellet burning are approximately $1,600 (Vendor Sources, 1995). Purchasing pellets is typically more expensive than wood, however, they are also more efficient (Collure, 1995). Assuming a 73 percent reduction and a 15-year phase-in period, the cost effectiveness is approximately $10,980 per ton of PM reduced. Table III-12 presents the assumptions used in the cost effectiveness calculation.

vi. Improve Wood Burning Performance - Wood Moisture Content

By limiting the range of moisture content of the wood used in residential combustion devices, PM emissions can be reduced. Counties in Oregon and Washington employ voluntary wood moisture control programs. Instruments that measure moisture content are available at local fire stations for public use. Jackson County suggests a moisture content between 6 and 12 percent; Washington State suggests a content less than 20 percent (EPA, 1989).

Because of the geographic and seasonal variability in wood moisture content and the difficulty in enforcing such a regulation, the emission reduction potential is fairly low. According to the EPA guidance document (EPA, 1989), an emission reduction of 5 percent can be assumed for a mandatory wood moisture content program.

Cost of such programs must include the costs for public education/instruction and the capital costs of the wood moisture monitoring instruments. Information regarding the cost of this program was not available.

vii. Summary

An effective mix of control measures to reduce PM emissions from RWC includes a PAE program in combination with mandatory curtailment and replacement programs. The replacement program can be used to replace wood stoves with Phase II EPA-certified stoves for those residences that qualify for exemptions in the mandatory curtailment plan.

c. Recommended Cost Model Inputs

Since the 1990 emissions estimated for residential wood combustion were developed using the emission factor for wood stoves, control measures for conventional wood stoves were exclusively examined in a previous analysis done for EPA/OPPE (Pechan, 1994a).

The natural turnover rate for residential wood stoves is assumed to be 15 years, or 6.6 percent per year. The penetration rate for measures affecting residential wood combustion must take this into consideration in determining the population mix of wood stoves, i.e., the percentage of conventional, Phase I-certified and Phase II-certified stoves. The controls examined herein yield different reductions depending upon the existing stove type. Thus, the population mix of stove types, accounting for the benefits of the wood stove NSPS, has been factored into the emission reductions. This is explained in the control measure descriptions.

Although the mandatory curtailment strategy is episodic in nature, it should be examined along with the permanent controls in this analysis since it is one of the more promising PM controls with respect to cost effectiveness. This control strategy has been implemented with a very high success rate in Oregon. Moreover, an enforcement mechanism has been established, which was one of EPA's concerns with granting credit to episodic control measures.

7. Prescribed Burning

Prescribed burning is defined as intentional burning of forest lands, agricultural fields, and rangelands. Prescribed burning may also extend to a fire that is ignited by natural forces and allowed to burn under pre-identified conditions. Prescribed burns are used primarily for the following purposes:

- Hazard reduction;
- Site preparation;
- Wildlife habitat improvement;
- Range improvement;
- Disease and insect control;
- Ecosystem maintenance;
- Management of competing vegetation;
- Aesthetics improvement;
- Access improvement;
- Recycle of nutrients;
- Waste disposal (agricultural); and
- Agronomic objectives.

Particulate matter emissions resulting from prescribed burning are generated by incomplete combustion. Prescribed burns go through a series of combustion phases; pre-ignition, flaming, smoldering, and glowing. Agricultural burns can be characterized by the flaming and smoldering phases (EPA, 1992). The most efficient combustion stage is the flaming phase, when the fire reaches its highest temperature. Most PM_{10} emissions are generated during the flaming and smoldering phases. Generally, emission rates during the smoldering phase are higher than during the flaming phase since the higher temperatures during the flaming phase foster more complete combustion (EPA, 1992). The emission factor for a prescribed wildland burn is a composite factor made up of the emissions that occur during the flaming phase and those that are generated during the smoldering phase. Thus, employing techniques that shift a portion of the burn from the smoldering phase to the flaming phase will lead to an emission reduction. Other factors affecting the magnitude of emissions generated during a burn are the age, type, size and moisture content of the fuel being consumed as well as the prevailing meteorology during the burn (EPA, 1992). Due to the number of factors that actively effect prescribed burning emissions, it is difficult to quantify the benefits of various emission reduction techniques.

Prescribed burning can generally be divided into agricultural burning and forest/rangeland or wildfire burning. Most of the forest/rangeland prescribed burning is classified as wildfire hazard reduction, while most agricultural burning is performed for waste reduction purposes (EPA, 1992). On average, PM_{10} emissions from prescribed forest and rangeland burning constitute a more significant portion of a State's total PM_{10} emissions than agricultural burning emissions (EPA, 1992). Control strategies used to minimize PM emissions associated with prescribed burns are focused on reducing the number of acres burned, reducing the pre-burn fuel loadings, reducing fuel consumption, and modifying burning techniques to lower applicable emission factors. The actual firing techniques used can also have an effect on the emissions produced during a burn. In fact, prescribed forest fire emissions can range over a factor of 10 depending on fire and fuel conditions that affect combustion efficiency (Ward, 1990). Emissions reductions associated

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with specific firing techniques are often species-specific and tend to vary with prevailing meteorology.

Mitigation strategies for PM_{10} emissions are discussed for both prescribed agricultural burning and forest/wildland burning. When available, emission reduction and cost estimates are provided. Assumptions regarding the relative effects of the control measures on particulate emissions less than 2.5 microns are also provided.

a. Agricultural Burning

i. Control Measures Evaluated

The applicable area source SCC for agricultural field burning is 2801500000. The viability of control techniques to reduce agricultural burning emissions depend on the ability of the alternative to adequately meet the objectives of agricultural burning. Emission reductions from agricultural burning controls are often difficult to quantify, since actual emissions reductions depend on many factors. A series of possible emission control strategies have been outlined in EPA's, "Prescribed Burning Background Document and Technical Information Document for Best Available Control Measures" (EPA, 1992). Identified control measures for agricultural burning are:

- Mobile Field Sanitizer;
- Propane Burning;
- Bale/Stack Burning;
- Less than Annual Burning;
- Soil Incorporation and Conservation Tillage;
- Alternative Crops;
- Mechanical Residue Removal;
- Chemical Treatment;
- Harvesting Unburned Sugar Cane;
- Firing Techniques; and
- Fuel Moisture Control.

A brief description of these measures follows. Table III-13 presents a summary of the emission reduction and costs estimates for these measures, when available.

Mobile Field Sanitizer

Mobile field sanitizers use thermal treatment of the soil to burn agricultural residues. A technical and economic evaluation concluded that this technique was not a viable alternative to open field burning (EPA, 1992).

Propane Burning

Propane flamers are an alternative to open field burning. Residue must be removed from a field prior to propane flaming treatment. Propane flaming has been shown to yield similar results to open field burning for sanitation objectives. However, annual ryegrass studies showed that the temperature of propane flaming was not adequate to destroy weed seeds. Emission factors developed for propane flaming are actually higher than open field burning. Net emission reductions of approximately 63 percent are achieved

Table III-13
Emission Reduction and Cost Estimates for PM_{10} and $PM_{2.5}$ Controls for Prescribed Agricultural Burning

Control Technique	Emission Reduction PM_{10} (%)	Emission Reduction $PM_{2.5}$ (%)	Cost
Mobile Field Sanitizer	NA	NA	NA
Propane Burning	63	63	$56 per acre
Bale/Stack Burning	35	35	$25.50 per ton burned
Less than Annual Burning	NA	NA	NA
Soil Incorporation	NA - depends on burning reduced	NA	$99 per acre
Alternative Crops	NA	NA	NA
Mechanical Residue Removal	NA	NA	$74 per acre
Chemical Treatment	NA	NA	NA
Harvesting Unburned Sugar Cane	14	14	$66 per ton of sugar produced
Fuel Distribution Control	60	60	NA
Firing Techniques	NA	NA	NA
Fuel Moisture Content	NA	NA	NA

with propane burning because this process is accompanied by substantial pre-burn residue removal, thereby reducing the amount of fuel consumed (EPA, 1992).

The cost of using a propane burner includes the cost for physical removal of residue, and the costs for operating the flamer, which vary with the speed of operation. The average cost of propane burning is $56 per acre; it includes the cost for residue removal and for the propane flaming.

Bale/Stack Burning

The stack burning technique is designed to increase the fire efficiency by stacking or baling the fuel before burning. Burning in piles or stacks tends to foster more complete combustion, thereby reducing PM emissions. Specific emission reductions will vary significantly depending on the type of fuel burned and the weather conditions. One air quality analysis of stack burning indicated an emission factor that yields a 35 percent reduction from burns that are characterized by the open field burning emission factor (EPA, 1992). The costs for baling and burning average $25 per ton of residue baled and $0.50 per ton to burn, or approximately $25.50 per ton of residue burned (EPA, 1992). This control may be better suited for certain crop types than others.

Less Than Annual Burning

Less than annual burning refers to alternating open field burning with mechanical or other residue removal methods. The frequency of burns may be reduced significantly in some cases. This alternative has been shown to reduce seed yields during no-burn years for some species. Cost and emission reduction data were not available.

Soil Incorporation

This technique incorporates straw and residue into the soil instead of burning it. Residue removal and chopping must accompany incorporation. This technique may also increase weed management problems, leading to increased herbicide use. The success of this technique also depends on the soil type and climate zone since residue decomposition is an important component. Emission reductions depend on the extent of burning avoided. If all of the residue collected is either incorporated into the soil, or disposed of without being burned, emission reductions would be 100 percent. No data regarding the emission reductions were presented in the EPA documentation. Costs include residue removal, chopping, application of herbicide, and fillage totaling $99 per acre (EPA, 1992).

Alternative Crops

An alternative to agricultural burning is the replacement of crops that produce residue with crops that produce little residue. This control is based on the assumption that the need for burning will diminish as the amount of residue diminishes. Emission reduction estimates were not available. The costs for this alternative depend on relative crop yields and their market values.

Mechanical Residue Removal

Mechanical removal methods replace the burning of residue with physical methods of collection such as raking, flail-chop removal, and close clip removal. Research in Oregon has indicated that mechanical removal can achieve the level of field sanitation necessary under certain conditions (EPA, 1992). Mechanical removal techniques can reduce seed yields depending on the species. Long term use of mechanical residue removal has the potential to result in adverse pest, weed, and disease control effects.

Residue collected mechanically may be burned or sold if a market exists. Emission reduction estimates for this measure are difficult to determine since the residue collected mechanically may eventually be burned. Assuming the residue is not burned, emission reductions would be 100 percent. However, this may not be a valid assumption; no additional information was available. An adequate rule penetration rate should be developed, since the procedure appears to have deleterious affects on the seed yields of certain crops.

Costs for close clip removal include manual removal costs, cut and vacuum costs, and stack burning, which total approximately $74 per acre.

Chemical Treatment

Chemical treatment has met with great resistance regarding contamination of ground and surface waters. Treatment results vary greatly depending on agricultural species.

Harvesting Unburned Sugar Cane

Sugar cane is burned in the field prior to harvesting to remove unwanted foliage and control insects and rodents (EPA, 1985a). Harvesting unburned versus burned sugar cane has been accomplished with mixed results in both Texas and Hawaii. The results indicated that sugar cane harvested from unburned crops required more labor hours for harvesting and hauling; increased production costs; produced a moderate reduction in factory operating rates; showed a small but significant improvement in yield of sugar per acre; and produced substantially poorer sugar refinability (EPA, 1992).

Emission reductions depend on whether or not the fields are burned to remove residue after the sugar cane is harvested and if the unused portion of the cane crop is burned after harvesting. No emission reduction estimates were available. Costs for harvesting unburned sugar cane, assuming an annual loss of $73 million dollars to sugar cane growers and 1.1 million tons of sugar produced per year at $400 per ton, is $66 per ton of sugar produced (EPA, 1992).

Firing Techniques

The firing technique used for a burn determines, to a large extent, the intensity and duration of the burn, and thereby, affects PM emissions. Agricultural fields are burned using several different techniques, the most commonly used are:

- Heading fire: single flame front, fire advances with surface wind direction;
- Backing fire: single flame front, fire advances into the surface wind direction;

- Into-the-wind strip lighting: backfiring with additional flame fronts advancing into the surface wind direction; and
- Perimeter lighting: all sides of the field are ignited.

Headfiring is the traditional technique used. Backfiring has been shown to produce the lowest emissions among the four techniques listed above (EPA, 1992). Since this fire progresses against the wind, it results in a slower fire with somewhat more complete combustion. Quantifying the emission reductions among firing techniques is difficult since numerous factors affect actual emissions. For example, a rice field study indicated that emissions from backing fires were reduced by 50 percent compared with similar burns using heading fires (EPA, 1992). However, no emission reduction was found in a similar study on wheat and barley fields.

Fuel Moisture

For agricultural burning, burning dryer residue leads to reduced PM emissions (EPA, 1992). Note that this is not the case with forest burning, which is discussed in the following section. The reduction is attributed to increased fuel combustion efficiency (EPA, 1992). Agricultural burns can achieve emission reductions from decreased fuel moisture by burning later in the day so residue has time to dry. This technique, although simplistic, can reduce emissions significantly and is easily applied at minimal costs (EPA, 1992).

ii. Agricultural Burning Emission Control Costs

Information regarding PM emission control techniques for agricultural burning is not well developed. The lack of substantive data regarding control measures may be a reflection of the fact that inventory estimates for agricultural burning emissions are also based on scant data. A comprehensive compilation of agricultural burning emissions was conducted as part of the National Acid Precipitation Assessment Program (NAPAP) effort. Agricultural burning emissions were not critical to the NAPAP inventory, and consequently the emission estimates do not adequately represent actual agricultural burning emissions. The NAPAP agricultural burning emissions were based on the assumption that 50 percent of the quantity burned was sugar cane and the other half was field crops (EPA, 1985b; EPA, 1988a). Since this inventory was compiled, national agricultural burning estimates have been updated by assuming no growth, or in some cases, activity has been adjusted using farm production indices and, therefore, may not accurately represent agricultural burning emissions. It is important to use reliable emission factor and fuel loading estimates to obtain realistic cost effectiveness estimates.

In order to more accurately estimate the control efficiencies and cost effectiveness associated with the above mentioned control techniques, State-level data were used. The number of acres grown by crop type for each State (see Table III-14) were used to apportion acres burned by crop type for each State. The number of acres grown by crop type and State were retrieved from the 1992 Agricultural Census data (DOC, 1995). Emission factor and fuel loadings by crop type were presented in AP-42 and are listed in Table III-15, along with the calculated crop specific control efficiency and cost effectiveness. State level cost effectiveness and control efficiencies are applied to State level emissions to determine total cost and emissions reductions. The calculated values for each State can be seen in Table III-16.

Table III-14
Acres Grown by State and Crop Type

State	Crop Type (acres grown)													
	Barley	Corn	Cotton	Hay	Oats	Orchards	Peanuts	Potatoes	Rice	Sorghum	Soybean	Sugarcane	Tobacco	Wheat
Alabama		281,053	431,665	678,725			237,516				305,713			569,044
California			1,066,060	1,531,230		2,245,781			401,194					14,625
Florida		86,407		270,404		914,642					49,072			292,362
Georgia		647,833	431,625	508,575			630,305				513,781		40,403	1,384,893
Idaho	691,273			1,063,292				372,028				202,115		9,942,149
Kansas		1,748,802		2,509,904	118,788					2,957,276	1,669,958			119,304
Louisiana			827,792	383,292					589,752		1,112,815	356,349		180,840
Mississippi		269,080	1,332,855	639,152					270,497		1,652,840			490,214
North Carolina		1,019,871	357,766	466,944			149,210				1,287,573		283,900	924,855
Oregon	127,185			872,535	38,241	96,166								2,495,940
Washington	422,447	94,619		740,586		256,282		129,110						

SOURCE: DOC, 1995.

Table III-15
Agricultural Burning PM_{10} Cost Effectiveness by Crop Type

Crop Type	Fuel Loading (tons refuse/acre)	Emission Factor (lb PM_{10}/ton refuse)	Cost Effectiveness ($/ton PM_{10} Reduced)	
			Propane Burning	Bale/Stack Burning
Barley	1.7	22	4,753	N/A
Corn	4.2	14	3,023	N/A
Cotton	1.7	8	13,072	N/A
Hay	1	32	5,556	N/A
Oats	1.6	44	2,525	N/A
Orchards	1	6	N/A	24,286
Peanuts	1.2	6	630	N/A
Potatoes	2.4	10.5	7,055	N/A
Rice	3	9	6,584	N/A
Sorghum	2.9	18	3,405	N/A
Soybean	2	21	4,233	N/A
Sugar Cane	10	7.2	N/A	N/A
Tobacco	2	21	4,233	N/A
Wheat	1.9	22	4,253	N/A

NOTE: All costs are in 1992 dollars. The index for converting costs to 1990 dollars is 0.919, and is based on O&M costs only.

Table III-16
Agricultural Burning Cost Effectiveness by State

State	Control Efficiency (PM_{10} reduced/PM_{10} emitted)	Cost Effectiveness (\$/ton PM_{10} reduced)
Alabama	0.63	2,591
California	0.596	7,637
Florida	0.56	8,164
Georgia	0.63	1,832
Idaho	0.565	4,515
Kansas	0.63	3,725
Louisiana	0.492	5,439
Mississippi	0.63	5,122
North Carolina	0.63	3,182
Oregon	0.628	4,452
Washington	0.627	4,311

State-level cost effectiveness is calculated by dividing State-level total cost by State-level emission reductions. State-level total cost is the weighted sum of the cost of each component crop grown; similarly, the State-level control efficiency is the weighted sum of the control efficiency for each individual crop within a given State. Weighting is based on the amount of PM_{10} emitted, which is the product of acres burned fuel loading, and the emission factor.

For the purposes of this analysis, only 11 States were assumed to have significant agricultural burning emissions, and consequently only the significant emitting States were considered for control.

b. Forest/Wildfire Burning

i. Control Measures Evaluated

The objectives of most prescribed wildland burns are hazard reduction, silvicultural purposes, and wildlife improvements. Most wildland fires are prescribed for hazard reduction. The various emission reduction techniques applied to prescribed forest fires must conform to the objectives of burning, or they will be of little utility. The applicable area source SCC for managed (or prescribed) burning is 2810015000.

Prescribed burning is regulated in many States through smoke management programs. Such programs are designed to reduce emissions from burning or minimize the impact of the smoke on populations. The level of regulation of smoke management programs varies from State to State. Typically, such a program provides some control over when, where, and how burning takes place. Smoke management programs can incorporate emission reduction goals and aid in distributing information on burning alternatives.

Emission reduction techniques that have been identified for prescribed forest fires are described below. The emission reductions and cost estimates available are presented in Table III-17. The controls examined include:

- No Treatment;
- Manual Removal;
- Chemical Treatment;
- Mechanical Methods;
- Air Curtain Destructor;
- Reduction in Pre-Burn Fuel Loading;
- Reduction in Fuel Consumption;
- Aerial Ignition;
- Placement of Residue;
- Rapid Mop-Up; and
- Mass Ignition.

No Treatment

This alternative would eliminate prescribed forest burning and allow natural processes of decomposition to occur. The reality of fuel build up and associated risk of

Table III-17
Emission Reduction and Cost Estimates for PM_{10} and $PM_{2.5}$ Controls for Prescribed Forest/Wildland Burning

Control Technique	Emission Reduction PM_{10} (%)	Emission Reduction $PM_{2.5}$ (%)	Cost
No Treatment	100	100	0
Manual Removal	NA	NA	NA
Mechanical Methods	NA	NA	$165 per acre
Air Curtain Destructor	NA	NA	$19 per ton burned
Reduction in Pre-Burn Fuel Loading	18	18	$0/Savings
Increased Fuel Moisture	54	54	$42.75 per acre
Aerial Ignition	20	20	$82 per acre
Placement of Residue	50	50	$130 per acre
Rapid Mop-Up	7	7	$88 per acre
Mass Ignition	35	35	NA

naturally ignited fires increases substantially, making no treatment a potentially dangerous and inefficient alternative (Sampson, 1995).

Manual Removal

Manual removal includes use of chainsaws and hand removal of forest slash or residue. These techniques can be dangerous to workers and are typically much more expensive than prescribed burning.

Chemical Treatment

Chemical treatment can be used to kill unwanted vegetation and allow for new growth. However, there is some resistance due to the dangers inherent with herbicide use. Costs for aerial and backpack application have been estimated at $60 per acre and $70 per acre, respectively. Emission reduction potential depends on the net amount of burning reduced, and was not available.

Mechanical Methods

Mechanical methods for treating slash are available that modify the size and shape of the residual materials and thereby eliminate or diminish the need for prescribed burning. Slash materials can be mechanically treated using mastication, chipping, piling, scarification, or burying. Mastication, or mechanically crushing small diameter slash, produces shredded residue that may be left to decompose. This method is generally considered sufficient for silvicultural objectives (EPA, 1992). Chipping may also be used to treat a variety of forest residue materials. Pits can be dug to accommodate the debris generated by chipping.

Emission reduction estimates were not available and depend on the amount of material removed and whether or not it is eventually burned. Costs range from $80 to $250 per acre depending on the equipment used.

