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EMISSION INVENTORY DEVELOPMENT FOR MOBILE SOURCES AND AGRICULTURAL DUST SOURCES FOR THE CENTRAL STATES

DRAFT FINAL REPORT
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QUALITY ASSURANCE STATEMENT

This report was reviewed and approved by the project Quality Assurance (QA) Officer or his delegated representatives, as provided in the project QA Plan (Sullivan, 2004).

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EXECUTIVE SUMMARY

The Central States Regional Air Planning Association (CENRAP) is researching visibility-related issues for its region and is developing a regional haze plan in response to the U.S. Environmental Protection Agency's (EPA) mandate to protect visibility in Class I areas. Mobile sources (both on- and off-road) and agricultural dust sources contribute to episodes of impaired visibility in the CENRAP region. Therefore, in support of the CENRAP's need to develop a regional haze plan, Sonoma Technology, Inc. (STI) developed emission inventories for on-road and off-road mobile sources and agricultural fugitive dust.

Appendix A, Emission Estimation Methods for Mobile Sources and Agricultural Dust Sources in the Central States, details the methods used throughout inventory development. Methods were based on EPA-accepted emissions models (e.g., NONROAD, SMOKE, and MOBILE6), emission factors gathered from EPA guidance documents or published literature, and geographic information systems (GIS) databases. Activity data sets were prepared using bottom-up methods or region-specific information whenever possible. Examples of bottom-up and region-specific data include the following:

- Facility-level estimates of cattle populations for confined animal feeding operations (CAFOs)
- Activity data gathered through telephone surveys to describe recreational boating and agricultural tilling activities
- Local activity data for commercial marine vessels and locomotives gathered directly from local agencies and industry sources, such as individual port operators and rail lines
- MOBILE6 inputs and vehicle activity data acquired from state and local information sources, including vehicle miles traveled (VMT), fleet characteristics, regulatory controls, and fuels characteristics (see Appendix C)
- Fuels characteristics acquired from state and local information sources and used as inputs for NONROAD 2004 when appropriate (see Appendix C)

Figures ES-1 and ES-2 illustrate highlights of the resultant emission inventories for on-road mobile sources, non-road mobile sources, and agricultural fugitive dust. The inventories are also tabulated in Appendix B, provided in electronic form in Appendix D, and illustrated in greater detail throughout the body of the report. In many respects, the CENRAP inventories represent substantial improvements and differ significantly from existing inventories, such as the 1999 National Emissions Inventory (NEI) and preliminary 2002 NEI, which were prepared with default guidance, national average activity data, or top-down disaggregation techniques. Some of the most important improvements include the spatial and temporal allocations of the CENRAP inventories, which are more representative and could significantly enhance efforts to perform photochemical modeling. In addition, the use of bottom-up data will lend credibility to any scientific conclusions that may be based on the CENRAP's emission inventories.

Figure ES-1 compares the CENRAP inventory to the preliminary 2002 NEI. Emissions totals of selected pollutants are plotted for the entire CENRAP region. Large revisions to the region-wide annual emissions for specific source categories produced only minor *apparent*

changes in the region-wide annual totals for all source categories. However, the use of region-wide annual totals as the basis of comparison masks the importance of large changes in state-level inventories and spatial and temporal distributions. It also underrates the disproportionate influences of certain source types on visibility in Class I areas. Class I areas are often remote and far removed from the urban areas that contribute most to region-wide inventories. Sources that tend to concentrate away from urban areas—e.g., recreational boating, agricultural activities, etc.—are likely to affect visibility in Class I areas to a greater degree than might be expected if only the relative magnitudes of their emissions are considered.

The most significant revision to the $PM_{2.5}$ emission inventory—a 22% reduction in estimated annual emissions for agricultural fugitive dust sources—was due mostly to improvements in the activity data for tilling operations. As a result of this and other more modest revisions, total $PM_{2.5}$ emissions in the CENRAP inventory are 4% less than those estimated for the preliminary 2002 NEI. Annual NO_x emissions from commercial marine vessels were estimated to be 69% less than those estimated for the preliminary 2002 NEI; and primarily as a result of this, total NO_x emissions estimated for the CENRAP are 4% less than those recorded in the preliminary 2002 NEI. Annual VOC emissions estimated for the CENRAP were 8% greater than those estimated for the preliminary 2002 NEI—a difference mostly due to improved activity data for recreational boating. The CENRAP's VOC inventory for recreational boating is more than a factor of two larger than that incorporated in the preliminary 2002 NEI. Total SO_x emissions estimated for the CENRAP are 2% less than those estimated for the preliminary 2002 NEI. This difference was due to the use of region-specific measurements of fuel sulfur contents rather than default guidance assumptions, and it corresponds primarily to 42% and 85% reductions in SO_x emissions from commercial marine vessels and "other" non-road mobile sources, respectively.[1]

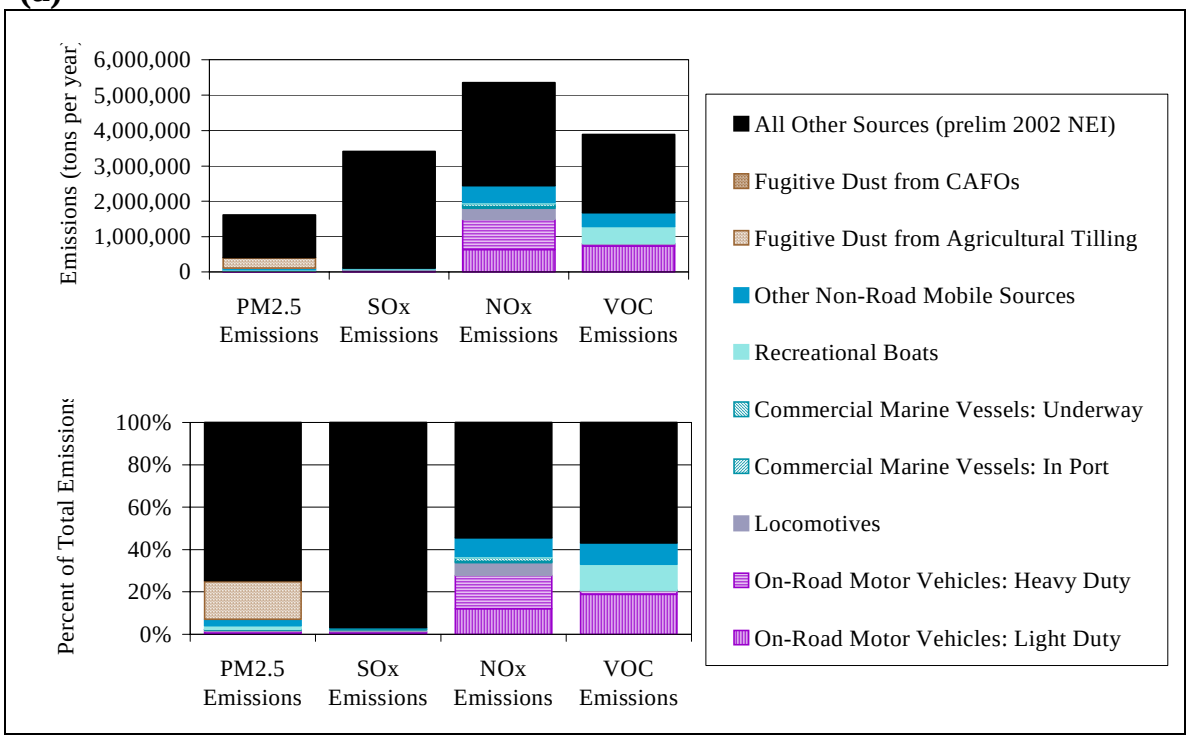
Figure ES-2 illustrates selected temporal profiles developed for or applied to the CENRAP inventories. Recent research has demonstrated that emissions from on-road mobile sources follow dramatically different patterns on weekend days than on weekdays, that patterns for light-duty vehicles are unique compared to those of heavy-duty vehicles, and that activities in rural areas differ from those in urban areas (Chinkin et al., 2003; Lawson, 2003; Croes et al., 2003). The CENRAP inventories reflect this latest understanding of weekday-weekend activity patterns for on-road mobile sources. The weekday-weekend activity patterns for recreational boating, which were based on surveys of representative groups of recreational boat owners in the CENRAP region, are even more dramatic than those of on-road mobile sources. Recreational boating activities tend to be extremely concentrated on weekends (whereas the reverse is true for on-road mobile sources and to a more moderate degree) and to vary diurnally and seasonally by type of boat and geographic area. Seasonal patterns for commercial marine vessels and agricultural tilling operations—also based on bottom-up data collection efforts—are related to the climates and crop types prevalent in different geographic areas.