Air Curtain Destructor

This method concentrates burning in a dugout or pit. Debris is collected and transported to a pit where it is burned. Combustion rates are higher using this alternative, since the fuel is more concentrated. This technique may reduce emissions substantially. However, the forest nutrient cycle would be disturbed since residue would be transported to the pit for burning and may not be distributed over the forest floor (Sampson, 1995). The costs for this alternative vary between $8 and $30 per ton of residue burned.

Reduction in Pre-Burn Fuel Loading

Reduction in pre-burn fuel loading refers to the practice of removing more residue during timber harvesting processes prior to burning. This practice has realized emissions reductions of 7 percent in Oregon and 14 percent in Washington (EPA, 1992). This control is more common for private land burns. The excess slash residue may be marketable depending on the quality and quantity of chips, and the market price. According to the EPA guidance document, "studies have shown that removing 16 tons per acre would eliminate the need to burn about half of the area scheduled for pile burning." Harvesting as much of the small wood debris as possible before burning can reduce emissions between 18 and 35 percent (Sandberg, 1988). An 18 percent reduction can be used as a conservative estimate. It should be noted that reductions are highly dependent upon the amount and type of debris collected.

Costs for collecting and marketing pre-burn fuel are variable and depend on the market price for the chips collected and the labor rate. A net savings of $290 per acre not burned as a result of this measure has been estimated for the combination of residue removal, marketing and selling the material collected (EPA, 1992). Based on the number of acres burned nationally, and assuming an 18 percent reduction, this measure would have a cost effectiveness (savings) of $3,150 per ton reduced. Since the net savings estimates provided could not be confirmed, a cost of $0 per ton may be assumed as a conservative estimate.

Increased Fuel Moisture

Increasing the fuel moisture content of forest materials to be burned can decrease emissions by decreasing the net amount of fuel consumed. This alternative can be accompanied by removing the lighter, drier fuels from the forest floor. When heavier, larger woody material contains a high moisture content, it is less likely to burn and, therefore, less fuel is ultimately consumed.

Re-scheduling burns from fall to spring has led to reductions in PM emissions in western States (McMahon, 1995). In the spring, the forest floor conditions tend to hold more moisture due to rains and green undergrowth, thus, less fuel is actually consumed by the fire, leading to a decrease in PM emissions (Hardy, 1995). Scheduling prescribed fires in the spring, or during spring-like conditions, can reduce emissions by as much as 54 percent (Sandberg, 1988; EPA, 1992).

The costs have been calculated assuming a smoke management plan and some degree of removing the lighter, drier fuels from the burn so that the moisture content is approximately 32 percent. Costs have been estimated as $38 per acre for private land, and $63 per acre of U.S. Forest Service (USFS) land. These costs were developed as part of a cost benefit analysis for Oregon. A weighted average based on acreage affected in Oregon yields a cost of $42.75 per acre. However, others believe that there is actually a net savings by burning land in the spring (Hardy, 1995).

Aerial Ignition

The use of helitorch or aerial ignition can reduce emissions by up to 20 percent, if a mass fire situation is achieved and an overall reduction in fuel consumption realized (EPA, 1992). Costs of aerial ignition include costs for a helicopter and crew, ground crew, equipment, and ignition materials. The costs decrease with increasing area coverage and average approximately $82 per acre (EPA, 1992).

Placement of Residue

Residue distribution, or placement alternatives, refers to gathering forest residue into piles and burning the piles. Burning the residue in piles tends to foster more complete combustion, thereby reducing PM emissions. Burning slash in clean piles rather than broadcast burning has the potential to reduce emissions by as much as 50 percent (Sandberg, 1988). Burning in "clean piles" refers to removal of soil and other forest detritus. Costs to gather and pile forest debris average approximately $130 per acre; this estimate is in 1978 dollars (EPA, 1992).

Rapid Mop-Up

Mop-up is typically conducted to minimize the risk of new fires from smoldering fuels and to eliminate smoldering emissions that may drift down slope into valleys. Mop-up procedures typically entail applying water to the burn area to insure fire extinction. Rapid mop-up of residual smoke following the flaming phase can significantly reduce emissions from the smoldering phase. Mop-up within 8 hours can reduce emissions by 10 percent, while mop-up within 4 hours can reduce emissions by about 17 percent (EPA, 1992). The costs of mop-up procedures vary, and depend on the amount of suppression needed. Transporting water to the burn site is often required and adds to the cost of this procedure (Mahaffey, 1995).

Mop-up procedures are often part of smoke management programs, or required by State regulations. The reductions from mop-up are difficult to determine since it is already required in some States. In such areas, reductions may be increased by decreasing mop-up time. Assuming all prescribed fires are treated with mop-up procedures, the incremental costs for a 50 percent decrease in mop-up time are $88 per acre for USFS land, and $56 per acre for private land (Mahaffey, 1995; EPA, 1992). Since prescribed burning also occurs on military land, Indian Reservation land, Fish and Wildlife Preserve land, etc., it is difficult to estimate a weighted average of the cost estimates provided (Hardy, 1995). Therefore, a conservative estimate of $88 per acre will be used until more complete information is obtained. The emission reduction for decreasing the mop-up time by 50 percent is 7 percent (EPA, 1992).

Mass Ignition

Mass ignition refers to a firing technique that ignites the entire area to be burned. This firing technique fosters a high energy fire with less heat penetration to the soil and woody materials. This technique reduces the smoldering phase of the fire, thereby reducing PM emissions. PM emissions are also reduced by this technique because fires that are mass ignited tend to consume less fuel (Hardy, 1995). Mass ignition techniques can reduce PM emissions by 35 percent (Hardy, 1995).

ii. Prescribed Burning Emission Control Costs

Many of the original cost estimates were presented as costs per acre of land burned. In order to convert these estimates to cost effectiveness estimates, the ratio of PM_{10} and $PM_{2.5}$ emitted per acre of land burned was obtained from "An Inventory of Particulate Matter and Air Toxic Emissions from Prescribed Fires in the United States for 1989" (USDA, 1989). This inventory was compiled using survey data containing individual estimates of fuel consumption and fuel bed components for each prescribed fire. Emission factors were selected based on the survey information. Since data are available on a State specific basis, cost effectiveness estimates can be determined for each State. National level data were used in this analysis. The estimates provided in Table III-18 show cost

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Table III-18
Emission Reduction and Cost Effectiveness Estimates for Prescribed Forest Burning Control Techniques

Control Measures	Emission Reduction (percent)	Cost per Acre ($/acre burned)	U.S. Average PM-10 Cost Effectiveness ($/ton reduced)	U.S. Average PM-2.5 Cost Effectiveness ($/ton reduced)
Increased Fuel Moisture	54	42.75	861	1,015
Aerial Ignition	20	82.00	4,457	5,256
Reduction in Pre-Burn Fuel Loading*	18	0.00	0	0
Rapid Mop-up	7	88.00	13,665	16,117
Placement of Residue	50	130.00	2,826	3,333

NOTES: Based on an estimate of tons of PM-10 and PM-2.5 emitted per acre burned using USDA, 1989.
*Costs for Reduction in Pre-Burn Fuel Loading were estimated as a net savings, the estimate was not confirmed. Therefore, a conservative approach was taken, and costs were assumed to be $0 per ton.

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effectiveness based on the national average of PM_{10} and $PM_{2.5}$ emissions per acre of land burned in 1989. All cost information is in 1992 dollars, unless otherwise noted. The cost effectiveness was determined using the calculation shown in the following example for Increased Fuel Moisture controls.

Example Cost Effectiveness Calculation: Prescribed Burning Control

Increased fuel moisture controls reduce emissions by approximately 54 percent, at a cost of $42.75 per acre of land burned.

Prescribed burning was applied to 5,082,334 acres of forest, resulting in 468,249 tons of PM_{10} emitted (USDA, 1989). Thus, the ratio of acres burned to tons emitted for the US is:

(468,249 tons)/(5,082,334 acres) = 0.092 tons/acre

$$\frac{\$42.75 \text{ per acre}}{0.092 \text{ tons/acre}} * \frac{1 \text{ ton emitted}}{0.54 \text{ tons reduced}} = \$861 \text{ per ton reduced}$$

Cost effectiveness = $861 per ton of PM_{10} reduced

iii. PM_{10} and $PM_{2.5}$

Specific information regarding the effectiveness of a PM_{10}-based control on $PM_{2.5}$ emissions was not available for many measures. For control measures that reduce emissions via reducing the amount of land burned or the amount of fuel consumed, it was assumed that $PM_{2.5}$ emissions would be reduced by an equivalent amount as PM_{10} emissions. The particle size distribution found using empirical analyses suggests that 40 to 95 percent of the PM mass from forest fire prescribed burns consists of particles less than 2.5 microns in diameter (Ward, 1990). The rate of heat release has a pronounced effect on the size, and mass of particulate matter resulting from prescribed burns (Ward, 1990). According to an inventory compiled by the USFS, 84 percent of the PM_{10} emissions are in the $PM_{2.5}$ range (USDA, 1989). Ninety-one percent of PM_{10} emissions are in the $PM_{2.5}$ range for agricultural burning (Pechan, 1994a). Due to the high percentage of PM_{10} emissions falling within the 2.5 micron range, it can be assumed, in the absence of more specific information, that the emissions reduction potential for control measures is equivalent for PM_{10} and $PM_{2.5}$ emissions. For agricultural burning controls, the cost effectiveness for $PM_{2.5}$ will be assumed equivalent to the cost per ton for PM_{10}. Since more complete data is available for prescribed forest burning, it was possible to calculate cost effectiveness for both PM_{10} and $PM_{2.5}$.

Tables III-16 and III-18 contain emission reduction and cost effectiveness estimates for the above-identified measures for agricultural burning and forest/wildfire burning, respectively. Estimates are State-specific for agricultural burning controls and based on a national average for prescribed forest burn controls. State-specific estimates for prescribed burns can be developed.

8. Residential and Commercial/Industrial Natural Gas Combustion

Attempts have been made by California air districts to regulate commercial water heaters and boilers in the 75,000 to 2,000,000 btu/hr size range (Pechan, 1994a). However, industry has claimed to need more time to develop the technology necessary to meet a tighter NO_x standard, and also noted that there was not an approved test method to certify new equipment. The SCAQMD is currently in the early phases of studying a NO_x standard for equipment in this size range (Haimov, 1995). Discussions with industry did not produce any new information regarding the technical feasibility or cost associated with reducing emissions from this source category (Bixby, 1995; Raypak, 1995). No additional controls are modeled other than water heater replacement and LNB space heaters based on input previously developed for ERCAM-NO_x (Pechan, 1994b).

C. PM POINT SOURCES

This section presents cost equations for controlling PM emissions from utility, institutional, commercial, and industrial (ICI) oil- and coal-fired boilers and space heaters. The cost equations were developed for use by ERCAM. Cost equations were developed for electrostatic precipitators (ESPs) and fabric filters. Spreadsheet programs developed by EPA were used to estimate ESP and fabric filter costs for a range of air flow rates. Cost equations were then developed to relate costs to air flow rates. The spreadsheets are based on the cost estimation procedures presented in the *OAQPS Control Cost Manual* (EPA, 1990b). Cost equations were not developed for natural gas-fired boilers because they are typically not significant sources of particulate matter emissions and, therefore, unlikely candidates for cost effective control.

Point source emissions data for oil- and coal-fired utility boilers and space heaters were downloaded from the National Particulate Inventory in May 1995 for use in developing input parameters for the control cost equations (Pechan, 1994). Part 2 of this section presents the input parameters for developing equations for oil-fired boilers and space heaters. The input parameters used to develop equations for coal-fired boilers is presented in Chapter II of the report entitled, *Development of Control Cost Equations for Particulate Matter* (Pechan, 1995a). Part 3 of this section presents the control cost equations for both oil- and coal-fired boilers and space heaters.

1. Overview

The National Particulate Inventory contains a total of 3,604 oil-fired utility and ICI boilers and space heaters. Total PM_{10} emissions for the 3,604 units are 39,372 tons per year (TPY). The inventory contains 557 utility boilers that use residual fuel as the primary fuel. None of the utility boilers were operated on distillate or waste oil. The utility boilers accounted for about 15 percent of the units and 23 percent of total emissions. The ICI category included 515 distillate oil-fired units, 2,493 residual oil-fired units, and 39 waste oil-fired units. The ICI distillate-, residual-, and waste oil-fired units accounted for about 5, 71, and 1 percent of total emissions. A total of 26 space heaters was included in the inventory for ICI distillate oil-fired units. All of the space heaters were uncontrolled, and accounted for 0.6 percent of total emissions.

The control cost spreadsheets for ESPs and fabric filters were used to generate capital and annual costs for the following air flow rates: 15,000; 50,000; 100,000; 150,000;

200,000; 250,000; 500,000; 750,000; 1,000,000; and 1,400,000 actual cubic feet per minute (acfm). The lowest and highest of these air flow rates represent the limits of the equations used in the spreadsheet for estimating ESP costs. According to the *OAQPS Control Cost Manual*, the equations in the control cost spreadsheets for fabric filters should not be used to extrapolate costs beyond the specified air flow rate limits. Depending on the type of fabric filter, the specified upper limits range from 80,000 to 130,000 acfm. When an emission source's air flow rate exceeds the limits of the equations, an acceptable procedure is to estimate costs for more than one fabric filter using an air flow rate within the limits of the equations. However, the cost equations for fabric filters are approximately linearly related to the air flow rate. After discussing this issue with EPA, it was determined that these cost equations could be applied up to 1,400,000 acfm with reasonable results. This decision was made primarily because of the large number of boilers in the inventory with air flow rates above the cost equation limits and the additional effort that would be needed to estimate costs for more than one fabric filter for a single emission source.

2. Input Parameters Used to Develop Cost Equations for Oil-Fired Boilers

The input parameters to the spreadsheets used for oil-fired boilers were the same as those used for coal-fired boilers except for temperature, mass median diameter, and inlet particulate loading. The input parameters for coal-fired boilers are presented in Tables II-1 and II-2 of Chapter II of the report entitled, *Development of Control Cost Equations for Particulate Matter* (Pechan, 1995a).

The input values for temperature, mass median diameter, and inlet particulate loading were changed to reflect typical values for oil-fired boilers. Typical input parameters were selected from an analysis of the range of the data reported for oil-fired boilers in the inventory. Table III-19 provides summary statistics of the air flow rates and stack temperatures for oil-fired utility boilers and ICI boilers and space heaters. Capital and annual O&M costs are directly proportional to temperature. Inlet temperature affects the capital costs of pulse-jet fabric filters and the annual O&M costs of shaker, reverse-air, and pulse-jet fabric filters. Temperature did not have an effect on the capital and O&M costs for ESPs. For this analysis, a temperature of 400°F was used as a typical value for ICI and utility boilers. The 400°F value represents the 50th percentile of the distribution of stack temperatures reported for ICI boilers and space heaters. For oil-fired utility boilers, 400°F falls between the 90th and 95th percentiles. To simplify the analysis, 400°F was used to represent a typical value for both ICI and utility boilers.

The mass median diameter of particulate loading is used in the equations for estimating capital costs for pulse-jet fabric filters and the annual costs of shaker, reverse-air, and pulse-jet fabric filters. It is not used in the equations for ESP costs. Particle size distribution data for oil-fired boilers are presented in AP-42 for the cumulative mass percentage less than or equal to 15 microns. These data are summarized in Table II-3, and the particle size data are presented in Appendix A of the *Development of Control Cost Equations for Particulate Matter* report (Pechan, 1995a). A mass median diameter of 5 microns was used for estimating fabric filter costs. This value was selected because it represents the median of the range of values reported in AP-42. A lower value for the mass median diameter would increase costs for all three types of fabric filters.

Table III-19
Summary Statistics of Stack Temperatures and Air Flow Rates for Utility, Industrial, Commercial, and Institutional Boilers and Space Heaters Fired With Distillate, Residual, or Waste Oil

	Temperature, F	Air Flow Rate, acfm
Distillate-Oil-Fired		
No. of Boilers	476	461
Min.	65	175
25th	330	8,100
50th	400	26,000
75th	500	67,490
85th	550	102,599
90th	600	139,750
95th	670	178,000
99th	925	508,939
Max.	1824	774,540
Avg.	425	55,878
Residual-Oil-Fired		
No. of Boilers	2,373	2,214
Min.	22	1
25th	350	12,400
50th	400	31,397
75th	500	77,162
85th	540	120,000
90th	550	155,972
95th	600	219,934
99th	786	461,661
Max.	1470	7,706,000
Avg.	412	67,136
Waste-Oil-Fired		
No. of Boilers	39	38
Min.	132	3,500
25th	333	33,000
50th	400	61,854
75th	475	103,500
85th	506	132,701
90th	520	152,000
95th	550	156,500
99th	550	265,791
Max.	550	315,001
Avg.	392	75,103

Table III-19 (continued)

	Temperature, F	Air Flow Rate, acfm
All Oil-Fired Institutional, Commercial, and Industrial Boilers		
No. of Boilers	2,888	2,713
Min.	22	1
25th	345	11,780
50th	400	31,200
75th	500	75,000
85th	548	118,818
90th	560	152,000
95th	623	212,365
99th	801	464,277
Max.	1824	7,706,000
Avg.	414	65,335
Utility Residual-Oil-Fired Boilers		
No. of Boilers	480	480
Min.	183	16,000
25th	271	244,140
50th	300	410,112
75th	330	970,822
85th	350	1,442,730
90th	363	1,718,100
95th	439	2,223,050
99th	661	4,215,910
Max.	785	5,388,000
Avg.	313	746,572

Inlet particulate loading has a directly proportional effect on annual costs for both ESPs and fabric filters, and capital costs for pulse-jet fabric filters. Two methods were used to estimate inlet particulate loadings using the inventory data. One method involved using uncontrolled PM_{10} emissions, annual operating hours, and stack gas flow rate to estimate the grains per actual cubic foot (gr/acf) of loading for each boiler. For controlled sources, emissions were divided by 1 minus the control efficiency (decimal) to estimate uncontrolled PM_{10} emissions. Uncontrolled PM_{10} emissions were then divided by the mass percentage less than 10 microns to estimate uncontrolled PM emissions. The particle size distribution data presented for the individual types of boilers in Appendix A of Pechan's report (Pechan, 1995a) were used to determine the value for the mass percentage less than 10 microns. For the second method, uncontrolled PM emission factors from AP-42 were used with the fuel throughput rate, annual operating hours, and stack gas flow rate to estimate the gr/acf of loading for each boiler. Table III-20 shows the results of these calculations. An average loading of 0.001 gr/acf was used in the cost spreadsheets for estimating ESP and fabric filter costs. It was difficult to determine a typical value from the data presented in Table III-20. At the 50th percentile, the 0.001 gr/acf value is between the values calculated by the two methods.

3. Cost Equations for Oil- and Coal-Fired Boilers

a. Electrostatic Precipitators

i. Capital Costs

Table III-21 shows the control cost equations for estimating purchased equipment costs for ESPs. The equations were generated for air flow rates ranging from 15,000 to 1,400,000 million acfm. Installed capital costs are estimated by multiplying purchased equipment costs by a factor of 2.24. Costs associated with retrofitting an existing boiler with an ESP are site specific and difficult to estimate. According to the *OAQPS Control Cost Manual*, a retrofit multiplier ranging from 1.3 to 1.5 times total installed capital costs can be used for ESPs. A median value of 1.4 will be used as a default factor for estimating retrofit costs in ERCAM.

ii. Annual O&M Costs

Table III-22 shows the equations for estimating electricity costs and total collector plate area. The equations for estimating electricity costs and total collector plate area are the same for oil- and coal-fired boilers. Table III-23 shows the equations for estimating dust disposal costs for oil- and coal-fired boilers.

The components of annual O&M costs include operating, supervisory, ESP coordinator, and maintenance labor; maintenance materials; electricity; dust disposal; overhead; taxes, insurance, and administration; and capital recovery. The following components were estimated using the factors outlined in the *OAQPS Control Cost Manual*:

- Supervisory labor;
- ESP coordinator labor;
- Maintenance materials;
- Overhead;

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Table III-20
Summary Statistics of Uncontrolled Particulate Matter Mass Loading to Control Devices for Utility, Industrial, Commercial, and Institutional Boilers and Space Heaters Fired With Distillate, Residual, or Waste Oil

	Calculated from AP-42 Uncontrolled PM Emission Factor, grains/actual ft^3	Calculated from PM_{10} Emissions in Inventory, grains/actual ft^3
Distillate-Oil-Fired		
No. of Boilers	391	412
Min.	0.00000028	0.0000000026
25th	0.00011	0.0000021
50th	0.00093	0.000021
75th	0.0035	0.000099
85th	0.0063	0.00026
90th	0.0088	0.00052
95th	0.018	0.0049
99th	27	0.35
Max.	173	2.3
Avg.	0.95	0.018
Residual-Oil-Fired		
No. of Boilers	2,206	2,027
Min.	0.00000041	0.0000000031
25th	0.00046	0.000026
50th	0.0017	0.0001
75th	0.0045	0.00029
85th	0.0071	0.00052
90th	0.01	0.00075
95th	0.018	0.0022
99th	0.3	1.2
Max.	165	1,682
Avg.	0.31	0.95
Waste-Oil-Fired		
No. of Boilers	4	32
Min.	0.000045	0.00000022
25th	0.0064	0.0000018
50th	0.01	0.0000095
75th	0.013	0.0001
85th	0.015	0.00027
90th	0.015	0.00032
95th	0.016	0.0015
99th	0.016	0.016
Max.	0.017	0.022
Avg.	0.0093	0.00083

Table III-20 (continued)

	Calculated from AP-42 Uncontrolled PM Emission Factor, grains/actual ft^3	Calculated from PM_{10} Emissions in Inventory, grains/actual ft^3
All Oil-Fired Institutional, Commercial, and Industrial Boilers		
No. of Boilers	2,421	2,471
Min.	0.00000028	0.0000000026
25th	0.00037	0.000017
50th	0.0015	0.000085
75th	0.0043	0.00026
85th	0.007	0.00049
90th	0.01	0.00073
95th	0.018	0.0025
99th	0.37	1
Max.	173	1,682
Avg.	0.41	0.79
Utility Residual-Oil-Fired Boilers		
No. of Boilers	478	478
Min.	0.0000013	0.00000017
25th	0.00026	0.000035
50th	0.0025	0.00027
75th	0.011	0.0025
85th	0.018	0.0044
90th	0.022	0.0055
95th	0.028	0.0088
99th	0.052	0.014
Max.	0.3	0.054
Avg.	0.0083	0.002

Table III-21
Equations for Estimating Capital Costs for ESPs on Utility, Industrial, Commercial, and Institutional Boilers and Space Heaters Fired With Oil or Coal*

Control Efficiency, Percent	Equation**	R2 Value
Total Purchased Equipment Cost Equations		
99.9	7.5902x + 498393	0.997
99.5	5.7182x + 394012	0.997
99	5.0711x + 359125	0.997
95	3.1899x + 268379	0.998
80	1.8425x + 211920	0.996
Purchased Equipment Cost Equations for Upgrade		
99.5 to 99.9	4.1934x + 233727	0.996
99 to 99.9	5.6422x + 312065	0.996
95 to 99.9	9.8569x + 514981	0.996
80 to 99.9	12.874x + 641765	0.997

NOTES: * Applies to units fired with any type of oil or coal.
** The variable "x" is the actual airflow rate into the ESP (actual cubic feet per minute).
Multiply purchased equipment costs by 2.24 to estimate total installed capital costs.
Multiply total installed capital costs by 1.4 to estimate retrofit costs.

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Table III-22
Equations for Estimating Annual Electricity Costs and Total Collector Plate Area for ESPs on Utility, Industrial, Commercial, and Institutional Boilers and Space Heaters Fired With Oil or Coal*

Control Efficiency, Percent	Electricity: Oil- and Coal-Fired Units		Total Collector Plate Area: Oil- and Coal-Fired Units	
	Equation**	R2 Value	Equation**	R2 Value
Total Cost Equations				
99.9	0.7172x + 7.0427	1.00	0.6777x + 15.381	1.00
99.5	0.5246x + 2.0256	1.00	0.4862x - 14.61	1.00
99	0.4606x - 0.0291	1.00	0.4226x - 11.696	1.00
95	0.2844x + 12.487	1.00	0.4232x - 521.35	1.00
80	0.1693x - 4.3012	1.00	0.1329x - 11.395	1.00
Cost Equations for Upgrade				
99.5 to 99.9	0.1926x + 3.8914	1.00	0.1915x + 13.428	1.00
99 to 99.9	0.2566x - 13.656	1.00	0.2551x + 7.4749	1.00
95 to 99.9	0.4329x - 11.395	1.00	0.2545x + 536.73	1.00
80 to 99.9	0.5479x + 10.233	1.00	0.5448x - 4.9008	1.00

NOTES: * Applies to units fired with any type of oil or coal.
** The variable "x" is the actual airflow rate into the ESP (actual cubic feet per minute).

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Table III-23
Equations for Estimating Annual Dust Disposal Costs for ESPs on Utility, Industrial, Commercial, and Institutional Boilers and Space Heaters Fired With Oil or Coal*

Control Efficiency, Percent	Dust Disposal: Oil-Fired Units		Dust Disposal: Coal-Fired Units	
	Equation**	R2 Value	Equation**	R2 Value
Total Cost Equations				
99.9	0.0007x - 0.1611	1.00	0.7406x + 1.146	1.00
99.5	0.0007x + 0.0882	1.00	0.7376x + 12.814	1.00
99	0.0007x - 0.0193	1.00	0.7339x - 0.4561	1.00
95	0.0007x + 0.0287	1.00	0.7042x + 2.943	1.00
80	0.0006x + 0.1418	1.00	0.5933x - 15.772	1.00
Cost Equations for Upgrade				
99.5 to 99.9	0.000003x - 0.095	0.959	0.003x + 16.378	1.00
99 to 99.9	0.000007x - 0.026	0.991	0.0067x - 0.6429	1.00
95 to 99.9	0.00004x + 0.0319	1.00	0.0363x - 3.6753	1.00
80 to 99.9	0.0001x - 0.0312	1.00	0.1475x + 14.113	1.00

NOTES: * Applies to units fired with any type of oil or coal.
** The variable "x" is the actual airflow rate into the ESP (actual cubic feet per minute).

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- Taxes, insurance, and administration; and
- Capital recovery.

The equation for total collector plate area was used to calculate operating labor and maintenance labor, using the factors and procedures presented in the *OAQPS Control Cost Manual*. Equations for electricity and dust disposal were calculated using the air flow rate as well as the total collector plate area.

b. Fabric Filters

i. Capital Costs

Table III-24 shows the control cost equations for estimating purchased equipment costs for fabric filters. The equations for shaker and reverse-air fabric filters are the same as those developed for coal-fired boilers. The equations were generated for air flow rates ranging from 15,000 to 1,400,000 acfm. Installed capital costs are estimated by multiplying purchased equipment costs by a factor of 2.17. Costs associated with retrofitting an existing boiler with a fabric filter are site specific and difficult to estimate. The *OAQPS Control Cost Manual* did not provide guidance for a retrofit multiplier for fabric filters. For ERCAM, the 1.4 multiplier used for ESPs will also be used as a default factor for estimating retrofit costs for fabric filters.

ii. Annual O&M Costs

Tables III-25 and III-26 show the equations for estimating electricity, dust disposal, bag replacement, and compressed air (pulse-jet only) costs for oil- and coal-fired boilers, respectively. The equation for estimating compressed air costs is the same for oil- and coal-fired boilers.

The components of annual O&M costs include operating, supervisory, and maintenance labor; maintenance materials; electricity; dust disposal; overhead; taxes, insurance, and administration; and capital recovery. The following components were estimated using the factors outlined in the *OAQPS Control Cost Manual*:

- Supervisory labor;
- Maintenance materials;
- Overhead;
- Taxes, insurance, and administration;
- Capital recovery;
- operating labor; and
- maintenance labor.

Equations for electricity dust disposal bag replacement costs and pulse-jet fabric filter compressed air costs were calculated using the air flow rate.

D. SO_2 POINT SOURCES

This section describes the control cost information developed during this study for point source SO_2 emitters that are candidates for control. These include petroleum refineries and industrial boilers. Investigation into petroleum refineries did not yield any

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Table III-24
Equations for Estimating Capital Costs for Fabric Filters on Utility, Industrial, Commercial, and Institutional Boilers and Space Heaters Fired with Oil or Coal*

Fabric Filter Type	Boiler Fuel Type	Equation**	R2 Value
		Total Purchased Equipment Cost Equations	
Shaker	Oil/Coal	5.7019x + 77489	1.00
Reverse-Air	Oil/Coal	5.7993x + 69721	1.00
Pulse-Jet	Oil	1.9634x + 59341	1.00
Pulse-Jet	Coal	2.4967 + 59491	1.00

NOTES: * Applies to units fired with any type of oil or coal.
** The variable "x" is the actual airflow rate into the fabric filter (actual cubic feet per minute).
Multiply purchased equipment costs by 2.17 to estimate total installed capital costs.
Multiply total installed capital costs by 1.4 to estimate retrofit costs.

Table III-25
Equations for Estimating Annual Operating and Maintenance Costs for Fabric Filters on Utility, Industrial, Commercial, and Institutional Boilers and Space Heaters Fired With Oil*

Fabric Filter Type	Electricity		Dust Disposal		Bag Replacement, $		Compressed Air, $	
	Equation**	R2 Value	Equation**	R2 Value	Equation**	R2 Value	Equation**	R2 Value
Shaker	0.1876x - 19.576	1.00	0.0007x + 0.1895	1.00	0.2411x + 1224.2	1.00	Not Applicable	
Reverse-Air	0.2809x + 542.09	1.00	0.0007x + 0.1895	1.00	0.2866x + 1486.8	1.00	Not Applicable	
Pulse-Jet	0.1962x - 21.837	1.00	0.0007x + 0.1895	1.00	0.1152x + 1.7916	1.00	0.1659x - 0.6381	1.00

NOTES: * Applies to any type of oil.
** The variable "x" is the actual airflow rate into the fabric filter (actual cubic feet per minute).

Table III-26
Equations for Estimating Annual Operating and Maintenance Costs for Fabric Filters on Utility, Industrial, Commercial, and Institutional Boilers and Space Heaters Fired With Coal*

Fabric	Electricity		Dust Disposal		Bag Replacement, $		Compressed Air, $	
Filter Type	Equation**	R2 Value	Equation**	R2 Value	Equation**	R2 Value	Equation**	R2 Value
Shaker	0.1941x - 15.956	1.00	0.7406x + 1.1461	1.00	0.2497x + 1220.7	1.00	Not Applicable	
Reverse-Air	0.2869x + 562.52	1.00	0.7406x + 1.1461	1.00	0.2952x + 1488.7	1.00	Not Applicable	
Pulse-Jet	0.2126x - 1.8948	1.00	0.7406x + 1.1461	1.00	0.1465x + 1.1497	1.00	0.1659x - 0.6381	1.00

NOTES: * Applies to any type of coal.
** The variable "x" is the actual airflow rate into the fabric filter (actual cubic feet per minute).

cost and emission reduction data that could easily be incorporated into the modeling at this time. Utility boiler SO_2 control cost equations are included in this study, but are not included in this section because they are already documented elsewhere.

1. Petroleum Refineries

While emissions sources and applicable controls are fairly well-defined, data relating control costs to emissions reduction or SCC units are not readily available for specific refinery units. Discussions with petroleum industry representatives showed that cost of control studies have not been done unit-by-unit (Krienen, 1995). The National Petroleum Council completed a six-volume petroleum refining report in 1993, but discussions with one of the authors revealed that this report does not have emissions control data for these individual refinery units (Oliver, 1995). The American Petroleum Institute (API) has done no work on this issue, but is beginning to address the impacts of a PM NAAQS revision with a meeting on September 6, 1995 (Baer, 1995). The National Petroleum Refiners Association (NPRA) also had no relevant data (Higgins, 1995).

a. Process Heaters

Process heaters in petroleum refineries are essentially furnaces that raise the temperature of process feed materials to distillation or reaction level. The major processing units in a refinery, such as distillation, alkylation, reforming, and cracking, include process heaters that burn fuels such as refinery gas, natural gas, and fuel oil. Combustion results in emissions of all criteria pollutants. Oil-fired process heaters are represented in SCC 3-06-001-01 (emission factor in lbs/1000 barrels oil burned) and in SCC 3-06-001-03 (lbs/1000 gallons). Refinery gas-fired process heaters are represented in SCC 3-06-001-02 (lbs/1000 ft^3 gas burned) and in SCC 3-06-001-04 (lbs/million ft^3).

PM and SO_2 emissions are present in flue gas from both oil-fired and refinery gas-fired process heaters. Uncontrolled SO_2 emissions depend on the sulfur content of the fuel being burned. PM emissions depend on the grade of fuel, with heavier oils generally producing higher PM levels than lighter distillate oils. PM emissions from gas-fired heaters are relatively low, and control strategies for these were not evaluated.

The 1990 base year data base shows that less than 5 percent of oil-fired process heaters (19 of 438 units) and just over 5 percent of refinery gas-fired process heaters (136/2605) are controlled for SO_2 (Pechan, 1995a). The two basic ways to control SO_2 emissions from process heaters are fuel desulfurization, which limits the amount of SO_2 that can form during the combustion process, and flue gas treatment to remove SO_2 from the exhaust stream. Because fuel desulfurization/low-sulfur fuel substitution may be very limited for a given refinery, flue gas treatment is the recommended method for process heater SO_2 control.

Commercially-available wet scrubbers, which remove over 90 percent of the SO_2, are the logical flue gas treatment for these SCCs. Lime/limestone, sodium carbonate, magnesium oxide/hydroxide, or dual alkali scrubbers are proven to be effective. Sodium carbonate scrubbers suffer from high reagent costs (EPA, 1993c).

Just 1 percent (5 of 438) of oil-fired process heaters are equipped with particulate controls in the base year (Pechan, 1995a). PM emissions from these heaters are caused

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by incomplete combustion, and proper design and maintenance can minimize particulate formation. Assuming combustion parameters are optimized to limit PM and external PM controls are deemed necessary, possibilities include high-efficiency ESPs with PM control efficiencies over 90 percent and wet scrubbing systems that can remove both SO_2 and PM from the flue gas. Scrubbing systems installed on oil-fired boilers to control both pollutants can achieve 90 to 95 percent SO_2 removal efficiency and 50 to 60 percent particulate control.

b. Fluidized Catalytic Cracker (FCC)

Catalytic cracking in a refinery is used to convert heavy oils into more valuable lighter products. Following their role in the high-temperature reaction, spent catalyst particles are conveyed to a regenerator. In the regenerator, coke on the catalyst is burned off in a controlled combustion process. Air emissions from an FCC unit consists of flue gas from this catalyst regeneration process. These emissions are represented by SCC 3-06-002-01.

FCC regenerators are typically followed by CO boilers, which reduce CO emissions to negligible levels (Koberlein, 1995). The flue gas can still contain significant amounts of SO_2 and PM.

The 1990 base year data base shows that less than 5 percent of FCC units (12 of 245) are controlled for SO_2 (Pechan, 1995a). Three ways to reduce SO_2 emissions from an FCC unit include desulfurization of FCC feed, use of specific catalysts for SO_2 control, and flue gas treatment such as the wet scrubbing techniques described above. Wet scrubbing, which achieves over 90 percent SO_2 reduction, is the logical control measure for modeling this SCC. The other two methods are highly dependent on specific refinery economics.

About 33 percent (82 of 245) of FCC units are equipped with particulate controls in the base year (Pechan, 1995a). Cyclone collection followed by an ESP is the proven PM control technique for this SCC, with control efficiencies up to 99.9 percent for particles less than 44 microns (EPA, 1982). Further penetration of the multistage cyclone/ESP control measure can significantly reduce PM emissions from this SCC.

c. Fluid Coker

Coking is a severe form of cracking used to convert residual oil to higher value light products. In fluid coking, feed is sprayed into a reactor containing a bed of preheated coke particles. Large hydrocarbon molecules in the liquid feed crack and vaporize. Nonvolatile material is deposited on the coke particles. Eventually the coke particles sink and flow to a burner for recycling. Flue gas from this burner is the source of SO_2 emissions from the fluid coking process. Some coke is also drawn off as product. Emissions from fluid cokers are represented by SCC 3-06-012-01.

None of the 20 fluid cokers in the base year data base list any form of SO_2 control (Pechan, 1995a). The applicable technology would be the wet scrubbing methods described above for the other SCCs. Scrubbing of the burner flue gas could reduce SO_2 emissions from this source by over 90 percent. SO_2 emission levels from each coker are of course dependent on the sulfur content of the feed and the coke particles.

PM controls are listed for several fluid cokers in the base year data base. Fluid cokers are not a major source of PM emissions compared with the older, more commonly used delayed-coking process. In delayed coking, significant particulate emissions are associated with removing coke from a coke drum and other handling and storage operations. Delayed coking is under a different SCC.

2. Industrial Boilers - SO_2 Controls

The control cost equations used for estimating the costs of applying flue gas desulfurization (FGD) to industrial boilers were originally developed for application to electric utility boilers. This analysis assumes that the costs for applying scrubbers to the an industrial boiler would be the same as applying a scrubber to a utility boiler of the same size. The cost equations used in this analysis are based on cost equations that apply to forced oxidation wet scrubbers developed by RCG/Hagler, Bailly, Inc. for EPA (RCG, 1989). The RCG costs follow Electric Power Research Institute (EPRI) costing guidelines and are based on data from EPRI, ICF, the Industrial Gas Cleaning Institute, and Peabody (RCG, 1989).

Several simplifying assumptions were made in developing the cost equations used for this analysis. An SO_2 removal efficiency of 80 percent and a fuel sulfur content of 2 percent are assumed. The capacity and energy penalties (resulting from the decrease in the effective capacity of the boiler and an increase in the heat rate) are assumed to be negligible. The resulting simplified cost equations for applying wet scrubbers to industrial boilers are listed below:

TPC=93.58*(500/CAPACITY)^0.33
CAPITAL=0.001561*CAPACITY*TPC+0.002089*CAPACITY
VARO&M=0.006828*CAPFAC*CAPACITY
FIXO&M=0.5357+0.000999*CAPACITY+0.00005398*CAPACITY*TPC
ANNCOST=CAPITAL*0.1098+VARO&M+FIXO&M

where:

TPC	=	total process capital (million 1990 dollars)
CAPACITY	=	unit capacity (MW)
CAPITAL	=	total capital cost (million 1990 dollars)
VARO&M	=	variable operating and maintenance costs (million 1990 dollars)
CAPFAC	=	capacity utilization factor (unitless)
FIXO&M	=	fixed operating and maintenance costs (million 1990 dollars)
ANNCOST	=	levelized total annual cost (million 1990 dollars)

Table III-27 presents scrubber cost estimates for a range of boiler sizes based on the above cost equations. A capacity utilization factor of 65 percent was assumed for all of these boilers.

Table III-27
Representative Scrubber Costs

Unit Capacity (MW)	Total Capital Cost (MM$)	Variable O&M Cost (MM$)	Fixed O&M Cost (MM$)	Levelized Total Annual Cost (MM$)
25	9.87	0.111	0.900	2.09
100	25.1	0.444	1.50	4.69
500	74.1	2.22	3.56	13.9

E. NO_x CONTROL MEASURES

Control measures for NO_x are based on information previously developed for use in ERCAM-NO_x (Pechan, 1994b). The control measures are listed in Table III-1. Control costs for several control techniques for utility boilers were updated based on more recent information (Acurex, 1995).

Cost equations for the capital and O&M costs for utility boilers were updated for the control technologies of natural gas reburn (NGR), selective non-catalytic reduction (SNCR), and selective catalytic reduction (SCR). Capital and O&M costs were available for boilers of 200 MW and of various fuel and firing types. NO_x control levels for these updated strategies range from a 40 to 90 percent NO_x reduction, dependent on boiler configuration. Average cost effectiveness values range from $900 per ton of NO_x removed for SCR control on wet bottomed, coal firing boilers to $2,000 per ton of NO_x removed for SCR control on oil firing boilers, both wet and dry bottomed.

Because cost data was not available for boilers of sizes other than 200 MW, it was necessary to estimate the capital cost of these boilers. Using the logarithmic relationship known as the *six-tenths-factor rule,* the capital cost of a unit is approximately $(X)^{0.6}$ times the cost of the 200 MW unit, where X indicates the capacity ratio of the new unit to the 200 MW unit. This relationship was utilized for capital cost estimation only and on units of sizes greater than 200 MW. Any unit of less than 200 MW capacity was assumed to have the same capital cost as a 200 MW boiler.

F. MOTOR VEHICLES

Control measures for reducing NO_x and VOC emissions from gasoline vehicles were previously developed for ozone-related analyses and are incorporated into ERCAM (Pechan, 1994b). Research focused on the development of measures for reducing PM and NO_x from diesel engines.

1. Background

Motor vehicle PM emission controls have focused primarily on diesel engines because gasoline-powered vehicles emit very little PM.

The first diesel particulate standards were established for LDVs and light-duty trucks (LDTs), effective beginning with the 1981 model year. A standard of 0.60 g/mi was established for both LDVs and LDTs, representing an achievable level for the (then) available technology. More stringent standards (at 0.26 for LDTs, and 0.20 for LDVs) were also promulgated effective beginning with the 1987 model year (EPA, 1993d).

Vehicles with a gross vehicle weight rating (GVWR) over $8,500 lbs are considered heavy-duty vehicles (HDVs). Heavy-duty engines are used in a wide range of HDV categories, from small utility vans to large trucks. Because the manufacturer of one type of heavy-duty engine may sell its engines to multiple vehicle manufacturers for use in different applications, EPA emission standards for HDVs are based on tests performed on the engine alone (and any associated aftertreatment devices). EPA introduced a heavy-duty engine PM standard for the 1988 model year. The initial standard was set initially at 0.60 g/bhp-hr, and was lowered to 0.25 g/bhp-hr with the 1991 model year.

The CAAA in Section 203 add new emission standards for conventional motor vehicles. First, Section 203(a) establishes PM standards for LDVs and LDTs of up to 6,000 lbs GVWR. The PM standards shown in Table III-28 below are effective with respect to model year 1994 and thereafter in the case of LDVs, and effective with respect to model year 1995 and thereafter in the case of LDTs of up to 6,000 lbs.