In summary, the CENRAP inventories of mobile sources and agricultural fugitive dust are highly region-specific, or even county-specific, and adhere closely to EPA's recommended guidance for inventory development. Additional refinements and improvements should be

[1] "Other" non-road mobile sources include all non-road mobiles sources other than locomotives, commercial marine vessels, recreational boats, and aircraft.

incorporated as better information become available. Recommended areas for future efforts and further research include (1) development of information to support day-of-week inventories (i.e., Sunday, Monday, Tuesday, etc.), rather than weekday-weekend inventories; (2) development and/or acquisition of local data as they become available (e.g., metropolitan VMT data, fuels testing programs); (3) investigation of state motor vehicle departments' records of vehicle registrations, including duplicate records and unusual age distributions; (4) use of vehicle registration records to adjust and refine VMT distributions by vehicle type; (5) continuation of bottom-up activity data acquisition for additional types of non-road mobile sources and sources of agricultural fugitive dust (such as agricultural equipment, construction and mining equipment, recreational all-terrain vehicles (ATVs), lawn and garden equipment, cotton ginning operations, and/or crop transport); and (6) development of process-based methods or emission factors to improve inventories of agricultural fugitive dust emissions.

(a)



(b)

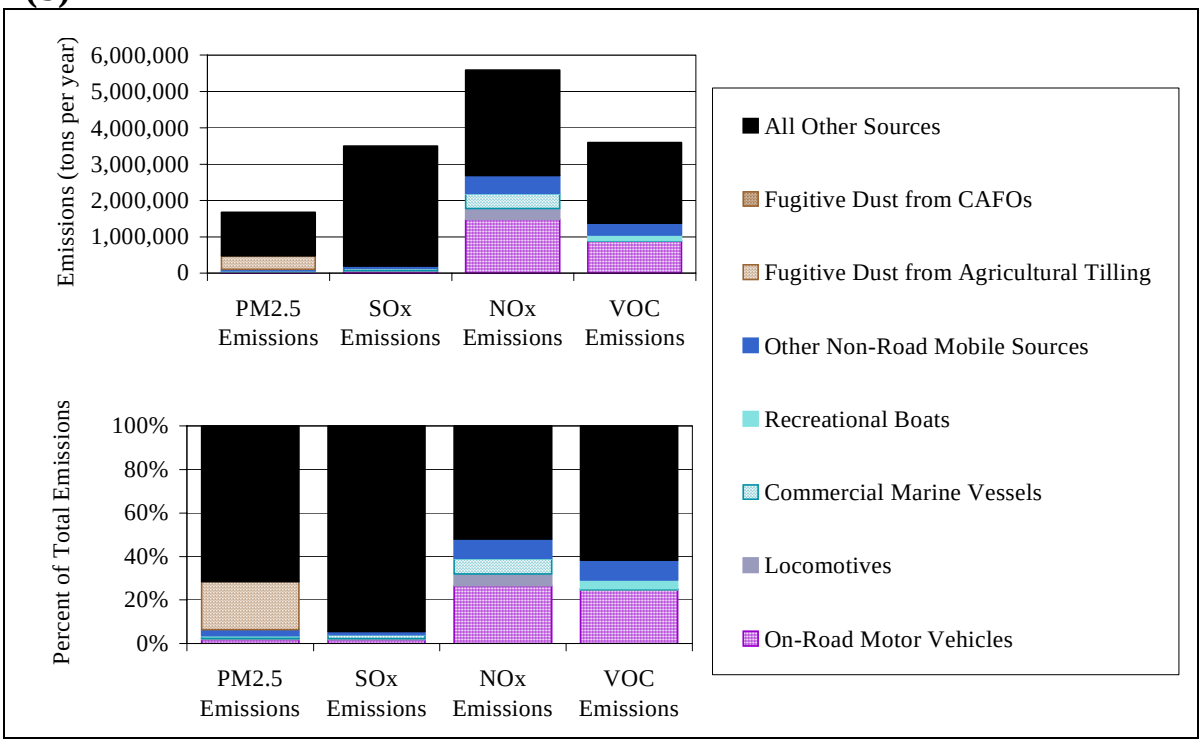


Figure ES-1. Annual emissions in the CENRAP region of selected pollutants as (a) calculated for the CENRAP for year 2002, and (b) recorded in the 1999 NEI or 2002 preliminary NEI.