Table III-28
PM Standard for LDTs of up to 6,000 lbs GVWR

Useful Life Period	Standard
5/50,000[1]	0.08 gpm
10/100,000[2]	0.10 gpm

NOTES: [1]The applicable useful life, for purposes of certification under Section 206 and for purposes of in-use compliance under Section 207, shall be 5 years or 50,000 miles (or the equivalent), whichever occurs first, in the case of the 5/50,000 standard.

[2]The applicable useful life, for purposes of certification under Section 206 and for purposes of in-use compliance under Section 207, shall be 10 years or 100,000 miles (or the equivalent), whichever occurs first in the case of the 10/100,000 standard.

Implementation Standard for PM Standards
(in percent)

Model Year	LDVs	LDTs
1994	40	---
1995	80	40
1996	100	80
After 1996	100	100

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PM Emission Standards for Diesel-Fueled Light Duty Trucks of More Than 6,000 lbs GVWR

LDT Test Weight	(11 yrs/120,000 mi)
3,751-5,750 lbs test weight	0.10
Over 5,750 lbs test weight	0.12

For LDTs of more than 6,000 lbs GVWR, new PM standards begin with the 1996 model years. Fifty percent of the manufacturers sales volume are to comply with the new PM standards in model year 1996, and 100 percent thereafter.

For buses, Section 202 of the CAAA was amended by adding the following new subsection:

Model Years After 1990 - For model years prior to model year 1994, the regulations under Section 202(a) applicable to buses other than those subject to standards under Section 219 shall contain a standard which provides that emissions of PM from such buses may not exceed the standards set forth in Table III-29:

Table III-29
PM Standard for Buses

Model Year	Standard
1991	0.25
1992	0.25
1993 and Thereafter	0.10

NOTE: Standards are expressed in grams per brake horsepower hour (g/bhp-hr).

The other CAAA motor vehicle provision potentially affecting PM emissions is the sulfur content limit for diesel fuel. Effective October 1, 1993, motor vehicle diesel fuel was limited to a sulfur content of 0.05 percent by weight.

As EPA's PART5 model is being used to make emission projections to 2007, it includes the expected effects of the above emission standards and fuel regulations in the baseline Clean Air Act (CAA) emission projection.

2. Control Measures Evaluated

One of the control options available to reduce diesel particulate emissions is performing emissions inspections. The problem associated with quantifying the benefit of such a program is that the PART5 model assumes that all vehicles currently meet their emission standards. As with other regulated pollutants, it is likely that PM emissions control performance degrades as cars and trucks age and as their accumulated mileage increases. Therefore, some PM nonattainment areas have been investigating the options of: (a) including light-duty diesel powered cars and trucks in their emission inspection programs; and (b) performing separate testing of heavy-duty diesel truck or bus emissions.

a. Light-Duty Diesel Emission Inspections

In most States, I/M programs have exempted diesel vehicles from idle emission tests because their hydrocarbon (HC) and carbon monoxide (CO) emissions are typically low. With more recent interest in testing and repairing cars and light trucks to reduce their NO_x emissions (and PM), more States are including light-duty diesels in their I/M programs.

Maryland is experimenting with a pilot smoke test for diesels using a smoke meter. This test is performed by shining a light through the exhaust plume. The Society of Automotive Engineers is working on a recommended opacity test for diesel vehicles.

The State of Colorado has been performing opacity tests on diesels for the past 4 years (CAQCC, 1991). Beginning in 1995, Colorado was planning to use IM240 for their light-duty diesel testing. Connecticut is planning to test tailpipe emissions of light-duty diesels at some future point; the State is planning to use the IM240 procedure on 1985 and newer model year cars. However, with the recent potential changes to many State's enhanced I/M programs, many of these programs are on hold.

There are two issues that increase the cost associated with including light-duty diesels in a IM240 test program. A heated flame ionization detector is needed for HC testing because the heavier HCs emitted by diesels condense out. Thus, sample lines would have to be heated to 350 to 375°F. The other sampling issue for diesels is the need to filter out particulate, and the need for more frequent cleaning of sample lines. Having one lane available for diesel testing at each facility is probably the best method for incorporating diesel emission tests into an IM240 testing regime. However, IM240 testing itself will not examine PM emissions (only CO, HC, and NO_x are measured). Therefore, unless one of these pollutants is a good surrogate for PM, then IM240 testing is probably not a good option for obtaining cost effective reductions in PM emissions.

Thus, the primary way that most States would try to obtain further reductions in motor vehicle PM exhaust is through *opacity testing*. A cost can be estimated for the time and equipment needed to perform such a test. However, data on repair costs and associated emission improvements is not likely to be available.

b. Heavy-Duty Diesel Emission Inspections

As with other vehicle types, poor maintenance and/or tampering with emission controls can greatly increase PM emissions from HDDVs. Until now, diesel vehicles in most States have been exempt from any type of I/M. This results from the lack of a well-documented emissions test procedure for diesels, and uncertainty about the cost effectiveness of such a program. To address these issues, the California Air Resources Board (CARB) sponsored a study (Weaver et al., 1988) to quantify the extent of excess emissions from HDDVs due to malmaintenance and/or tampering; develop and validate suitable I/M procedures for heavy-duty diesel trucks and buses; and estimate the costs and emission benefits of implementing a heavy-duty diesel I/M program.

Two types of inspection procedures for HDDVs were evaluated: (1) a periodic I/M procedure; and (2) a roadside smoke opacity check. The periodic I/M procedure is intended to be used in an annual or biennial inspection program similar to the types of tests that are currently performed to examine CO and HC emissions from LDVs. The roadside smoke opacity check was designed as a random enforcement testing tool. This type of test would normally be performed at a truck weigh station.

The I/M program scenarios investigated in the CARB-sponsored study consisted of a number of variations on two basic approaches: a dynamometer-based periodic I/M program, and a program of in-use smoke opacity enforcement and random anti-tampering inspections.

Case 1, the basic periodic I/M scenario, consists of periodic, annual inspections enforced through the registration process. It assumes a decentralized, garage-based inspection program, using chassis dynamometer test procedures for smoke opacity and gaseous pollutant concentration in specific operating modes. In addition, an anti-tampering inspection and functional check of emission controls such as exhaust gas recirculation valves, trap-oxidizers, timing advance units, etc., is included. The basic scenario includes a $1,000 cost limit for repairs, with no cost limit for correcting tampering. Cost waivers require approval by a referee station.

Cases 1a through 1f consist of variations on this basic scenario. In Case 1a, the inspection is performed in central, State-operated inspection stations, rather than in truck garages. In Case 1b, the repair cost limit is reduced to $500. In Case 1c, the repair cost limit is eliminated — i.e., *fix it or park it.* In Case 1d, the gaseous pollutant concentration measurements are eliminated. Case 1e is a biennial inspection program. Case 1f, the final variation, reflects the legal constraints of the current Smog Check legislation in California. These include: biennial inspection, $100 cost limit, and a limit on the charge for a Smog Certificate of $6.

Case 2 is a very different I/M program, with in-use smoke opacity enforcement and anti-tampering inspections. This would include stationing Smoke Inspectors at highway patrol truck scales and inspection stations to maintain continuous visual screening for excessive smoke, and with the authority to pull a truck over for a smoke test and/or anti-tampering inspection. Trucks cited for excessive smoke would be required to be repaired and test below the standards within 2 weeks, unless they receive a cost waiver. The cost limit for repairs in the basic scenario is $1,000 (a variant, Case 2a, eliminates the cost limit). Smoke tests after repairs may be performed by authorized garages. Trucks cited for excessive smoke more than once in 6 months are subject to a $250 fine (except where the first citation resulted in a waiver). Tampering with emission controls, or knowingly operating a truck with tampered controls, is subject to a $1,000 fine for the first offense, and $2,500 fine for each subsequent occurrence. Tampering must be corrected within 2 weeks, with no cost limit.

In addition, inspectors would accompany highway patrol truck inspection teams to conduct anti-tampering inspections at the same time the highway patrol conducts safety inspections. At the same time, the existing truck smoke law would be tightened, and local police forces trained in enforcing it. Dedicated roving smoke patrol officers would be assigned in critical air pollution areas.

Analysis results showed that all of the annual inspection programs are reasonably effective in reducing excess NO_x, but they are less effective in reducing HC and PM emissions. The centralized program in Case 1a is marginally more effective in this regard, reflecting the greater probability of deterring or detecting tampering with the central inspection. All of these programs are hampered, however, by their relatively infrequent and predictable inspections, which limit the deterrence of *reversible* tampering and do relatively little to reduce the overall incidence of non-tampered high-emitting vehicles.

The in-use inspection programs, on the other hand, are highly effective in reducing particulate and HC emissions — resulting in more than a 50 percent reduction in excess PM. These programs are less effective in reducing NO_x, however, due to the inability to perform gaseous emissions measurements in the field.

Colorado's Regulation No. 12 seeks to reduce air pollution resulting from emissions by diesel-powered motor vehicles through opacity inspections by all diesel fleets registered or required to be registered in the program area with nine or more vehicles over 7,500 lbs empty weight. Annual opacity compliance tests are required, with fleets using one of the following two methods of evaluating smoke opacity:

1. A visual evaluation by a trained, certified smoke observer; or
2. Opacity meter evaluation of the exhaust stream by means of a portable full-flow light extinction opacity meter (the meter is to be attached to the exhaust piping).

For LDDVs (those weighing 7,500 lbs and less empty weight) a minimum expenditure of $750 must be made in an attempt to comply with smoke opacity standards (before a waiver can be granted). For HDDVs (greater than 7,500 lbs empty weight), a minimum expenditure of $1,500 must be made.

Colorado fees for diesel opacity inspections are not to exceed $45 for the initial inspection, and $35 for a reinspection (after a failure).

c. Reformulated Diesel

The State of California regulation establishes a 500 parts per million (ppm) sulfur limit as well as a 10 percent limit on aromatics (this limit is 20 percent for small refiners) for its vehicular diesel fuel. Diesel normally has about 30 percent aromatics. The rule contains an equivalency provision that allows refiners to make diesel with more than 10 percent aromatics if engine testing demonstrates equivalent emissions.

If other States adopt California reformulated diesel, associated sulfur emissions should be lowered by the ratio of post-control to pre-control sulfur content. If refiners simply meet the 500 ppm limit, there will be no reduction in sulfur emissions.

3. Recommended Cost Model Inputs

a. Measures

It is recommended that the primary highway vehicle exhaust emission control measure require that California reformulated diesel be sold. Applicable area source SCCs for this measure include 2230001110 through 2230070330. Pechan does not believe that it is appropriate to apply emission inspection benefits to the emission factors from the PART5 model, because PART5 assumes that PM emissions are at certification levels. I/M is beneficial in situations where vehicle emission control systems deteriorate with mileage. Therefore, if I/M is to be examined as a diesel PM control measure, excess emissions associated with poor emission control performance would have to be added to the 1990 baseline PM_{10} and $PM_{2.5}$ emissions.

Another highway vehicle control measure that was considered, but not included in the analysis, is retrofitting emission control devices on heavy-duty diesel buses. This will not be included in the control measure analysis because such a measure is likely to be applied as a local, rather than a regional, strategy.

b. Control Effectiveness

California reformulated diesel fuel will reduce motor vehicle-emitted PM, SO_2, and NO_x when compared with equivalent emission rates from diesel-powered vehicles fueled with low sulfur diesel that meets current Federal requirements.

Emission benefits of California reformulated diesel fuel are estimated using emission data presented in the CARB Technical Support Document (CARB, 1988). Because CARB's analysis was performed before the CAAA of 1990, the baseline for comparison at the time was a diesel fuel with a higher sulfur content than now exists. Motor vehicle diesel fuel now has a Federal limit of 0.05 percent sulfur. Therefore, the emission effects on California reformulated diesel fuel are computed from a 0.05 percent sulfur baseline.

CARB's analysis presents results of different diesel fuel formulations on PM and NO_x emissions. CARB concluded that testing performed by the Coordinating Research Council (CRC) was the most representative of expected benefits because it observed the full effects of both current and future prototype engines likely to be in service in the 1990s and beyond. CARB's analysis of the CRC data showed a 16.7 percent and a 10.3 percent reduction in PM emissions for two engine types when comparing a 31 versus a 10 percent aromatic HC content diesel fuel (both 0.05 percent sulfur). NO_x benefits were 5.75 and 12.5 percent, respectively.

Averaging the above results produces a 13.5 percent PM and a 9 percent NO_x benefit from California reformulated diesel.

c. Cost Equation

Control costs for California reformulated diesel are estimated to be 1 to 4 cents per gallon of diesel fuel above the cost of motor vehicle diesel fuel that meets the Federal EPA requirements that went into effect on October 1, 1993 (CARB, 1993).

d. Penetration Factor

A 100 percent penetration rate can be assumed, although there will be some long distance travel that is fueled with regular diesel.

G. NONROAD ENGINES

Nonroad engines are significant emitters of NO_x, PM, and VOC. Diesel engines account for most of the NO_x and PM emissions, while gasoline engines emit most of the VOC. EPA has already promulgated NO_x standards for large diesel engines and is considering more stringent standards as well as standards for other engine types.

1. Background

The court-ordered regulations on nonroad engine emissions are expected to limit the permissible level for emissions of HC, CO, NO_x, and in some cases smoke and PM. Nonroad emission sources that are expected to be Federally regulated include heavy duty compression ignition (CI) (diesel) engines, small spark ignition (SI) (gasoline) engines, marine engines, and locomotive engines.

Note that smoke is defined as that portion of the PM emissions that is visible. It is composed mostly of carbon, and is the large, visible PM (above 10 microns). Therefore, smoke standards would not necessarily limit PM emissions contributing to either PM_{10}, or $PM_{2.5}$ levels. Those strategies that are usually used to limit smoke emissions (e.g., leaner air/fuel ratio, advanced end of injection, better mixing, and better atomization) can be relied on to control PM as well, especially when applied to uncontrolled engines. As limits get lower and control strategies become more sophisticated, the correlation becomes weaker and smoke control is less likely to reduce PM.

The pollutants to be regulated for nonroad sources are those with the highest contributions to uncontrolled nonroad emissions. NO_x is the primary pollutant of concern from HDDEs, therefore, regulations will focus on limiting NO_x emissions from such sources. HC emissions are the pollutant of greatest concern from small gasoline and recreational marine engines emissions, therefore, regulations will primarily limit HC emissions. The effect of NO_x and HC emission controls on PM emissions is not well documented in the Regulatory Impact Analyses (RIAs) performed for the regulations. In most cases, unless a specific standard is set for PM emissions, the effect of Federally-mandated nonroad standards on PM emissions is assumed to be negligible. Nonroad engines affected by PM standards are:

- CI engines with an output at or above 130 kilowatts (kW);
- CI marine engines; and
- Locomotive engines.

A summary of the court-ordered nonroad emissions standards follows. With the exception of the heavy-duty CI engine rule, which was finalized in May of 1994 (59 FR31306, 1994), the nonroad standards summarized below are subject to change. Table III-30 presents a summary of the Federally-mandated nonroad regulations.

Many of the nonroad Federal standards set for PM are designed to cap emissions at their current level and eliminate the potential for PM emissions to increase as a result of NO_x controls. Of the Federal nonroad engine standards, only the Phase II locomotive engine standards are actually designed to result in PM emissions reduction. California standards are stricter than Federal standards for heavy-duty engines, greater than 130 kW, manufactured after the year 2001. Similarly, California standards for small gasoline-

Table III-30
Federal Regulations for Nonroad Engines

Engine Type	Engine Size (output)	Emission Standard or Percent Reduction	Implementation Date	Pollutant
Heavy-Duty CI-Diesel	> or = 37kW	9.2 g/kW-hr	1998	NO_x
Heavy-Duty CI-Diesel	> or = 37kW	20/15/50 A/L/P Percent	1998	Smoke
Heavy-Duty CI-Diesel	> or = 130kW	1.3 g/kW-hr	1996	HC
Heavy-Duty CI-Diesel	> or = 130kW	11.4 g/kW-hr	1996	CO
Heavy-Duty CI-Diesel	> or = 130kW	0.54 g/kW-hr	1996	PM
Small Spark Ignition (gasoline)	< = 19kW	Phase I 295, 241, 161 g/kW-hr for Classes* III, IV, V, resp.	1997	HC
Small Spark Ignition (gasoline)	< = 19kW	Phase I 402 or 805 g/kW-hr for Classes I, II, V or III and IV, resp.	1997	CO
Small Spark Ignition (gasoline)	< = 19kW	Phase I 5.36 g/kW-hr for Classes III, IV, and V	1997	NO_x
Small Spark Ignition (gasoline)	< = 19kW	Phase II Currently in Reg. Neg. (exhaust and evap) may parallel CA FIP	Not Available	(PM standards will not be set in Phase II**)
Marine - gasoline-powered/spark	Outboard and personal watercraft	75%	1998 9-year phase-in	HC
Marine - gasoline-powered/spark	Outboard and personal watercraft	400 g/kW-hr	1998	CO
Marine - gasoline-powered/spark	Outboard and personal watercraft	6.0 g/kW-hr	1998	NO_x
Marine - gasoline-powered/spark	Sterndrive and inboard	8.0 g/kW-hr	1998	HC
Marine - gasoline-powered/spark	Sterndrive and inboard	400 g/kW-hr	1998	CO
Marine - gasoline-powered/spark	Sterndrive and inboard	6.5 g/kW-hr	1998	NO_x
Marine - diesel	All diesel-powered marine engines	1.3 g/kW-hr	1999 for <560kw, 2000 for > or = 560kW	HC
Marine - diesel	All diesel-powered marine engines	11.4 g/kW-hr	1999 for <560kw, 2000 for > or = 560kW	CO
Marine - diesel	All diesel-powered marine engines	9.2 g/kW-hr	1999 for <560kw, 2000 for > or = 560kW	NO_x
Marine - diesel	All diesel-powered marine engines	0.54 g/kW-hr	1999 for <560kw, 2000 for > or = 560kW	PM
Marine - diesel	All diesel-powered marine engines	20/50 maximum percentage opacity	1999 for <560kw, 2000 for > or = 560kW	smoke

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Table III-30 (continued)

Engine Type	Engine Size (output)	Emission Standard or Percent Reduction	Implementation Date	Pollutant
Locomotives-Tier I	New and remanufactured engines	50 % reduction for new, 30 % for remanufactured	2000	NO_x
Locomotives-Tier I	New and remanufactured engines	No net increase	2000	HC
Locomotives-Tier I	New and remanufactured engines	No net increase	2000	CO
Locomotives-Tier I	New and remanufactured engines	No net increase	2000	PM
Locomotives-Tier I	New and remanufactured engines	No net increase	2000	Smoke
Locomotives-Tier II	New engines	60% from uncontrolled baseline	2005	NO_x
Locomotives-Tier II	New engines	50% from uncontrolled baseline	2005	PM

NOTE: *Classes for small gasoline nonroad engines are based on engine displacement and the type of equipment powered by the engines.

powered engines manufactured after the year 1999 are stricter than those planned by EPA.

2. Control Measures Evaluated

a. Heavy-Duty CI Engines

The heavy-duty diesel standards regulate NO_x emissions from nonroad CI engines at or above 37 kW (50 horsepower), and emissions of NO_x, HC, CO, PM for new engines at or above 130 kW (175 horsepower). Such engines are primarily used in agricultural, heavy construction, and industrial equipment; they have an average lifetime of 10 years (EPA, 1994b).

According to the RIA for emission standards applying to nonroad CI engines with an output greater than 37 kW and less than 130 kW, engine technology changes will not significantly impact PM emissions (EPA, 1994b). EPA is adopting the NO_x standard for nonroad CI engines at 9.2 g/KW-hr because it not only provides a substantial NO_x emission reduction, but also minimizes the risk of causing an in-use PM emission increase (EPA, 1994b). PM emission levels will not be entirely unaffected by the NO_x emission standard. PM emissions may increase slightly depending upon the control technology used to reduce NO_x formation. For example, if NO_x emissions are reduced through retarding injection timing, PM emissions will likely increase.

The agency is also establishing HC, CO, PM and smoke standards for nonroad CI engines at or above 130 kW. Heavy-duty diesel standards for PM are 0.54 g/kW-hr (0.4 g/bhp-hr) for engines with a power output at or above 130 kW (EPA, 1994b). These standards apply to nonroad engines manufactured after 1995. No PM emission reduction is being claimed as a result of this standard by EPA (North, 1995).

California PM emission standards for heavy-duty nonroad engines at or above 130 kW are the same as the Federal standards, 0.54 g/kW-hr, for engines manufactured between 1996 and 2000. The California PM standards become more stringent after 2001 for all newly manufactured engines at or above 130 kW and below 560 kW. Such engines are required to conform with a PM emissions limit of 0.21 g/kW-hr (0.16 g/bhp-hr) (CARB, 1994). This emission standard has an estimated cost effectiveness of $5,320 per ton PM reduced (Rowland, 1995).

Currently, EPA is assessing a potential diesel particulate national rule that would affect heavy-duty onroad and nonroad engines. No information was available regarding projected emission reductions or cost effectiveness. An advanced notice of proposed rulemaking should be issued in June 1995.

Nonroad diesel vehicle emissions can be reduced through the use of clean fuels. For this analysis reformulated diesel fuel was chosen as the control option. Reformulated diesel has been used successfully to reduce highway diesel emissions in California and is a viable option for nonroad vehicles. Regulatory requirements for reformulated diesel include a 500 ppm sulfur limit as well as a 10 percent limit on aromatics (this limit is 20 percent for small refineries). Diesel normally contains 30 percent aromatics. The rule contains an equivalency provision that allows refineries to make diesel with more than 10 percent aromatics if engine testing demonstrates equivalent emissions.

b. Small SI Engines

SI gasoline-powered small nonroad engines mainly represent lawn and garden equipment, but also include small farm, construction, and light industrial equipment types. The regulation sets standards in two phases for HC, CO, and NO_x emissions for new small gasoline engines with an output at or below 19 kW (25 horsepower) (EPA, 1994c). Phase I standards focus mainly on exhaust emissions, and are scheduled to become effective for engines manufactured after August 1, 1996. The proposed standards are based on engine class. Engine class is a function of the type of equipment powered by the engines and engine displacement (EPA, 1994c).

Phase II standards for small gasoline engines will cover exhaust and evaporative emissions. They are currently undergoing regulatory negotiation. Neither Phase I nor Phase II regulations will include a PM standard (Caffrey, 1995).

The SI standards are not predicted to have a significant effect on PM emissions (Caffrey, 1995). The main strategies outlined to comply with the SI regulations reduce the amount of gas and oil consumed by an engine. Since PM emissions are a function of the amount of uncombusted oil and gas, the SI regulations may have a slight minimizing effect on PM emissions. A conservative approach will be used for modeling purposes, which assumes that the nonroad SI regulations will have no effect on PM emission rates.

California nonroad PM standards for SI engines are 1.2 g/kW-hr (0.9 g/bhp-hr) for engines manufactured between 1995 and 1998. The PM standard tightens to 0.33 g/kW-hr (0.25 g/bhp-hr) for engines manufactured in 1999 and later. Hand-held equipment manufactured in 1999 and later will also be subject to a PM standard of 0.33 g/kW-hr (CARB, 1994).

c. Marine Engines

Emission standards have been proposed for all new gasoline (SI) and diesel (CI) marine engines. The proposed standards for gasoline engines will be in two groups: (1) outboard engines and personal watercraft; and (2) inboard and stern drive engines.

EPA has proposed HC, NO_x, and CO emission standards for gasoline-powered marine engines. Standards proposed for HC emissions would represent an emission reduction in HC emissions of approximately 75 percent (EPA, 1994d) for outboards and personal watercraft. The potential impact of this regulation on PM emissions can be assumed to be negligible according to EPA sources (Samulski, 1995). Since CO nonattainment episodes are primarily a wintertime phenomena and recreational boating occurs mainly during the summer months, CO reductions were not a primary focus of the rulemaking (EPA, 1994d). However, to meet the VOC standards in this rule, a modest reduction in CO emissions from marine engines is expected. The CO emission standard set in the rule is a cap, 400 g/kW-hr, meant to eliminate marine engines that emit excessive amounts.

EPA has proposed to amend the existing heavy-duty diesel regulations to include diesel-powered marine engines. EPA believes that marine CI engines are similar in design to currently regulated nonroad CI engines, therefore, emission standards and control technologies are expected to be reasonably applicable to marine CI engines. This proposed regulation would subject all marine diesel engines to the NO_x, HC, CO, PM and

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smoke standards that have been promulgated for land-based diesel engines with a power output of 130kW or more. The nonroad diesel engine standards would affect all engine sizes; however, two effective dates would be set based on engine size as follows: January 1999 for output below 560 kW; and January 2000 for output at or above 560 kW. The percentage reduction in emissions from diesel-powered marine vessels has not been estimated, though (Samulski, 1995).

d. Locomotive Engines

Tier I locomotive NO_x standards are scheduled to be implemented in January 2000 and will affect newly manufactured locomotive engines between the years 2000 and 2004 (EPA, 1995b). EPA also plans to regulate locomotive engine emissions for engines remanufactured after January 2000 at a level that will reduce NO_x emissions by 30 percent from uncontrolled levels (EPA, 1995b). Locomotive engines are typically rebuilt on a 5 to 7-year schedule. EPA expects to regulate emissions from remanufactured engines after January 1, 2000. Rebuild standards for engines originally built after this date will be the same as those that apply when the engine is originally manufactured, thus, ensuring that the locomotive engines continue to meet the emission levels they were designed to conform with throughout their lifecycle (EPA, 1995b).

Tier I standards are expected to reduce NO_x emissions from newly manufactured locomotive engines by 50 percent from uncontrolled levels. Locomotive engines have a life time of approximately 35 to 40 years (EPA, 1995b). NO_x controls implemented will likely increase PM emissions, however, EPA expects to set standards for HC, CO, PM, and smoke emissions as a component of Tier I standards for newly and re-manufactured engines. These standards will approximately equal present emission levels - constraining any increase in other pollutants as a result of the NO_x control technologies implemented (EPA, 1995b). Thus, no increase in PM emission rates should be assumed as a result of the Tier I locomotive engine emissions controls.

Tier II standards for locomotive engines will apply to engines manufactured after January 2005. Tier II standards for NO_x are scheduled to reduce emissions by an additional 30 percent from uncontrolled levels (EPA, 1995b). Tier II standards for PM will reduce emissions by approximately 50 percent from uncontrolled levels (EPA, 1995b).

e. Aircraft

No control methods for this source category were identified. This source category includes emissions only from aircraft engines during landing and takeoff cycles (Demmy et al, 1988). It is not known whether or not evaporative emissions are quantified under a separate source category. Regardless, this is a category that appears to be ripe for revision. The emission factors from fourth edition of AP-42 were developed from 1978 data. The weighted emission factors developed by Demmy et al (1988) were taken from 1980-1981 data from the Federal Aviation Administration and other sources. Revised emission factors can be found in the 1992 revision of Volume IV of AP-42. Also, it seems likely that the fleet mix of aircraft in 1990 may be significantly different than that used to develop the weighted emission factors (i.e., 1980-1981).

3. Recommended Cost Model Inputs

Applicable area source SCCs for nonroad engines/vehicles and penetration rates for measures are detailed in Section III of a 1994 report prepared by Pechan for OPPE (Pechan, 1994a).

For heavy-duty CI engines, the CAA baseline will include new Federal emission standards, but no change in PM emission rates are expected as a result. California PM emission standards are more stringent than Federal emission limits for this category, and can be modeled as a potential control measure. The California PM standard is 0.21 g/kW-hr, which compares with the Federal standard of 0.54 g/kW-hr. The California emission standard cost is $5,320 per ton PM reduced.

Reformulated diesel fuel was selected as the only control option beyond the CAA for developing cost inputs.

It is assumed that reformulated diesel fuel will reduce both directly emitted PM and NO_x. Since over 90 percent of PM emissions from diesel exhaust gases have aerodynamic diameters less than 2.5 microns, it is assumed that the reduction in PM_{10} and $PM_{2.5}$ are equivalent. For this analysis a control effectiveness of 13.5 percent was assumed for PM and 9 percent for NO_x. These values were derived by averaging the values published by both CARB and CRC.

Control costs for reformulated diesel are estimated to be 3 cents per gallon higher than diesel fuels which meet the Federal EPA requirements that went into effect on October 1, 1993. A cost per ton of NO_x reduced was developed since this is the primary pollutant controlled. In order to convert this cost to dollars per ton NO_x reduced, a brake horsepower specific emission rate of 6.9 grams NO_x per brake horsepower-hour was used. This basic emission rate is mandated under the CAA by the EPA for large diesel engines (>50 hp). The conversion from dollars per gallon to dollars per ton NO_x reduced assumed a diesel fuel density of 7.1 pounds per gallon and an average brake specific fuel economy of 0.4 lb per horsepower hour (EPA, 1991). When converting to dollars per ton NO_x reduced the costs associated with reformulated diesel fuel becomes $2470/ton NO_x reduced. Both penetration rate and rule effectiveness are assumed to 100 percent for this control option.

For small SI engines, because there are no PM limits in the new Federal standards, it is estimated that nonroad SI PM emission rates will not change in future years.

Similarly, marine engine PM emission rates are not expected to be significantly affected by new Federal standards.

For locomotive engines, PM emission rates are expected to remain unaffected by new emission standards until Tier II standards apply. These Tier II standards for newly manufactured locomotive engines provide a 50 percent reduction in PM emissions. However, because locomotive engines have a 35 to 40 year life, by 2007 only 5 percent of locomotive engines would be those that met a Tier II PM standard. With each Tier II engine having a 50 percent PM reduction, the estimated locomotive PM emission reduction is 2.5 percent from baseline emission rates.

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CHAPTER VI
OPTIMIZATION MODEL

This section discusses the calculation methodology used to derive the "optimal" solution, defined as achieving the level of emissions reduction to meet alternative ambient PM_{10} and $PM_{2.5}$ concentrations at the lowest possible cost. Because fractional components of the control technologies that can be applied to a source do not generally exist, and because "mixes" of the different technologies do not make sense, the problem cannot be solved by basic linear programming methods. Instead, the problem is a class of integer programming in which individual variables can be either 0 (no control) or 1 (control applied) with a further restriction that the sum of controls for each source must equal 0 or 1. In other words, a source either adds a control device or it does not. No partial control devices are allowed. This type of optimization model is referred to as an integer programming problem. The general form of the model is:

$$minimize \sum_{j=1}^{n} c_j x_j$$

subject to:

$$\sum_{j=1}^{n} a_{ij} x_j \leq b_i \; for \; i = 1,2,...,m$$

$$x_j \geq 0 \; for \; j = 1,2,...,n$$

$$x_j \; integer\text{-}valued \; for \; j = 1,2,...,p \; (\leq n)$$

When p=n, so that every variable must be integer-valued, the model is called a *pure* integer programming problem; otherwise, it is called a *mixed* integer programming problem (Wagner, 1969).

Generally, the steps in the optimization approach are:

(1) Develop control cost data for all sources and control levels.

(2) Sort control cost data and eliminate invalid or nonconvex options.

(3) Combine valid convex control options and sort in order of increasing marginal control cost per additional ton of emissions reduction.

(4) Select "optimum" control level and report results.

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This chapter will be completed when the air quality modeling task is completed and the optimization is deployed to examine regional PM control strategies. Model testing has been accomplished during the project period using the Phase I source-receptor matrix.

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APPENDIX A

Table A-1
United States 1990 NH_3 Emissions by EPA Region

Source Category		Region I	Region II	Region III	Region IV	Region V	Region VI	Region VII	Region VIII	Region IX	Region X	National Total
FUEL COMB. ELEC. UTIL.												
Coal		0	0	0	0	0	19	0	0	0	0	19
Oil		19	18	11	26	8	195	1	0	8	0	286
Gas		3	57	11	40	28	4,544	4	2	38	0	4,727
	Total	22	75	22	67	36	4,758	4	2	46	1	5,033
FUEL COMB. INDUSTRIAL												
Coal		0	1	2	4	6	2	1	1	0	0	18
Oil		294	574	322	832	385	1,088	54	89	528	127	4,292
Gas		105	270	610	1,091	1,671	4,280	397	317	3,516	703	12,960
	Total	399	845	934	1,926	2,062	5,370	452	407	4,045	830	17,271
FUEL COMB. OTHER												
Commercial/Institutional Coal		0	0	0	0	1	0	0	0	0	0	2
Commercial/Institutional Oil		375	637	324	369	184	181	39	50	153	72	2,384
Commercial/Institutional Gas		26	79	61	68	189	78	50	32	79	16	677
Residential Other		961	1,089	962	390	889	145	125	90	156	104	4,910
	Total	1,362	1,804	1,347	827	1,263	405	213	171	388	193	7,973
CHEMICAL & ALLIED PRODUCT MFG												
Agricultural Chemical Mfg		0	0	4,277	48,478	10,193	73,825	41,477	52	3,319	954	182,574
METALS PROCESSING												
Ferrous Metals Processing		0	43	1,154	338	4,060	0	9	288	0	0	5,893
PETROLEUM & RELATED INDUSTRIES												
Petroleum Refineries & Related Industries		0	0	2,176	1,498	8,689	19,195	934	1,739	8,007	607	42,845
OTHER INDUSTRIAL PROCESSES												
Agriculture, Food, & Kindred Products		0	0	0	0	0	0	0	0	0	2,079	2,079
Miscellaneous Industrial Processes		0	0	2	17	3,113	22,929	6,899	2	1,088	1,445	35,495
	Total	0	0	2	17	3,113	22,929	6,899	2	1,088	3,524	37,574
WASTE DISPOSAL & RECYCLING												
POTW		5,540	10,176	8,421	11,566	20,675	7,032	3,677	2,501	9,479	2,694	81,761
HIGHWAY VEHICLES												
Light-Duty Gas Vehicles & Motorcycles		8,433	13,159	16,352	32,633	30,416	20,513	8,413	5,238	24,203	6,254	165,614
Light-Duty Gas Trucks		1,599	2,438	3,218	6,480	5,942	4,009	1,712	1,065	4,470	1,240	32,173
Heavy-Duty Gas Vehicles		20	29	42	85	76	52	23	15	53	16	411
Diesels		13	19	29	59	53	35	16	10	35	11	281
	Total	10,065	15,645	19,640	39,258	36,488	24,609	10,165	6,327	28,761	7,522	198,479
NONROAD ENGINES AND EQUIPMENT												
Marine Vessels		11	69	117	170	31	365	20	0	285	71	1,139
Railroads		33	50	132	281	317	319	199	152	195	108	1,788
	Total	44	119	249	451	348	684	219	152	480	179	2,926
AGRICULTURE & FORESTRY												
Fertilizer Application		546	370	9,780	64,346	114,564	63,957	111,811	26,219	25,291	2,860	419,744
Animal Husbandry		19,180	42,705	182,814	569,190	715,635	730,941	953,362	616,848	232,103	155,947	4,218,725
TOTAL		37,157	71,783	230,816	737,961	917,128	953,703	1,129,223	654,711	307,822	175,067	5,215,370

Table A-2
United States 1990 NO_x Emissions by EPA Region (tons)

Source Category		Region I	Region II	Region III	Region IV	Region V	Region VI	Region VII	Region VIII	Region IX	Region X	National Total
FUEL COMB. ELEC. UTIL.												
Coal		66,724	130,382	846,588	1,464,738	1,964,368	842,255	582,874	580,980	173,863	36,714	6,689,486
Oil		49,019	62,854	18,207	50,211	4,049	1,246	159	133	5,644	44	191,566
Gas		12,524	47,984	5,822	50,290	6,915	316,621	6,005	1,479	38,444	568	486,652
Other		0	0	0	0	0	0	0	0	837	0	837
Internal Combustion		1,794	14,631	1,725	12,196	3,493	7,966	5,787	177	9,333	0	57,102
	Total	130,062	255,851	872,342	1,577,435	1,978,824	1,168,088	594,825	582,769	228,121	37,326	7,425,643
FUEL COMB. INDUSTRIAL												
Coal		4,732	31,920	83,245	145,057	216,226	55,357	22,330	31,141	7,477	12,941	610,425
Oil		20,527	28,008	18,210	46,391	52,302	88,351	3,007	5,937	11,077	14,056	287,867
Gas		11,007	23,232	91,565	164,141	178,658	853,194	79,591	103,544	82,948	19,126	1,607,004
Other		3,906	2,193	9,008	38,771	10,568	24,731	2,420	5,046	7,044	23,932	127,617
Internal Combustion		1,628	6	34,343	39,064	46,055	306,251	63,132	26,489	74,955	466	592,389
	Total	41,799	85,359	236,371	433,423	503,808	1,327,884	170,479	172,156	183,501	70,522	3,225,302
FUEL COMB. OTHER												
Commercial/Institutional Coal		1,067	2,341	7,023	4,316	17,721	265	2,975	2,372	118	868	39,067
Commercial/Institutional Oil		14,153	33,513	11,505	16,913	6,736	5,628	1,049	1,772	4,741	3,580	99,590
Commercial/Institutional Gas		5,476	18,958	13,481	14,502	46,953	18,473	10,417	10,644	13,780	5,254	157,938
Misc. Fuel Comb. (Except Residential)		1,204	141	624	852	1,553	3,496	38	417	11,537	319	20,182
Residential Wood		3,010	2,233	5,677	12,734	8,443	4,810	3,357	2,020	4,772	5,337	52,393
	Total	24,910	57,186	38,310	49,317	81,408	32,672	17,836	17,225	34,949	15,358	369,170
RESIDENTIAL COMBUSTION												
Distillate Oil		20,455	21,142	18,677	5,832	10,355	438	698	940	256	2,042	80,834
Natural Gas		10,569	30,385	26,239	26,573	87,545	25,641	19,147	9,830	28,742	2,665	267,336
Anthracite Coal		23	27	620	24	20		16				730
Bituminous/Subbituminous Coal		2	61	547	394	378	32	149	335		83	1,980
Residual Oil				65								65
Liquified Petroleum Gas										1,739		1,739
	Total	31,049	51,616	46,148	32,823	98,297	26,111	20,009	11,105	30,737	4,790	352,685
CHEMICAL & ALLIED PRODUCT MFG												
Organic Chemical Mfg		18	237	74	1,684	97	35,979	3,531	0	12	0	41,632
Inorganic Chemical Mfg		14	820	130	1,450	140	15,035	0	35	65	3	17,692
Polymer & Resin Mfg		5	8,034	84	11,078	79	4,209	0	0	12	0	23,500
Agricultural Chemical Mfg		0	151	966	30,663	9,999	47,798	31,499	5,985	455	25,942	153,457
Paint, Varnish, Lacquer, Enamel Mfg		0	0	0	0	59	0	0	0	9	0	68
Pharmaceutical Mfg		0	0	0	0	1	24	0	0	0	0	25
Other Chemical Mfg		0	5,186	12,860	12,519	2,795	3,737	215	0	1,055	615	38,981
	Total	37	14,427	14,114	57,394	13,170	106,782	35,245	6,020	1,607	26,560	275,356

Table A-2 (continued)

Source Category	Region I	Region II	Region III	Region IV	Region V	Region VI	Region VII	Region VIII	Region IX	Region X	National Total
METALS PROCESSING											
Non-Ferrous Metals Processing	0	1,497	297	5,744	1,399	2,502	1,400	1,528	744	364	15,475
Ferrous Metals Processing	0	1,411	9,844	7,727	22,534	4,956	48	6,522	34	281	53,358
Metals Processing NEC	0	196	2	11,658	297	282	10	0	91	102	12,637
Total	0	3,104	10,143	25,129	24,230	7,740	1,458	8,050	868	747	81,470
PETROLEUM & RELATED INDUSTRIES											
Oil & Gas Production	0	0	0	169	20	48,514	0	707	20,534	0	69,944
Petroleum Refineries & Related Industries	0	225	3,775	3,200	8,717	19,601	2,156	3,193	6,081	1,683	48,631
Asphalt Manufacturing	31	0	41	201	171	65	6	0	216	20	750
Total	31	225	3,816	3,570	8,909	68,179	2,162	3,900	26,831	1,703	119,325
OTHER INDUSTRIAL PROCESSES											
Agriculture, Food, & Kindred Products	546	921	91	379	1,646	97	73	395	54	338	4,540
Textiles, Leather, & Apparel Products	0	0	0	59	0	0	0	0	27	0	86
Wood, Pulp & Paper, & Publishing Products	1,114	351	3,040	45,336	2,204	16,451	26	1,334	1,876	6,714	78,447
Rubber & Miscellaneous Plastic Products	0	0	0	6	5	34	0	0	4	1	50
Machinery Products	149	2	33	45	1,366	0	0	0	58	0	1,653
Electronic Equipment	0	0	0	0	0	0	0	0	0	0	0
Transportation Equipment	0	0	0	0	0	0	0	0	0	0	1
Miscellaneous Industrial Processes	82	2,528	602	625	553	1,344	317	262	146	12	6,471
Total	1,890	3,802	3,766	46,450	5,774	17,927	417	1,990	2,165	7,066	91,246
MINERAL PRODUCTS											
Cement Manufacturing	0	0	12,852	16,405	14,410	39,707	11,628	5,553	18,648	1,557	120,759
Glass Manufacturing	509	1,726	11,522	4,010	7,966	6,533	522	435	5,563	1,332	40,118
Miscellaneous	64	261	6,105	13,382	8,777	3,586	9,551	3,744	3,711	2,583	51,764
Total	573	1,987	30,478	33,796	31,153	49,826	21,701	9,732	27,922	5,472	212,641
SOLVENT UTILIZATION											
Degreasing	0	1	0	0	45	0	0	0	3	0	48
Graphic Arts	4	1	3	30	229	12	4	0	7	0	290
Dry Cleaning	0	0	0	0	0	0	0	0	1	0	1
Surface Coating	1	4	1,773	194	106	27	18	0	15	0	2,137
Other Industrial	0	0	0	12	0	2	0	0	8	0	23
Nonindustrial	0	0	0	0	0	0	0	0	13	0	13
Solvent Utilization NEC	0	0	0	0	0	0	0	0	0	0	0
Total	5	6	1,776	236	381	41	22	0	46	0	2,512
STORAGE & TRANSPORT											
Bulk Terminals & Plants	0	0	0	0	0	0	0	0	3	0	3
Petroleum & Petroleum Product Storage	0	0	0	4	0	1,046	0	5	1	0	1,056
Petroleum & Petroleum Product Transport	0	0	0	0	0	47	0	0	3	108	158
Service Stations: Stage I	0	0	0	0	0	0	0	0	0	0	0
Service Stations: Stage II	0	0	0	0	0	0	0	0	0	0	0
Service Stations: Breathing & Emptying	0	0	0	0	0	0	0	0	0	0	0