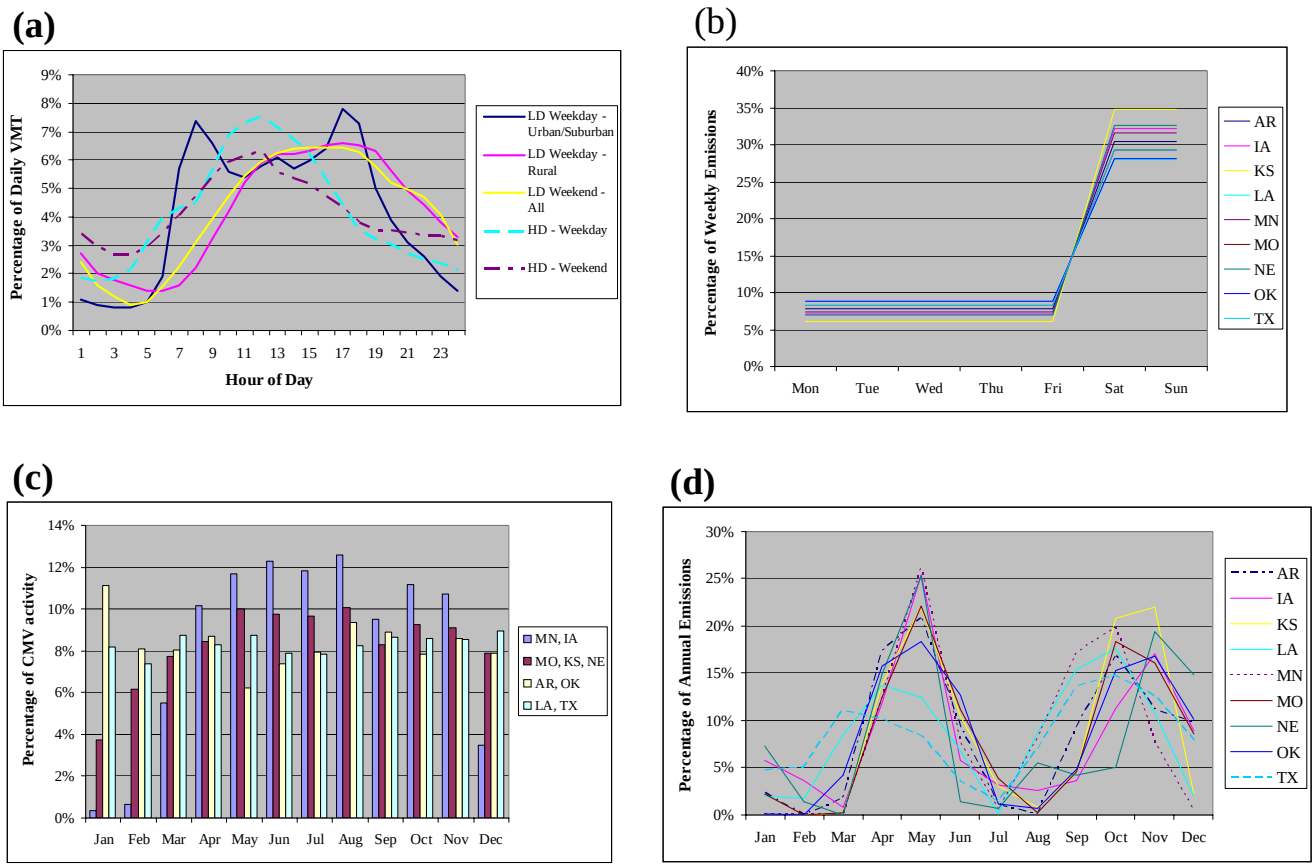


Figure ES-2. Selected temporal patterns, including (a) diurnal patterns for on-road mobile sources, (b) day-of-week patterns for recreational boats, (c) monthly patterns for commercial marine vessels by state, and (d) monthly patterns for agricultural tilling dust.