Table A-2 (continued)

Source Category		Region I	Region II	Region III	Region IV	Region V	Region VI	Region VII	Region VIII	Region IX	Region X	National Total
Organic Chemical Storage		0	0	0	0	0	511	0	0	0	0	511
Organic Chemical Transport		0	0	0	0	0	0	0	0	0	0	0
Inorganic Chemical Storage		0	82	0	45	0	8	11	0	9	0	155
Inorganic Chemical Transport		0	0	0	0	0	0	0	0	0	0	0
Bulk Materials Storage		0	0	0	35	0	0	0	0	510	0	545
Bulk Materials Transport		0	0	0	0	0	0	0	0	0	0	0
	Total	0	82	0	84	0	1,613	11	5	525	108	2,428
WASTE DISPOSAL & RECYCLING												
Incineration		2,946	7,622	4,003	2,79	7,142	4,305	1,093	433	419	976	31,733
Open Burning		2,362	3,173	5,750	12,800	10,741	5,652	3,659	1,774	1,550	1,266	48,727
POTW		0	0	0	0	0	0	0	0	4	0	4
Industrial Waste Water		0	0	0	0	0	0	0	0	0	0	0
TSDF		0	0	0	0	0	0	0	0	0	0	0
Landfills		0	0	0	0	0	0	0	0	132	0	132
Other		0	0	0	0	45	0	3	0	5	0	53
	Total	5,308	10,795	9,753	15,594	17,928	9,957	4,755	2,207	2,110	2,242	80,648
HIGHWAY VEHICLES												
Light-Duty Gas Vehicles & Motorcycles		183,679	269,520	349,045	669,017	671,204	416,981	186,681	115,841	417,191	138,551	3,417,710
Light-Duty Gas Trucks		69,298	99,676	137,877	267,802	262,397	164,708	76,079	45,991	154,350	54,778	1,332,957
Heavy-Duty Gas Vehicles		16,645	23,603	34,718	67,938	64,297	40,391	19,653	10,337	41,716	13,809	333,107
Diesels		110,901	160,964	242,610	500,801	442,710	297,890	137,231	85,388	288,507	94,803	2,361,806
	Total	380,523	553,763	764,250	1,505,557	1,440,608	919,971	419,644	257,558	901,763	301,941	7,445,579
NONROAD ENGINES & EQUIPMENT												
Non-Road Gasoline		5,190	10,990	11,508	22,568	25,610	16,704	6,698	4,057	62,037	10,674	176,035
Non-Road Diesel		51,850	94,681	136,611	291,793	221,838	262,794	71,022	48,578	215,303	43,915	1,438,383
Aircraft		6,707	9,325	10,662	33,812	18,046	21,201	5,141	7,344	22,335	5,114	139,688
Marine Vessels		2,390	8,461	17,374	33,194	7,276	59,077	4,701	0	42,881	8,362	183,716
Railroads		17,312	25,868	68,796	146,139	164,827	165,976	103,647	78,805	87,941	38,658	897,969
	Total	83,448	149,325	244,951	527,505	437,597	525,751	191,209	138,783	430,497	106,725	2,835,791
MISCELLANEOUS												
Other Combustion		561	1,147	2,899	88,842	5,318	26,322	12,297	23,378	32,606	30,685	224,056
NEC		0	0	0	0	0	0	0	0	8,772	0	224,056
	Total	561	1,147	2,899	88,842	5,318	26,322	12,297	23,378	41,378	30,685	448,113
TOTAL		700,196	1,188,673	2,279,118	4,397,157	4,647,404	4,288,862	1,492,071	1,234,879	1,913,021	611,244	22,967,908

Table A-3
United States 1990 SO_x Emissions by EPA Region

Source Category		Region I	Region II	Region III	Region IV	Region V	Region VI	Region VII	Region VIII	Region IX	Region X	National Total
FUEL COMB. ELEC. UTIL.												
Coal		155,937	340,851	2,618,768	4,200,380	5,387,965	799,557	1,105,921	379,192	174,598	58,723	15,221,892
Oil		210,447	152,989	53,814	174,711	8,444	2,071	621	133	7,660	84	610,975
Gas		18	79	7	67	9	426	10	2	155	2	774
Other		0	0	0	0	0	0	0	0	123	0	123
Internal Combustion		629	26,869	289	1,408	1,071	98	37	9	332	0	30,742
	Total	367,030	520,788	2,672,878	4,376,566	5,397,489	802,152	1,106,588	379,336	182,868	58,810	15,864,506
FUEL COMB. INDUSTRIAL												
Coal		6,360	85,388	239,361	330,158	847,894	133,495	129,828	46,394	3,886	19,900	1,842,663
Oil		84,266	63,797	58,376	197,905	115,630	208,102	10,481	31,279	15,675	48,522	834,033
Gas		26	5,430	10,328	19,927	50,276	196,800	3,881	55,691	4,684	3,910	350,954
Other		487	2,690	13,894	15,253	6,633	22,312	6,266	3,446	2,421	1,336	74,738
Internal Combustion		466	0	5	474	85	4,616	30	123	733	0	6,530
	Total	91,605	157,305	321,965	563,716	1,020,517	565,325	150,486	136,932	27,398	73,668	3,108,917
FUEL COMB. OTHER												
Commercial/Institutional Coal		2,471	9,613	27,464	14,322	91,021	883	24,251	4,856	41	1,564	176,484
Commercial/Institutional Oil		32,514	54,789	27,904	63,738	14,250	17,056	1,838	5,477	2,314	13,867	233,746
Commercial/Institutional Gas		33	442	70	76	377	98	186	48	213	211	1,754
Misc. Fuel Comb. (Except Residential)		67	10	48	160	117	83	8	162	907	50	1,611
Residential Wood		429	318	809	1,816	1,204	686	479	288	423	778	7,230
	Total	35,514	65,172	56,294	80,112	106,969	18,805	26,761	10,831	3,897	16,470	420,825
RESIDENTIAL COMBUSTION												
Anthracite Coal		217	255	5,647	221	230		142				6,711
Bituminous/Subbituminous Coal		15	844	7,773	5,037	8,476	782	3,746	2,237		659	29,569
Distillate Oil		32,713	33,734	34,325	9,311	16,524	905	1,114	1,682	618	3,416	134,340
Residual Oil				526								526
Natural Gas		64	182	156	152	519	151	117	58	162	15	1,575
Liquified Petroleum Gas										366		366
	Total	33,009	35,014	48,427	14,720	25,748	1,838	5,119	3,977	1,147	4,089	173,087
CHEMICAL & ALLIED PRODUCT MFG												
Organic Chemical Mfg		10	18	9	1,709	19	9,083	2,226	4,022	4	0	17,100
Inorganic Chemical Mfg		305	5,891	10,941	77,497	32,140	136,747	2,190	15,491	41,901	8,517	331,620
Polymer & Resin Mfg		0	16	0	4,367	78	2,376	0	0	0	0	6,836
Agricultural Chemical Mfg		0	0	22	2,109	6	1,246	406	0	4	2	3,793

Table A-3 (continued)

Source Category		Region I	Region II	Region III	Region IV	Region V	Region VI	Region VII	Region VIII	Region IX	Region X	National Total
Paint, Varnish, Lacquer, Enamel Mfg		0	0	0	0	0	0	0	0	0	0	0
Pharmaceutical Mfg		1	0	0	217	10	0	0	0	0	0	228
Other Chemical Mfg		0	785	7,286	8,415	15,559	39,012	4	0	1,876	7,550	80,487
	Total	316	6,710	18,257	94,312	47,812	188,464	4,826	19,514	43,785	16,069	440,064
METALS PROCESSING												
Non-Ferrous Metals Processing		0	157	8,549	28,149	18,450	172,777	63,529	36,409	386,180	14,980	729,180
Ferrous Metals Processing		5	3,789	62,164	14,268	67,927	6,284	616	3,564	8	1,386	160,010
Metals Processing NEC		0	170	111	1,147	245	3,158	0	39	26	15,834	20,730
	Total	5	4,116	70,824	43,563	86,623	182,219	64,144	40,011	386,215	32,200	909,920
PETROLEUM & RELATED INDUSTRIES												
Oil & Gas Production		0	55	0	45,901	112	112,460	0	5,129	1,516	0	165,174
Petroleum Refineries & Related Industries		0	5,325	33,265	26,524	80,210	78,647	9,422	8,969	22,696	4,756	269,813
Asphalt Manufacturing		68	0	108	282	151	319	59	0	183	68	1,238
	Total	68	5,380	33,373	72,707	80,473	191,426	9,481	14,099	24,395	4,824	436,225
OTHER INDUSTRIAL PROCESSES												
Agriculture, Food, & Kindred Products		23	3	261	195	1,644	14	135	851	341	56	3,523
Textiles, Leather, & Apparel Products		0	1	0	0	0	0	0	0	0	0	1
Wood, Pulp & Paper, & Publishing Products		4,330	265	11,072	76,697	6,004	24,153	1	374	2,640	8,481	134,017
Rubber & Miscellaneous Plastic Products		0	1	0	0	0	6	828	0	0	0	835
Machinery Products		29	1	0	23	203	0	0	0	4	0	259
Electronic Equipment		0	311	0	0	0	0	0	0	0	0	311
Transportation Equipment		0	0	0	0	0	0	0	0	0	0	0
Miscellaneous Industrial Processes		7	947	435	157	274	271	149	176	16	14	2,446
	Total	4,389	1,529	11,768	77,072	8,124	24,443	1,114	1,402	3,001	8,551	141,392
MINERAL PRODUCTS												
Cement Manufacturing		0	1	26,833	19,503	27,581	37,225	45,372	4,207	2,369	3,596	166,687
Glass Manufacturing		487	1,050	5,600	2,842	4,997	1,659	458	239	2,121	636	20,089
Miscellaneous		257	344	10,532	25,087	11,695	9,867	3,781	388	1,595	2,996	66,542
	Total	743	1,396	42,965	47,432	44,274	48,751	49,610	4,834	6,085	7,228	253,318
SOLVENT UTILIZATION												
Degreasing		0	0	0	0	31	0	0	0	0	0	31
Graphic Arts		0	0	0	0	3	0	0	0	0	0	3
Dry Cleaning		0	0	0	0	0	0	0	0	0	0	0
Surface Coating		1	0	667	11	26	46	2	0	1	0	754
Other Industrial		0	0	0	49	0	0	0	0	2	0	51
Nonindustrial		0	0	0	0	0	0	0	0	0	0	0
Solvent Utilization NEC		0	0	0	0	0	0	0	0	0	0	0
	Total	1	0	667	60	60	46	2	0	3	0	840

Table A-3 (continued)

Source Category		Region I	Region II	Region III	Region IV	Region V	Region VI	Region VII	Region VIII	Region IX	Region X	National Total
STORAGE & TRANSPORT												
Bulk Terminals & Plants		0	0	0	0	0	0	0	0	0	0	0
Petroleum & Petroleum Product Storage		0	0	0	4	136	95	0	38	0	0	272
Petroleum & Petroleum Product Transport		0	0	0	0	0	1,128	0	0	0	248	1,376
Service Stations: Stage I		0	0	0	0	0	0	0	0	0	0	0
Service Stations: Stage II		0	0	0	0	0	0	0	0	0	0	0
Service Stations: Breathing & Emptying		0	0	0	0	0	0	0	0	0	0	0
Organic Chemical Storage		0	0	0	0	0	740	0	0	0	0	740
Organic Chemical Transport		0	0	0	0	0	0	0	0	0	0	0
Inorganic Chemical Storage		0	7	13	318	0	0	0	0	0	0	337
Inorganic Chemical Transport		0	0	0	0	1	0	0	0	0	0	1
Bulk Materials Storage		0	0	0	181	516	0	0	0	1,158	0	1,855
Bulk Materials Transport		0	0	0	0	0	0	0	0	0	0	0
	Total	0	7	13	502	653	1,963	0	38	1,158	248	4,581
WASTE DISPOSAL & RECYCLING												
Incineration		3,011	5,852	3,143	2,037	3,892	9,020	688	209	132	325	28,308
Open Burning		343	460	836	1,856	1,557	754	534	243	284	183	7,048
POTW		0	0	0	0	0	0	0	0	6	0	6
Landfills		0	0	0	0	0	0	0	0	19	0	19
Other		0	0	0	0	1	319	42	0	1	0	362
	Total	3,354	6,311	3,980	3,893	5,450	10,093	1,263	452	441	508	35,743
HIGHWAY VEHICLES												
Light-Duty Gas Vehicles & Motorcycles		7,296	11,393	14,145	28,236	26,316	17,741	7,269	4,526	20,942	5,408	143,272
Light-Duty Gas Trucks		2,888	4,402	5,813	11,712	10,736	7,243	3,094	1,924	8,073	2,240	58,125
Heavy-Duty Gas Vehicles		516	757	1,099	2,241	2,007	1,355	612	380	1,381	428	10,776
Diesels		16,651	23,823	36,648	75,326	66,553	44,925	20,957	13,017	43,281	14,356	355,537
	Total	27,352	40,376	57,704	117,514	105,613	71,264	31,932	19,847	73,677	22,432	567,710
NONROAD ENGINES & EQUIPMENT												
Non-Road Gasoline		0	0	0	0	0	0	0	0	2,808	405	3,213
Non-Road Diesel		0	0	0	0	0	0	0	0	15,702	1,035	16,737
Aircraft		340	474	550	1,792	914	1,132	260	380	1,824	361	8,026
Marine Vessels		614	14,460	19,576	16,193	5,765	53,451	658	0	27,812	8,931	147,460
Railroads		1,262	1,885	5,014	10,651	12,011	12,096	7,553	5,745	6,402	4,014	66,632
	Total	2,216	16,819	25,140	28,636	18,690	66,679	8,470	6,125	54,548	14,746	242,067

Table A-3 (continued)

Source Category		Region I	Region II	Region III	Region IV	Region V	Region VI	Region VII	Region VIII	Region IX	Region X	National Total
MISCELLANEOUS												
Other Combustion		7	17	84	3,151	162	647	445	337	655	684	6,188
Fugitive Dust		0	0	0	0	0	0	0	0	2	0	2
NEC		0	0	0	0	0	0	0	0	767	0	767
	Total	7	17	84	3,151	162	647	445	337	1,424	684	6,190
TOTAL		565,608	860,939	3,364,338	5,523,955	6,948,656	2,174,114	1,460,241	637,734	810,042	260,526	22,606,153

Table A-4
United States 1990 PM_{10} and $PM_{2.5}$ Emissions by Region

Source Category		Region I		Region II		Region III		Region IV		Region V		Region VI	
		PM-10	PM-2.5	PM-10	PM-2.5	PM-10	PM-2.5	PM-10	PM-2.5	PM-10	PM-2.5	PM-10	PM-2.5
FUEL COMB. ELEC. UTIL.													
Coal		2,301	850	3,237	1,303	40,140	12,326	78,243	21,219	44,870	19,258	56,789	28,877
Oil		2,134	1,216	2,293	1,294	1,073	614	3,177	1,798	117	73	45	30
Gas		16	2	124	12	22	8	167	54	56	47	508	74
Other		0	0	0	0	0	0	0	0	0	0	0	0
Internal Combustion		0	0	1,815	1,811	68	67	537	534	87	87	338	328
	Total	4,451	2,068	7,468	4,420	41,302	13,014	82,125	23,605	45,130	19,464	57,681	29,310
FUEL COMB. INDUSTRIAL													
Coal		416	212	8,054	2,125	5,853	2,872	14,037	6,392	23,063	8,486	9,452	5,341
Oil		3,833	2,640	5,513	3,611	2,972	1,857	10,426	6,344	5,286	2,744	10,505	4,726
Gas		81	76	1,565	1,518	1,792	1,733	4,505	4,390	6,838	6,686	22,241	21,520
Other		2,171	1,596	630	508	1,993	1,595	29,287	25,079	2,162	1,691	20,972	16,126
Internal Combustion		1	0	0	0	111	98	162	137	70	55	1,668	1,560
	Total	6,501	4,525	15,762	7,763	12,720	8,155	58,417	42,342	37,419	19,662	64,838	49,273
FUEL COMB. OTHER													
Commercial/Institutional Coal		155	67	3,660	646	2,727	1,175	1,104	597	3,957	1,656	96	46
Commercial/Institutional Oil		1,583	615	3,550	1,498	1,258	566	2,706	1,017	649	254	582	218
Commercial/Institutional Gas		148	140	644	617	355	333	401	377	1,257	1,190	608	573
Misc. Fuel Comb. (Except Residential)		415	382	21	18	135	114	498	457	151	140	485	435
Residential Wood		32,898	32,898	24,404	24,404	62,050	62,050	139,185	139,185	92,287	92,287	52,577	52,577
Residential Other		2,120	962	2,819	1,544	4,337	2,111	1,716	1,065	3,848	2,851	807	717
	Total	37,320	35,064	35,099	28,728	70,862	66,350	145,609	142,698	102,148	98,377	55,155	54,566
CHEMICAL & ALLIED PRODUCT MFG													
Organic Chemical Mfg		10	9	32	30	1,508	736	661	573	158	74	2,595	1,510
Inorganic Chemical Mfg		0	0	251	214	932	587	1,889	1,432	2,034	1,694	2,179	1,571
Polymer & Resin Mfg		10	10	123	116	536	439	535	442	1,001	840	2,289	1,977
Agricultural Chemical Mfg		0	0	14	12	102	93	3,066	2,764	961	812	3,263	2,671
Paint, Varnish, Lacquer, Enamel Mfg		0	0	0	0	41	14	90	34	147	56	0	0
Pharmaceutical Mfg		15	14	0	0	138	115	0	0	6	5	15	13
Other Chemical Mfg		0	0	237	213	1,793	1,629	4,125	3,676	1,698	1,519	4,192	3,769
	Total	35	33	657	585	5,050	3,613	10,366	8,921	6,005	5,001	14,534	11,511

Table A-4 (continued)

Source Category	Region I		Region II		Region III		Region IV		Region V		Region VI	
	PM-10	PM-2.5	PM-10	PM-2.5	PM-10	PM-2.5	PM-10	PM-2.5	PM-10	PM-2.5	PM-10	PM-2.5
METALS PROCESSING												
Non-Ferrous Metals Processing	0	0	2,083	915	2,788	2,096	9,882	5,694	2,509	1,833	18,431	10,944
Ferrous Metals Processing	4	4	732	566	14,829	11,502	8,114	6,561	57,719	40,837	3,048	2,278
Metals Processing NEC	0	0	345	311	20	14	1,087	655	1,910	1,665	909	722
Total	4	4	3,160	1,792	17,638	13,612	19,082	12,910	62,138	44,335	22,388	13,945
PETROLEUM & RELATED INDUSTRIES												
Oil & Gas Production	0	0	0	0	0	0	1	1	0	0	214	150
Petroleum Refineries & Related Industries	0	0	100	96	2,030	1,687	1,580	1,142	3,883	2,649	10,771	7,565
Asphalt Manufacturing	0	0	0	0	160	66	550	344	1,063	705	829	426
Total	0	0	100	96	2,190	1,754	2,130	1,487	4,947	3,354	11,814	8,141
OTHER INDUSTRIAL PROCESSES												
Agriculture, Food, & Kindred Products	26	10	389	248	395	265	2,432	1,334	15,003	8,068	4,669	2,514
Textiles, Leather, & Apparel Products	0	0	15	8	59	56	379	326	0	0	14	13
Wood, Pulp & Paper, & Publishing Products	2,927	2,423	363	277	5,725	4,710	56,647	45,307	7,728	6,296	21,711	17,193
Rubber & Miscellaneous Plastic Products	16	15	311	260	113	104	2,513	2,132	1,035	904	273	229
Mineral Products	261	187	797	411	33,068	20,727	52,231	26,343	45,373	23,228	32,505	17,870
Machinery Products	0	0	102	94	54	19	202	79	325	159	797	270
Electronic Equipment	0	0	653	316	144	75	0	0	0	0	0	0
Transportation Equipment	0	0	20	18	0	0	0	0	63	35	32	20
Miscellaneous Industrial Processes	150	104	4,479	1,980	2,246	1,556	3,172	2,035	3,955	2,546	2,146	1,481
Total	3,380	2,739	7,130	3,612	41,804	27,513	117,575	77,556	73,482	41,235	62,146	39,590
SOLVENT UTILIZATION												
Degreasing	0	0	17	17	0	0	0	0	2	2	4	3
Graphic Arts	0	0	1	1	120	99	0	0	54	51	0	0
Dry Cleaning	0	0	3	2	0	0	0	0	0	0	0	0
Surface Coating	12	12	29	25	59	51	583	513	372	323	518	438
Other Industrial	0	0	0	0	2	2	123	102	17	14	0	0
Total	12	12	50	45	181	152	706	615	446	390	522	441
STORAGE & TRANSPORT												
Bulk Terminals & Plants	0	0	18	15	0	0	0	0	0	0	0	0
Petroleum & Petroleum Product Storage	0	0	2	2	0	0	8	6	7	6	8	6
Petroleum & Petroleum Product Transport	0	0	0	0	0	0	0	0	0	0	5	4
Organic Chemical Storage	0	0	61	51	9	7	121	107	207	154	626	527
Organic Chemical Transport	0	0	0	0	0	0	0	0	0	0	54	45
Inorganic Chemical Storage	0	0	3	3	2	2	51	48	262	103	109	48
Inorganic Chemical Transport	0	0	0	0	0	0	0	0	0	0	0	0