1. INTRODUCTION

The Central States Regional Air Planning Association (CENRAP) is developing a regional haze plan in response to the U.S. Environmental Protection Agency's (EPA) mandate to protect visibility in Class I areas.[2] To develop an effective regional haze plan, the CENRAP ultimately must develop a conceptual model of the phenomena that lead to episodes of low visibility in the CENRAP region. Thus, the CENRAP is researching visibility-related issues for its region, which includes Texas, Oklahoma, Louisiana, Arkansas, Kansas, Missouri, Nebraska, Iowa, and Minnesota. Both primary particulate matter (which is emitted directly to the atmosphere in particulate form) and the formation of secondary particulate matter (which is generated from chemical transformations in the atmosphere of gaseous precursor species such as ammonia, nitrogen oxides, sulfur oxides, and volatile organic compounds) contribute to regional haze issues in the CENRAP region. In recognition of these issues, the CENRAP sponsored the development of improved emission inventories for mobile sources and sources of agricultural dust.

In support of the CENRAP's need to develop a regional haze plan, Sonoma Technology, Inc. (STI) conducted CENRAP Work Assignment Number 03-0214-RP-003-004, "Mobile Source and Agricultural Dust Emission Inventory Development for the Central States." Consistent with the project goals presented in the Work Plan and Methods Document (Sullivan, 2004; Reid et al., 2004b), emissions were calculated for on-road mobile sources, off-road mobile sources, and sources of fugitive agricultural dust throughout the CENRAP region. Bottom-up or region-specific activity data were developed to model emissions from these source categories. These data were developed for compatibility with the MOBILE6 and NONROAD models; SMOKE 1.5 (which runs MOBILE6 internally); and the latest version of the National Emission Inventory Input Format (NIF).

1.1 BACKGROUND AND KEY ISSUES

1.1.1 Prior Status of the Emission Inventories

As a whole, few areas of the CENRAP region have experienced significant air quality problems in the past. Therefore, emission inventories and regionally representative activity data are relatively incomplete or scarce. In most areas of the CENRAP, existing emission inventories are based on the EPA's nationally representative defaults, which could be greatly improved with local or region-specific data, such as region-specific or state-specific fleet characteristics and improved vehicle miles traveled (VMT) estimates for rural areas. Prior to the completion of this project, the most comprehensive source of emissions estimates available for the CENRAP region was the EPA's National Emissions Inventory (NEI), which is used as the basis of the EPA's National Emission Trends (NET) document series and analyses (U.S. Environmental Protection Agency, 2003a, 2004a). In the NEI, estimates of emissions from mobile sources and sources of agricultural dust in the CENRAP region amount to 4% to 49% of the total inventories of nitrogen

[2] Class I areas include national parks, wilderness areas, and national monuments. These areas have been granted special air quality protections under the federal Clean Air Act.

oxides (NO_x), volatile organic compounds (VOC), particulate matter of 2.5 microns aerodynamic diameter or less ($PM_{2.5}$), sulfur dioxide (SO_2), and ammonia (NH_3) for the region (see **Table 1-1**). The NEI indicates that fugitive dust from agricultural tilling operations is a significant $PM_{2.5}$ source, particularly in of Iowa, Kansas, and Nebraska. Mobile sources are a significant source of NO_x and VOC, particularly in Minnesota and Missouri.

The most significant sources of uncertainties in the NEI are associated with the national-scale representativeness and top-down methods that were applied to generate the inventory (approaches that were dictated by resource constraints). The results of this project substantially address these weaknesses of the NEI for the CENRAP region. As a result, the emission inventories produced through this project differ significantly from the emissions estimates in the NEI in a number of areas.

Table 1-1. Estimates of emissions in the CENRAP region from the preliminary 2002 NEI (U.S. Environmental Protection Agency, 2004a).

State	NO_x		VOC		PM_{25}		SO_2		NH_3	
	tons/year	percent	tons/year	percent	tons/year	percent	tons/year	percent	tons/year	percent
Arkansas										
On-road Mobile	88,781	38%	49,525	9%	1,869	2%	3,610	2%	3,005	2%
Non-road Mobile	63,117	27%	30,343	5%	4,068	5%	6,665	3%	41	0%
Ag Dust (Tilling)	0	0%	0	0%	26,577	32%	0	0%	0	0%
Stationary Sources	83,253	35%	484,229	86%	50,494	61%	201,450	95%	129,188	98%
All Sources	235,151	100%	564,098	100%	83,008	100%	211,725	100%	132,234	100%
Iowa										
On-road Mobile	91,840	29%	50,816	23%	1,894	2%	3,520	1%	3,065	1%
Non-road Mobile	85,277	27%	34,771	16%	7,125	6%	8,735	4%	77	0%
Ag Dust (Tilling)	0	0%	0	0%	53,054	44%	0	0%	0	0%
Stationary Sources	135,678	43%	135,757	61%	57,649	48%	233,916	95%	223,502	99%
All Sources	312,796	100%	221,344	100%	119,722	100%	246,171	100%	226,644	100%
Kansas										
On-road Mobile	82,475	23%	48,692	25%	1,680	1%	3,192	2%	2,889	2%
Non-road Mobile	81,868	23%	24,426	13%	6,048	4%	7,598	5%	65	0%
Ag Dust (Tilling)	0	0%	0	0%	67,217	42%	0	0%	0	0%
Stationary Sources	198,667	55%	120,478	62%	85,377	53%	146,752	93%	135,475	98%
All Sources	363,010	100%	193,595	100%	160,322	100%	157,542	100%	138,429	100%
Louisiana										
On-road Mobile	119,067	16%	72,130	22%	2,488	2%	4,868	1%	4,220	6%
Non-road Mobile	230,407	31%	55,827	17%	11,342	10%	33,028	9%	52	0%
Ag Dust (Tilling)	0	0%	0	0%	12,649	11%	0	0%	0	0%
Stationary Sources	398,375	53%	193,623	60%	87,899	77%	347,159	90%	61,320	93%
All Sources	747,849	100%	321,581	100%	114,379	100%	385,054	100%	65,591	100%
Minnesota										
On-road Mobile	153,145	35%	87,926	23%	3,010	2%	4,168	3%	5,482	3%
Non-road Mobile	113,288	26%	97,023	25%	9,469	5%	12,395	8%	99	0%
Ag Dust (Tilling)	0	0%	0	0%	50,009	25%	0	0%	0	0%
Stationary Sources	171,536	39%	196,362	51%	136,045	69%	135,908	89%	160,447	97%
All Sources	437,969	100%	381,311	100%	198,534	100%	152,471	100%	166,028	100%

Table 1-1. Estimates of emissions in the CENRAP region from the preliminary 2002 NEI (U.S. Environmental Protection Agency, 2004a).

State	NO_x		VOC		PM_{25}		SO_2		NH_3	
	tons/year	percent	tons/year	percent	tons/year	percent	tons/year	percent	tons/year	percent
Missouri										
On-road Mobile	188,404	36%	109,927	31%	3,877	2%	6,845	2%	6,958	6%
Non-road Mobile	117,011	22%	55,279	15%	7,363	4%	12,034	3%	71	0%
Ag Dust (Tilling)	0	0%	0	0%	27,251	14%	0	0%	0	0%
Stationary Sources	216,722	42%	193,867	54%	163,294	81%	353,408	95%	112,354	94%
All Sources	522,137	100%	359,073	100%	201,784	100%	372,287	100%	119,383	100%
Nebraska										
On-road Mobile	55,284	25%	31,291	24%	1,131	1%	2,094	2%	1,850	1%
Non-road Mobile	89,946	41%	18,882	15%	5,323	5%	7,394	8%	49	0%
Ag Dust (Tilling)	0	0%	0	0%	38,068	38%	0	0%	0	0%
Stationary Sources	73,046	33%	77,809	61%	55,683	56%	83,563	90%	133,536	99%
All Sources	218,276	100%	127,982	100%	100,204	100%	93,051	100%	135,435	100%
Oklahoma										
On-road Mobile	126,710	30%	77,579	30%	2,615	2%	5,756	3%	4,468	4%
Non-road Mobile	51,962	12%	30,513	12%	3,940	3%	4,736	2%	45	0%
Ag Dust (Tilling)	0	0%	0	0%	27,732	19%	0	0%	0	0%
Stationary Sources	242,264	58%	150,107	58%	111,473	76%	182,502	95%	110,303	96%
All Sources	420,937	100%	258,199	100%	145,759	100%	192,994	100%	114,815	100%
Texas										
On-road Mobile	577,082	25%	349,211	30%	11,778	2%	23,343	1%	22,340	7%
Non-road Mobile	377,155	16%	153,570	13%	21,998	4%	42,373	3%	210	0%
Ag Dust (Tilling)	0	0%	0	0%	67,342	12%	0	0%	0	0%
Stationary Sources	1,377,264	59%	661,726	57%	453,992	82%	1,622,787	96%	278,886	93%
All Sources	2,331,502	100%	1,164,507	100%	555,111	100%	1,688,503	100%	301,436	100%
All States										
On-road Mobile	1,482,789	27%	877,097	24%	30,342	2%	57,397	2%	54,277	4%
Non-road Mobile	1,210,032	22%	500,634	14%	76,677	5%	134,957	4%	708	0%
Ag Dust (Tilling)	0	0%	0	0%	369,899	22%	0	0%	0	0%
Stationary Sources	2,896,806	52%	2,213,958	62%	1,201,905	72%	3,307,446	95%	1,345,010	96%
All Sources	5,589,626	100%	3,591,689	100%	1,678,823	100%	3,499,799	100%	1,399,995	100%