Table A-4 (continued)

Source Category		Region I		Region II		Region III		Region IV		Region V		Region VI	
		PM-10	PM-2.5	PM-10	PM-2.5	PM-10	PM-2.5	PM-10	PM-2.5	PM-10	PM-2.5	PM-10	PM-2.5
Bulk Materials Storage		0	0	64	28	10,722	4,033	4,327	1,981	23,200	9,482	5,582	2,092
Bulk Materials Transport		0	0	0	0	0	0	0	0	40	3	0	0
	Total	0	0	149	98	10,733	4,042	4,506	2,142	23,716	9,746	6,384	2,722
WASTE DISPOSAL & RECYCLING													
Incineration		2,514	1,742	4,880	3,393	2,051	1,569	3,896	2,821	13,678	9,483	3,133	2,212
Open Burning		9,118	8,289	12,187	11,079	22,247	20,225	49,143	44,675	41,253	37,503	20,147	18,330
Industrial Waste Water		0	0	0	0	0	0	0	0	0	0	11	9
TSDF		0	0	0	0	0	0	0	0	0	0	0	0
Landfills		0	0	0	0	0	0	0	0	0	0	0	0
Other		0	0	0	0	0	0	0	0	13	11	105	98
	Total	11,632	10,030	17,067	14,473	24,297	21,794	53,039	47,497	54,944	46,997	23,398	20,649
HIGHWAY VEHICLES													
Light-Duty Gas Vehicles & Motorcycles		3,230	1,966	5,029	3,045	6,268	3,792	12,498	7,484	11,650	7,018	7,858	4,739
Light-Duty Gas Trucks		1,593	1,038	2,424	1,576	3,211	2,088	6,474	4,196	5,931	3,850	4,004	2,601
Heavy-Duty Gas Vehicles		507	334	744	490	1,079	711	2,201	1,451	1,971	1,299	1,331	877
Diesels		11,660	10,549	16,758	15,161	25,596	23,158	52,632	47,621	46,532	42,101	31,386	28,397
	Total	16,990	13,888	24,954	20,272	36,154	29,750	73,806	60,752	66,084	54,269	44,578	36,613
OFF-HIGHWAY													
Non-Road Gasoline		1,687	1,414	2,172	1,821	3,248	2,723	10,382	8,703	7,540	6,326	8,364	7,008
Non-Road Diesel		5,986	5,507	13,881	12,771	18,780	17,278	36,946	33,991	30,259	27,838	41,109	37,820
Aircraft		873	616	1,250	882	2,506	1,767	14,941	10,537	2,123	1,497	9,492	6,694
Marine Vessels		265	236	1,308	851	2,381	1,735	3,910	3,287	3,668	1,952	7,700	5,882
Railroads		876	806	1,309	1,204	3,482	3,203	7,396	6,805	8,342	7,675	8,400	7,728
	Total	9,686	8,578	19,921	17,529	30,397	26,706	73,576	63,323	51,931	45,288	75,065	65,131
OTHER COMBUSTION													
Wildfires		602	548	319	290	2,856	2,597	34,909	31,735	13,903	12,639	18,681	16,540
Agricultural Burning		299	272	0	0	75	68	29,641	26,946	0	0	26,998	24,544
Prescribed Burning		0	0	1,293	1,095	4,149	3,516	224,392	190,163	105	89	44,159	37,423
Structural Fires		3,554	3,231	7,454	6,776	6,817	6,197	9,533	8,666	12,028	10,934	5,943	5,403
	Total	4,455	4,050	9,066	8,162	13,897	12,378	298,475	257,512	26,036	23,663	95,781	83,909
FUGITIVE DUST - NATURAL SOURCES													
Wind Erosion - Agricultural Land		52,703	21,081	403	161	2	1	1,147	459	178,304	71,322	2,990,045	1,196,018
FUGITIVE DUST - AGRICULTURE													
Agricultural Crops		20,355	9,689	80,408	38,274	179,487	85,436	556,726	265,002	1,685,903	802,490	1,000,794	476,378
Agricultural Livestock		11,438	5,447	26,020	12,390	36,895	17,569	169,751	80,834	426	203	67,826	32,298
	Total	31,793	15,136	106,428	50,665	216,381	103,005	726,477	345,835	1,686,329	802,693	1,068,620	508,676

Table A-4 (continued)

Source Category		Region I		Region II		Region III		Region IV		Region V		Region VI	
		PM-10	PM-2.5	PM-10	PM-2.5	PM-10	PM-2.5	PM-10	PM-2.5	PM-10	PM-2.5	PM-10	PM-2.5
FUGITIVE DUST - OTHER													
Wind Erosion (Non Agricultural Land)													
Paved Roads		257,062	107,994	336,641	140,693	526,754	221,778	1,247,365	527,955	1,026,705	434,450	826,773	350,396
Unpaved Roads		260,396	68,598	221,852	58,508	465,391	122,633	1,733,151	457,166	1,659,140	437,717	4,660,328	1,227,800
Construction Activities		421,951	8,540	892,373	18,062	894,884	18,112	1,626,119	32,913	1,433,334	29,011	1,491,563	30,189
Miscellaneous		0	0	0	0	0	0	45	0	505	1	468	0
	Total	939,409	185,133	1,450,866	217,263	1,887,030	362,524	4,606,680	1,018,033	4,119,684	901,179	6,979,131	1,608,384
NEC		0	0	0	0	0	0	0	0	0	0	0	0
GRAND TOTAL		1,118,373	302,341	1,698,280	375,662	2,410,638	694,361	6,273,716	2,105,687	6,538,742	2,186,973	11,572,080	3,728,879

Table A-4 (continued)

Source Category		Region VII		Region VIII		Region IX		Region X		National Totals	
		PM-10	PM-2.5	PM-10	PM-2.5	PM-10	PM-2.5	PM-10	PM-2.5	PM-10	PM-2.5
FUEL COMB. ELEC. UTIL.											
Coal		9,508	3,532	19,177	8,446	12,707	2,971	1,807	621	268,779	99,402
Oil		7	5	2	1	920	626	4	3	9,773	5,661
Gas		49	38	5	3	680	628	13	12	1,640	878
Other		0	0	0	0	78	39	0	0	78	39
Internal Combustion		50	48	7	7	1,050	746	0	0	3,952	3,628
	Total	9,614	3,623	19,191	8,457	15,435	5,011	1,824	637	284,221	109,608
FUEL COMB. INDUSTRIAL											
Coal		2,352	996	1,988	883	655	284	2,175	785	68,044	28,376
Oil		683	384	1,545	832	1,181	484	2,526	2,426	44,471	26,047
Gas		1,040	1,020	1,498	1,453	3,673	3,450	4,745	4,469	47,977	46,315
Other		601	589	1,853	1,639	4,177	4,012	21,281	20,299	85,128	73,135
Internal Combustion		173	138	86	75	1,083	671	0	0	3,354	2,734
	Total	4,849	3,127	6,970	4,882	10,769	8,900	30,727	27,979	248,974	176,607
FUEL COMB. OTHER											
Commercial/Institutional Coal		1,177	551	722	311	4	2	270	70	13,871	5,121
Commercial/Institutional Oil		80	30	237	90	227	162	625	765	11,497	5,215
Commercial/Institutional Gas		364	347	258	243	513	473	162	136	4,711	4,427
Misc. Fuel Comb. (Except Residential)		10	10	474	406	346	181	154	144	2,689	2,287
Residential Wood		36,689	36,689	22,078	22,078	28,036	28,036	60,263	60,263	550,466	550,466
Residential Other		796	606	702	414	1,100	1,121	326	234	18,570	11,625
	Total	39,116	38,233	24,470	23,540	30,226	29,975	61,799	61,611	601,803	579,142
CHEMICAL & ALLIED PRODUCT MFG											
Organic Chemical Mfg		16,868	5,687	15	12	10	5	0	0	21,858	8,636
Inorganic Chemical Mfg		0	0	137	124	49	27	52	32	7,523	5,681
Polymer & Resin Mfg		40	34	0	0	73	40	0	0	4,607	3,898
Agricultural Chemical Mfg		1,700	1,456	5	4	59	29	62	54	9,231	7,896
Paint, Varnish, Lacquer, Enamel Mfg		105	37	0	0	34	19	0	0	416	160
Pharmaceutical Mfg		0	0	0	0	1	0	1	1	176	147
Other Chemical Mfg		164	148	176	146	414	217	4,927	4,076	17,725	15,392
	Total	18,877	7,361	333	286	638	337	5,043	4,163	61,537	41,811

Table A-4 (continued)

Source Category	Region VII		Region VIII		Region IX		Region X		National Totals	
	PM-10	PM-2.5	PM-10	PM-2.5	PM-10	PM-2.5	PM-10	PM-2.5	PM-10	PM-2.5
METALS PROCESSING										
Non-Ferrous Metals Processing	3,118	1,883	1,694	1,619	1,513	1,099	3,912	2,787	45,930	28,871
Ferrous Metals Processing	277	208	1,198	992	473	424	563	476	86,957	63,848
Metals Processing NEC	0	0	19	12	221	106	698	226	5,209	3,710
Total	3,395	2,091	2,911	2,623	2,208	1,629	5,173	3,489	138,096	96,429
PETROLEUM & RELATED INDUSTRIES										
Oil & Gas Production	0	0	8	6	532	1,564	0	0	756	1,721
Petroleum Refineries & Related Industries	2,697	1,541	1,389	868	1,336	733	361	213	24,146	16,494
Asphalt Manufacturing	842	589	0	0	568	346	167	105	4,179	2,582
Total	3,539	2,131	1,397	874	2,435	2,643	528	318	29,080	20,797
OTHER INDUSTRIAL PROCESSES										
Agriculture, Food, & Kindred Products	5,113	2,376	271	176	11,427	9,718	764	289	40,490	24,999
Textiles, Leather, & Apparel Products	0	0	0	0	29	21	0	0	496	424
Wood, Pulp & Paper, & Publishing Products	11	9	887	660	6,474	4,179	10,338	7,886	112,810	88,940
Rubber & Miscellaneous Plastic Products	56	50	1	1	298	211	10	7	4,624	3,912
Mineral Products	31,233	12,944	3,436	2,039	15,703	7,401	4,603	1,989	219,211	113,140
Machinery Products	2,075	728	0	0	508	273	7	3	4,070	1,626
Electronic Equipment	0	0	0	0	0	0	0	0	797	391
Transportation Equipment	0	0	0	0	4	3	0	0	119	76
Miscellaneous Industrial Processes	918	635	219	152	9,444	6,690	150	104	26,879	17,283
Total	39,406	16,743	4,815	3,028	43,887	28,496	15,872	10,279	409,497	250,790
SOLVENT UTILIZATION										
Degreasing	1	1	0	0	8	6	0	0	33	29
Graphic Arts	30	28	0	0	8	6	0	0	214	184
Dry Cleaning	0	0	0	0	0	0	0	0	3	2
Surface Coating	20	18	8	7	122	75	11	7	1,735	1,469
Other Industrial	0	0	0	0	1	1	6	4	150	123
Total	51	46	8	7	139	88	17	11	2,134	1,807
STORAGE & TRANSPORT										
Bulk Terminals & Plants	0	0	0	0	0	0	0	0	18	15
Petroleum & Petroleum Product Storage	0	0	0	0	0	0	0	0	24	20
Petroleum & Petroleum Product Transport	0	0	0	0	2	2	20	17	27	22
Organic Chemical Storage	25	11	0	0	9	5	24	15	1,082	877
Organic Chemical Transport	0	0	0	0	1	1	0	0	55	45
Inorganic Chemical Storage	0	0	0	0	5	3	0	0	431	206
Inorganic Chemical Transport	0	0	0	0	1	0	0	0	1	0

Table A-4 (continued)

Source Category		Region VII		Region VIII		Region IX		Region X		National Totals	
		PM-10	PM-2.5	PM-10	PM-2.5	PM-10	PM-2.5	PM-10	PM-2.5	PM-10	PM-2.5
Bulk Materials Storage		8,061	2,671	856	238	8,591	4,339	1,079	401	62,482	25,265
Bulk Materials Transport		40	2	0	0	92	26	26	7	199	39
	Total	8,126	2,685	856	238	8,700	4,375	1,149	440	64,319	26,489
WASTE DISPOSAL & RECYCLING											
Incineration		5,728	4,309	2,196	1,513	1,107	779	2,334	1,629	41,518	29,449
Open Burning		14,131	12,848	6,504	5,913	4,640	4,210	4,963	4,520	184,333	167,592
Industrial Waste Water		0	0	0	0	0	0	0	0	11	9
TSDF		0	0	0	0	1	1	0	0	1	1
Landfills		0	0	0	0	21	14	0	0	21	14
Other		82	75	0	0	1	1	0	0	202	185
	Total	19,941	17,232	8,700	7,426	5,770	5,005	7,296	6,149	226,085	197,250
HIGHWAY VEHICLES											
Light-Duty Gas Vehicles & Motorcycles		3,229	1,945	2,009	1,217	9,504	5,750	2,512	1,520	63,787	38,476
Light-Duty Gas Trucks		1,713	1,113	1,064	693	4,574	2,974	1,299	845	32,287	20,975
Heavy-Duty Gas Vehicles		601	396	374	246	1,396	920	442	291	10,646	7,016
Diesels		14,584	13,196	9,061	8,198	31,274	28,293	10,535	9,532	250,018	226,207
	Total	20,127	16,649	12,508	10,355	46,748	37,938	14,788	12,188	356,738	292,674
OFF-HIGHWAY											
Non-Road Gasoline		3,673	3,079	938	786	2,934	2,207	1,203	967	42,141	35,034
Non-Road Diesel		10,102	9,294	6,881	6,331	14,124	12,994	7,569	6,963	185,638	170,787
Aircraft		942	664	1,896	1,337	5,204	3,670	1,149	810	40,377	28,475
Marine Vessels		504	463	0	0	3,343	2,649	1,107	792	24,185	17,846
Railroads		5,246	4,826	3,988	3,669	2,757	2,536	2,206	2,030	44,002	40,482
	Total	20,468	18,326	13,704	12,124	28,362	24,057	13,234	11,562	336,343	292,624
OTHER COMBUSTION											
Wildfires		38,464	34,967	29,881	25,973	34,331	29,469	397,408	360,276	571,356	515,034
Agricultural Burning		3,755	3,413	0	0	14,904	13,483	18,769	17,004	94,439	85,729
Prescribed Burning		0	0	21,600	18,305	39,953	34,040	111,480	94,475	447,131	379,107
Structural Fires		3,321	3,019	1,667	1,515	1,459	1,326	1,696	1,541	53,470	48,609
	Total	45,540	41,400	53,148	45,794	90,647	78,318	529,352	473,296	1,166,395	1,028,479
FUGITIVE DUST - NATURAL SOURCES											
Wind Erosion - Agricultural Land		808,792	323,517	44,604	17,841	104,549	27,130	434	174	4,180,983	1,657,704
FUGITIVE DUST - AGRICULTURE											
Agricultural Crops		1,763,311	839,336	1,320,707	628,657	42,647	16,010	220,616	103,866	6,870,955	3,265,138
Agricultural Livestock		5,123	2,440	38,996	18,569	38,064	22,418	678	323	395,217	192,490
	Total	1,768,434	841,776	1,359,703	647,226	80,712	38,428	221,294	104,189	7,266,172	3,457,629

Table A-4 (continued)

Source Category		Region VII		Region VIII		Region IX		Region X		National Totals	
		PM-10	PM-2.5	PM-10	PM-2.5	PM-10	PM-2.5	PM-10	PM-2.5	PM-10	PM-2.5
FUGITIVE DUST - OTHER											
Wind Erosion (Non Agricultural Land)		56	16	104	30					160	47
Paved Roads		362,896	155,046	256,456	109,859	888,216	368,266	238,281	101,253	5,967,150	2,517,691
Unpaved Roads		1,652,875	435,609	691,859	182,473	234,762	62,227	745,847	196,658	12,325,601	3,249,389
Construction Activities		325,127	6,581	473,004	9,574	456,329	10,024	474,300	9,600	8,488,983	172,605
Miscellaneous		522	4	194	106	824	284	0	0	2,558	395
	Total	2,341,477	597,256	1,421,617	302,042	1,580,130	440,802	1,458,428	307,511	26,784,452	5,940,127
NEC		0	0	0	0	12	7	0	0	12	7
GRAND TOTAL		5,151,754	1,932,195	2,974,935	1,086,742	2,051,367	733,137	2,366,958	1,023,996	42,156,842	14,169,974

Table A-5
United States 1990 VOC and SOA Emissions by Region

Source Category	Region I		Region II		Region III		Region IV		Region V		Region VI	
	VOC	SOA	VOC	SOA	VOC	SOA	VOC	SOA	VOC	SOA	VOC	SOA
FUEL COMB. ELEC. UTIL.												
Coal	223	4	446	9	3,169	61	5,473	106	6,677	129	4,906	95
Oil	1,337	38	1,852	53	489	14	1,220	35	101	3	29	1
Gas	51	0	224	0	23	0	190	0	26	0	1,218	1
Other	0	0	0	0	0	0	0	0	0	0	0	0
Internal Combustion	115	0	267	1	45	0	303	1	81	0	17	0
Total	1,727	43	2,789	62	3,725	75	7,186	141	6,885	132	6,170	96
FUEL COMB. INDUSTRIAL												
Coal	17	0	323	6	393	8	1,975	38	2,056	40	1,984	38
Oil	2,342	67	3,674	81	551	15	1,020	29	2,513	71	3,597	102
Gas	812	1	3,323	2	2,766	3	2,984	2	3,212	2	41,074	92
Other	1,320	57	889	19	1,155	48	17,858	767	1,999	63	7,077	266
Internal Combustion	26	0	0	0	213	0	1,491	1	1,523	1	9,022	6
Total	4,517	124	8,209	108	5,078	75	25,327	837	11,304	177	62,754	504
FUEL COMB. OTHER												
Commercial/Institutional Coal	62	1	52	1	220	4	320	6	425	8	4	0
Commercial/Institutional Oil	396	11	1,316	37	321	9	497	14	198	6	157	4
Commercial/Institutional Gas	129	0	400	0	312	0	350	0	1,035	1	500	0
Misc. Fuel Comb. (Except Residential)	161	3	21	1	73	2	168	5	1,432	5	477	3
Residential Wood	47,089	2,030	34,931	1,506	88,817	3,828	199,224	8,587	132,096	5,693	75,256	3,244
Residential Other	1,634	46	1,899	51	5,311	115	1,818	39	2,120	48	134	3
Total	49,471	2,090	38,620	1,596	95,055	3,958	202,376	8,651	137,305	5,760	76,528	3,254
CHEMICAL & ALLIED PRODUCT MFG												
Organic Chemical Mfg	6,393	12	34,424	64	36,519	54	100,234	84	52,890	62	268,204	1,930
Inorganic Chemical Mfg	0	0	1,779	4	137	0	9	0	178	0	36,036	84
Polymer & Resin Mfg	2,206	2	17,235	194	113,902	201	168,398	564	17,988	71	148,864	988
Agricultural Chemical Mfg	0	0	81	1	220	2	560	1	1,982	6	20,358	184
Paint, Varnish, Lacquer, Enamel Mfg	0	0	35	0	2,217	27	957	12	6,544	62	85	1
Pharmaceutical Mfg	6,125	12	12,465	25	5,744	11	6,495	12	23,209	47	1,697	3
Other Chemical Mfg	130	1	19,631	42	36,527	73	136,277	349	33,265	64	115,660	209
Total	14,854	27	85,650	329	195,265	368	412,930	1,022	136,056	313	590,904	3,399

Table A-5 (continued)

Source Category	Region I		Region II		Region III		Region IV		Region V		Region VI	
	VOC	SOA	VOC	SOA	VOC	SOA	VOC	SOA	VOC	SOA	VOC	SOA
METALS PROCESSING												
Non-Ferrous Metals Processing	0	0	5,558	29	903	5	5,726	22	1,338	3	5,616	19
Ferrous Metals Processing	1	0	27	0	11,421	10	7,731	6	25,376	109	6,537	5
Metals Processing NEC	0	0	108	0	0	0	449	2	34	0	4	0
Total	1	0	5,693	29	12,324	15	13,906	30	26,749	113	12,156	24
PETROLEUM & RELATED INDUSTRIES												
Oil & Gas Production	168	0	3,234	5	2,123	3	2,402	4	5,464	8	45,854	75
Petroleum Refineries & Related Industries	495	19	10,872	30	32,979	85	32,556	84	94,893	287	256,372	615
Asphalt Manufacturing	127	4	0	0	42	1	2,610	97	440	12	7	0
Total	790	24	14,106	35	35,144	89	37,568	184	100,797	306	302,233	690
OTHER INDUSTRIAL PROCESSES												
Agriculture; Food, & Kindred Products	3,993	0	4,928	0	12,794	0	62,147	0	58,847	28	13,497	1
Textiles, Leather, & Apparel Products	697	167	215	47	3,516	90	5,287	1,227	260	2	0	0
Wood, Pulp & Paper, & Publishing Products	1,750	242	492	69	981	16	16,806	1,661	4,528	172	12,433	946
Rubber & Miscellaneous Plastic Products	1,350	4	850	1	4,001	49	14,433	84	7,373	84	9,212	151
Mineral Products	70	1	37	0	4,808	36	2,438	22	2,712	20	3,116	28
Machinery Products	149	2	755	7	310	3	961	8	634	5	572	6
Electronic Equipment	0	0	321	3	0	0	0	0	0	0	0	0
Transportation Equipment	0	0	405	4	0	0	0	0	0	0	0	0
Miscellaneous Industrial Processes	959	7	51,564	521	4,571	32	29,635	299	4,065	30	8,674	63
Total	8,968	422	59,567	652	30,981	227	131,707	3,301	78,419	341	47,504	1,194
SOLVENT UTILIZATION												
Degreasing	49,267	327	55,943	386	75,999	413	124,643	837	194,013	1,273	72,506	468
Graphic Arts	14,229	138	26,095	253	46,938	597	103,656	1,666	95,405	1,177	13,167	120
Dry Cleaning	9,887	48	15,945	78	19,996	98	49,993	245	38,706	201	27,887	137
Surface Coating	150,970	1,665	213,891	2,226	317,845	3,804	500,909	5,588	683,655	9,451	211,554	2,203
Other Industrial	3,297	9	5,535	23	56,185	347	17,242	78	32,878	158	2,528	6
Nonindustrial	88,441	973	177,299	1,946	181,549	1,978	322,831	3,462	375,115	3,908	235,288	2,439
Solvent Utilization NEC	0	0	0	0	0	0	0	0	0	0	0	0
Total	316,091	3,161	494,707	4,911	698,513	7,237	1,119,275	11,876	1,419,771	16,169	562,931	5,373
STORAGE & TRANSPORT												
Bulk Terminals & Plants	23,591	35	70,671	147	61,477	88	121,035	166	99,168	138	112,103	175
Petroleum & Petroleum Product Storage	645	1	17,734	79	4,632	36	18,341	63	35,014	184	110,841	699

Table A-5 (continued)

Source Category	Region I		Region II		Region III		Region IV		Region V		Region VI	
	VOC	SOA	VOC	SOA	VOC	SOA	VOC	SOA	VOC	SOA	VOC	SOA
Petroleum & Petroleum Product Transport	7,481	146	7,184	139	10,295	175	14,143	260	14,884	276	55,333	1,039
Service Stations: Stage I	9,436	185	17,094	335	19,681	386	56,294	1,103	37,061	726	30,749	602
Service Stations: Stage II	23,718	465	37,245	730	47,304	922	93,184	1,826	85,989	1,685	57,140	1,120
Service Stations: Breathing & Emptying	2,964	58	4,656	91	5,880	115	11,648	228	10,746	211	7,140	140
Organic Chemical Storage	0	0	6,945	14	694	1	3,189	2	680	23	22,608	53
Organic Chemical Transport	0	0	0	0	0	0	692	5	0	0	14,940	131
Inorganic Chemical Storage	0	0	217	2	0	0	1	0	0	0	56	0
Inorganic Chemical Transport	0	0	0	0	0	0	0	0	0	0	1	0
Bulk Materials Storage	0	0	0	0	1	0	235	2	2	0	14	0
Bulk Materials Transport	0	0	0	0	0	0	0	0	0	0	0	0
Total	67,835	890	161,744	1,537	149,964	1,723	318,763	3,655	283,544	3,242	410,925	3,960
WASTE DISPOSAL & RECYCLING												
Incineration	3,355	8	2,732	7	1,077	3	4,727	12	15,730	38	5,935	13
Open Burning	12,453	14	16,721	18	30,331	33	67,541	74	56,647	62	27,400	30
POTW	985	0	1,066	1	964	0	1,889	1	3,383	2	508	0
Industrial Waste Water	0	0	0	0	466	1	0	0	0	0	1,120	2
TSDF	6,287	3	71,347	36	414,106	207	540,189	270	120,419	60	660,233	330
Landfills	0	0	0	0	0	0	0	0	0	0	15	0
Other	0	0	0	0	0	0	0	0	130	0	82	0
Total	23,080	25	91,865	61	446,943	244	614,345	357	196,309	162	695,293	376
HIGHWAY VEHICLES												
Light-Duty Gas Vehicles & Motorcycles	196,640	1,200	323,949	1,976	405,386	2,473	939,430	5,731	780,179	4,759	552,013	3,367
Light-Duty Gas Trucks	81,256	496	129,933	793	170,825	1,042	383,232	2,338	326,930	1,994	227,067	1,385
Heavy-Duty Gas Vehicles	19,795	145	32,642	238	44,677	326	109,129	797	80,865	590	62,000	453
Diesels	15,097	345	22,725	517	32,430	743	67,234	1,541	59,923	1,372	42,861	983
Total	312,788	2,184	509,250	3,524	653,318	4,584	1,499,025	10,406	1,247,898	8,715	883,941	6,188
NONROAD ENGINES												
Non-Road Gasoline	84,073	615	107,131	783	145,468	1,063	328,211	2,399	297,997	2,180	281,885	2,059
Non-Road Diesel	7,330	174	12,179	289	18,382	436	37,010	877	30,924	733	34,697	822
Aircraft	7,248	172	9,970	236	13,406	318	52,295	1,239	20,206	479	33,566	796
Marine Vessels	589	17	1,761	50	3,885	110	7,984	227	2,478	64	13,559	385
Railroads	784	19	1,173	28	3,119	74	6,624	157	7,470	177	7,523	178
Total	100,025	995	132,213	1,386	184,259	2,001	432,124	4,899	359,075	3,632	371,230	4,240

Table A-5 (continued)

Source Category		Region I		Region II		Region III		Region IV		Region V		Region VI	
		VOC	SOA	VOC	SOA	VOC	SOA	VOC	SOA	VOC	SOA	VOC	SOA
OTHER COMBUSTION													
Wildfires		866	1	459	0	4,107	3	50,200	35	19,993	14	18,747	13
Agricultural Burning		278	0	0	0	70	0	27,605	19	0	0	25,143	18
Prescribed Burning		0	0	480	0	1,487	1	80,717	57	38	0	16,630	12
Structural Fires		2,686	2	5,634	4	5,153	4	7,205	5	9,091	6	4,492	3
Miscellaneous		0	0	0	0	0	0	0	0	0	0	0	0
	Total	3,830	3	6,574	5	10,817	8	165,727	116	29,121	20	65,012	46
HEALTH SERVICES													
Miscellaneous		0	0	0	0	0	0	0	0	0	0	0	0
MISCELLANEOUS													
Geogenic		0	0	0	0	0	0	0	0	0	0	0	0
Agriculture & Forestry		0	0	0	0	0	0	0	0	0	0	0	0
NEC		0	0	0	0	0	0	0	0	0	0	0	0
	Total	0	0	0	0	0	0	0	0	0	0	0	0
SUBTOTAL ANTHROPOGENIC		903,976	9,990	1,610,986	14,236	2,521,384	20,605	4,980,260	45,476	4,033,232	39,084	4,087,581	29,346
BIOGENIC SOURCES													
All Landcover		567,445	74,862	387,225	48,984	1,093,213	128,967	4,840,213	511,199	2,173,981	302,052	6,069,112	729,211
TOTAL		1,471,421	84,852	1,998,211	63,220	3,614,597	149,572	9,820,473	556,675	6,207,213	341,136	10,156,693	758,557

Table A-5 (continued)

Source Category	Region VII		Region VIII		Region IX		Region X		National Totals	
	VOC	SOA	VOC	SOA	VOC	SOA	VOC	SOA	VOC	SOA
FUEL COMB. ELEC. UTIL.										
Coal	2,200	42	3,026	58	815	16	171	3	27,106	523
Oil	3	0	3	0	302	9	0	0	5,336	152
Gas	28	0	5	0	1,188	2	4	0	2,958	3
Other	0	0	0	0	372	5	0	0	372	5
Internal Combustion	31	0	3	0	10,321	114	0	0	11,183	117
Total	2,262	43	3,037	58	12,998	146	175	3	46,954	800
FUEL COMB. INDUSTRIAL										
Coal	275	5	201	4	420	8	143	3	7,786	150
Oil	228	6	150	4	457	10	580	16	15,111	402
Gas	2,683	2	1,259	1	3,078	3	1,015	1	62,206	110
Other	5	0	733	31	3,079	121	6,390	272	40,505	1,643
Internal Combustion	418	0	1,112	2	30,103	28	31	0	43,938	39
Total	3,608	14	3,455	42	37,136	171	8,159	292	169,546	2,344
FUEL COMB. OTHER										
Commercial/Institutional Coal	45	1	283	5	1	0	38	1	1,450	28
Commercial/Institutional Oil	356	10	47	1	472	2	68	2	3,828	97
Commercial/Institutional Gas	307	0	264	0	3,545	9	2,664	18	9,506	29
Misc. Fuel Comb. (Except Residential)	19	0	8	0	1,458	2	1,281	4	5,099	24
Residential Wood	52,515	2,263	31,601	1,362	34,695	1,495	77,029	3,320	773,254	33,327
Residential Other	860	18	1,190	24	1,740	4	381	8	17,086	356
Total	54,103	2,293	33,393	1,393	41,911	1,512	81,461	3,353	810,223	33,861
CHEMICAL & ALLIED PRODUCT MFG										
Organic Chemical Mfg	50,346	46	8	0	872	0	685	0	550,575	2,252
Inorganic Chemical Mfg	0	0	37	0	374	1	0	0	38,550	89
Polymer & Resin Mfg	2,375	1	2	0	4,292	0	1	0	475,263	2,023
Agricultural Chemical Mfg	1,776	8	0	0	26	0	0	0	25,003	203
Paint, Varnish, Lacquer, Enamel Mfg	831	10	0	0	822	10	0	0	11,490	122
Pharmaceutical Mfg	2,145	4	13	0	170	0	73	0	58,137	115
Other Chemical Mfg	3,067	10	337	1	1,286	3	12,794	26	358,975	777
Total	60,539	80	397	1	7,843	15	13,554	26	1,517,993	5,581

Table A-5 (continued)

Source Category	Region VII		Region VIII		Region IX		Region X		National Totals	
	VOC	SOA	VOC	SOA	VOC	SOA	VOC	SOA	VOC	SOA
METALS PROCESSING										
Non-Ferrous Metals Processing	4	0	96	2	117	0	389	10	19,747	90
Ferrous Metals Processing	209	0	550	0	29	0	41	0	51,923	132
Metals Processing NEC	48	0	0	0	227	3	85	0	956	6
Total	262	0	646	2	374	3	515	10	72,625	227
PETROLEUM & RELATED INDUSTRIES										
Oil & Gas Production	3,477	5	5,252	8	302,375	464	84	0	370,435	572
Petroleum Refineries & Related Industries	11,835	32	32,886	61	27,008	40	23,077	60	522,973	1,312
Asphalt Manufacturing	7	0	0	0	281	6	517	0	4,032	121
Total	15,319	37	38,139	69	329,665	509	23,678	60	897,439	2,005
OTHER INDUSTRIAL PROCESSES										
Agriculture, Food, & Kindred Products	4,200	2	330	0	18,767	24	3,211	0	182,715	55
Textiles, Leather, & Apparel Products	0	0	0	0	91	12	0	0	10,065	1,545
Wood, Pulp & Paper, & Publishing Products	15	0	503	5	1,145	125	8,605	509	47,257	3,746
Rubber & Miscellaneous Plastic Products	4,270	58	121	0	5,646	30	1,254	1	48,511	460
Mineral Products	375	3	46	0	1,350	11	84	1	15,037	123
Machinery Products	65	1	0	0	83	1	39	0	3,567	33
Electronic Equipment	0	0	0	0	0	0	0	0	321	3
Transportation Equipment	0	0	0	0	0	0	0	0	405	4
Miscellaneous Industrial Processes	1,049	7	199	1	395	3	216	2	101,326	965
Total	9,974	71	1,199	7	27,478	206	13,410	513	409,205	6,934
SOLVENT UTILIZATION										
Degreasing	43,945	296	18,821	130	81,087	491	17,409	120	733,633	4,740
Graphic Arts	22,809	290	6,174	58	12,134	96	6,875	68	347,482	4,462
Dry Cleaning	9,268	45	6,045	30	16,060	119	4,722	24	198,508	1,026
Surface Coating	139,664	1,731	57,749	663	198,203	2,227	57,094	712	2,531,533	30,271
Other Industrial	2,250	6	1,786	9	24,937	169	2,030	11	148,667	815
Nonindustrial	140,468	1,317	94,735	876	216,902	2,699	67,169	652	1,899,797	20,251
Solvent Utilization NEC	0	0	0	0	3,157	0	0	0	3,157	0
Total	358,403	3,685	185,308	1,765	552,481	5,802	155,299	1,587	5,862,778	61,566
STORAGE & TRANSPORT										
Bulk Terminals & Plants	60,566	84	37,195	53	9,993	16	22,116	37	617,915	939
Petroleum & Petroleum Product Storage	6,412	38	9,349	67	7,945	64	2,338	8	213,250	1,239

Table A-5 (continued)

Source Category	Region VII		Region VIII		Region IX		Region X		National Totals	
	VOC	SOA	VOC	SOA	VOC	SOA	VOC	SOA	VOC	SOA
Petroleum & Petroleum Product Transport	3,681	72	2,153	16	9,458	154	13,874	216	138,486	2,493
Service Stations: Stage I	18,075	354	10,035	197	8,197	160	6,578	129	213,200	4,178
Service Stations: Stage II	21,749	426	14,842	291	25,307	494	11,517	226	417,995	8,186
Service Stations: Breathing & Emptying	2,719	53	1,856	36	8,104	159	1,440	28	57,153	1,120
Organic Chemical Storage	2,026	12	7	0	912	18	0	0	37,061	123
Organic Chemical Transport	0	0	0	0	23	0	0	0	15,654	137
Inorganic Chemical Storage	0	0	0	0	150	1	0	0	424	3
Inorganic Chemical Transport	0	0	0	0	0	0	0	0	1	0
Bulk Materials Storage	124	1	0	0	34	1	0	0	410	4
Bulk Materials Transport	0	0	0	0	0	0	0	0	0	0
Total	115,351	1,041	75,437	660	70,122	1,068	57,863	643	1,711,548	18,422
WASTE DISPOSAL & RECYCLING										
Incineration	4,824	11	2,777	7	1,470	4	3,981	9	46,607	110
Open Burning	19,295	21	8,870	10	7,453	8	6,680	7	253,391	279
POTW	504	0	234	0	750	1	166	0	10,449	6
Industrial Waste Water	0	0	0	0	5	0	0	0	1,591	3
TSDF	4,119	2	4,392	2	18,771	10	3,819	2	1,843,681	922
Landfills	0	0	0	0	629,344	4	0	0	629,359	4
Other	0	0	0	0	18	0	0	0	230	0
Total	28,742	35	16,273	19	657,811	26	14,645	19	2,785,306	1,324
HIGHWAY VEHICLES										
Light-Duty Gas Vehicles & Motorcycles	210,781	1,286	134,104	818	564,981	3,446	150,239	916	4,257,703	25,972
Light-Duty Gas Trucks	90,805	554	61,411	375	221,759	1,353	64,296	392	1,757,513	10,721
Heavy-Duty Gas Vehicles	23,585	172	15,589	114	62,211	454	16,429	120	466,922	3,409
Diesels	17,784	409	17,820	413	39,937	919	12,568	288	328,380	7,529
Total	342,955	2,421	228,925	1,719	888,889	6,172	243,532	1,717	6,810,518	47,630
NONROAD ENGINES										
Non-Road Gasoline	90,647	662	54,371	397	147,937	1,087	62,680	460	1,600,400	11,705
Non-Road Diesel	9,811	233	6,157	146	23,767	563	5,556	132	185,812	4,404
Aircraft	6,577	156	9,910	235	34,430	816	7,328	174	194,935	4,620
Marine Vessels	1,174	33	0	0	3,322	87	1,733	49	36,485	1,023
Railroads	4,697	111	3,572	85	3,990	95	5,325	126	44,276	1,049
Total	112,906	1,195	74,010	863	213,445	2,649	82,623	940	2,061,908	22,801

Table A-5 (continued)

Source Category		Region VII		Region VIII		Region IX		Region X		National Totals	
		VOC	SOA	VOC	SOA	VOC	SOA	VOC	SOA	VOC	SOA
OTHER COMBUSTION											
Wildfires		55,312	39	21,294	15	14,121	10	8,169	6	193,268	135
Agricultural Burning		3,497	2	0	0	19,284	13	7,474	5	83,351	58
Prescribed Burning		0	0	9,074	6	23,857	17	47,686	33	179,968	126
Structural Fires		2,510	2	1,260	1	1,210	1	1,819	1	41,059	29
Miscellaneous		0	0	0	0	1,074	1	0	0	1,074	1
	Total	61,318	43	31,627	22	59,546	42	65,148	46	498,719	349
HEALTH SERVICES											
Miscellaneous		0	0	157	0	469	0	0	0	625	0
MISCELLANEOUS											
Geogenic		0	0	0	0	18,389	0	0	0	18,389	0
Agriculture & Forestry		0	0	0	0	101,403	71	0	0	101,403	71
NEC		0	0	0	0	10,247	122	0	0	10,247	122
	Total	0	0	0	0	119,792	71	0	0	119,792	71
SUBTOTAL ANTHROPOGENIC		1,165,741	10,959	692,004	6,621	3,030,205	18,512	760,060	9,209	23,785,429	204,036
BIOGENIC SOURCES											
All Landcover		700,198	86,467	3,471,146	488,444	4,206,002	552,774	2,479,590	401,921	25,988,126	3,324,882
TOTAL		1,865,939	97,426	4,163,150	495,065	7,236,207	571,286	3,239,650	411,130	49,773,555	3,528,918

APPENDIX B
THE NATIONAL PARTICULATES INVENTORY PHASE II EMISSION ESTIMATES

Table B-1
The National Particulates Inventory Phase II Emission Estimates

FIELD_NAME	FIELD_TYPE	FIELD_LEN	FIELD_DEC	FIELD_DESC
ID	N	7	0	Identification Code
FIPSST	C	2	0	FIPS State Code
STATENM	C	15	0	State Name
FIPSCNTY	C	3	0	FIPS County Code
COUNTYNM	C	20	0	County Name
PLANTID	C	4	0	Plant ID
PLANTNAME	C	40	0	Plant Name
POINTID	C	2	0	Point ID
LATC	N	9	4	Latitude
LONC	N	9	4	Longitude
STKHGT	N	4	0	Stack Height (ft)
STKDIAM	N	6	2	Stack Diameter (ft)
STKTEMP	N	4	0	Stack Temperature (degrees F)
STKFLOW	N	10	2	Exhaust Gas Flow Rate (ft^3/sec)
STKVEL	N	9	2	Stack Gas Velocity (ft/sec)
PLUMHGT	N	8	1	Plume Height (m)
EMISS1-7	N	16	4	Annual Emissions (tons)
WIN1-7	N	16	4	Dec-Feb Emissions (tons)
SPR1-7	N	16	4	Mar-May Emissions (tons)
SUM1-7	N	16	4	Jun-Aug Emissions (tons)
FAL1-7	N	16	4	Sep-Nov Emissions (tons)

FIELD_NAME	FIELD_TYPE	FIELD_LEN	FIELD_DEC	FIELD_DESC
ID	N	7	0	Identification Code
FIPSST	C	2	0	FIPS State Code
STATENM	C	15	0	State Name
FIPSCNTY	C	3	0	FIPS County Code
COUNTYNM	C	20	0	County Name
EMISS1-7	N	16	4	Annual Emissions (tons)
WIN1-7	N	16	4	Dec-Feb Emissions (tons)
SPR1-7	N	16	4	Mar-May Emissions (tons)
SUM1-7	N	16	4	Jun-Aug Emissions (tons)
FAL1-7	N	16	4	Sep-Nov Emissions (tons)

Table B-1 (continued)

FIELD_NAME	FIELD_TYPE	FIELD_LEN	FIELD_DEC	FIELD_DESC
ID	N	7	0	Identification Code
FIPSST	C	2	0	FIPS State Code
STATENM	C	15	0	State Name
FIPSCNTY	C	3	0	FIPS County Code
COUNTYNM	C	20	0	County Name
AREA	N	14	0	Area (sq mi)
LAT	N	15	2	Latitude
LON	N	15	2	Longitude
WIN1-7	N	16	4	Dec-Feb Emissions (tons)
SPR1-7	N	16	4	Mar-May Emissions (tons)
SUM1-7	N	16	4	Jun-Aug Emissions (tons)
FAL1-7	N	16	4	Sep-Nov Emissions (tons)

NOTE: Emission variables are as follows: (1) VOC, (1_P) SOA, (2) NO_x, (3) CO, (4) SO_2, (5) PM_{10}, (6) $PM_{2.5}$, and (7) NH_3.