1.1.2 Current Status of the CENRAP Emission Inventories

As detailed in the attached Methods Document (Appendix A), emissions estimates were prepared for mobile sources and sources of agricultural dust throughout the CENRAP region. These emission inventories were prepared with EPA-accepted emissions models (e.g., NONROAD, SMOKE, and MOBILE6), emission factors gathered from EPA guidance documents or published literature, and geographic information systems (GIS) databases of land cover. All activity data sets were prepared using bottom-up methods or region-specific information whenever possible.

The MOBILE6 emissions model, the EPA's approved emission factor model for on-road mobile sources, was operated within SMOKE 1.5 to produce emission factors for January and July at the county level. Spatially and temporally distributed MM5 temperature fields for each day in January and July 2002 were averaged and used as inputs for these MOBILE6 runs so that outputs would represent an entire month rather than a specific episode date. The MOBILE6 outputs were matched with region-specific, county-level estimates of VMT, which also were distributed seasonally and by day of week according to temporal profiles, to estimate county-level emissions for the winter and summer runs. January and July emissions were averaged to estimate annual emissions at the county level. MOBILE6 inputs were prepared at the county level to represent region-specific fleet distributions, fuels characteristics (which can also vary by season), and local regulations (e.g., inspection and maintenance programs, etc.).

The latest version of the NONROAD emissions model (NONROAD 2004), the EPA's approved emission factor model for most off-road mobile sources, was used to produce emissions estimates at the county level for most off-road sources. In addition, EPA guidance documents were consulted for emissions estimation methods for locomotives and commercial marine vessels (U.S. Environmental Protection Agency, 1999c, 1998b, 2000, 2003b, 1999a, 1997, 1992). Bottom-up activity data were gathered for recreational boats, locomotives, and commercial marine vessels—considered to be the most important or uncertain off-road mobile sources affecting regional haze in the CENRAP region. For other source categories, NONROAD default activity data were used in conjunction with region-specific fuels information to estimate emissions. Emissions from aircraft were considered to be a lower priority than other nonroad mobile sources and were not included in the scope of this project.

The Emission Inventory Improvement Program and recent research findings from the University of California at Davis and Texas A&M University were consulted for emission factors and emissions estimation methods for agricultural fugitive dust sources (U.S. Environmental Protection Agency, 2004b; Goodrich et al., 2002; Flocchini and James, 2001). County-level annual emission inventories were prepared for agricultural tilling operations and confined animal feeding operations (CAFOs). Bottom-up activity data included facility-specific animal populations developed for CAFOs in the CENRAP region (Coe and Reid, 2003), agricultural tilling activity information developed through systematic telephone surveys of county agricultural extension services (AES) throughout the CENRAP region (Reid et al., 2004a), and county-level estimates of crop-acreages in 2002 from the National Agricultural Statistics Service (NASS).

The resulting emission inventories are illustrated in **Figures 1-1 through 1-6** and tabulated in Appendix B. In all cases, the inventories were based on generally accepted emission factors and the most complete and up-to-date activity data sets that could be identified and acquired. However, we recognize that available emission factors are uncertain and continue to be the subject of research. In anticipation of future efforts to improve emissions estimation techniques and to further develop or improve the CENRAP's inventories, the deliverables of this project include systems of data files that can be updated with revised emission factors, activity data, and/or emissions estimates as new information becomes available (see Appendix D).

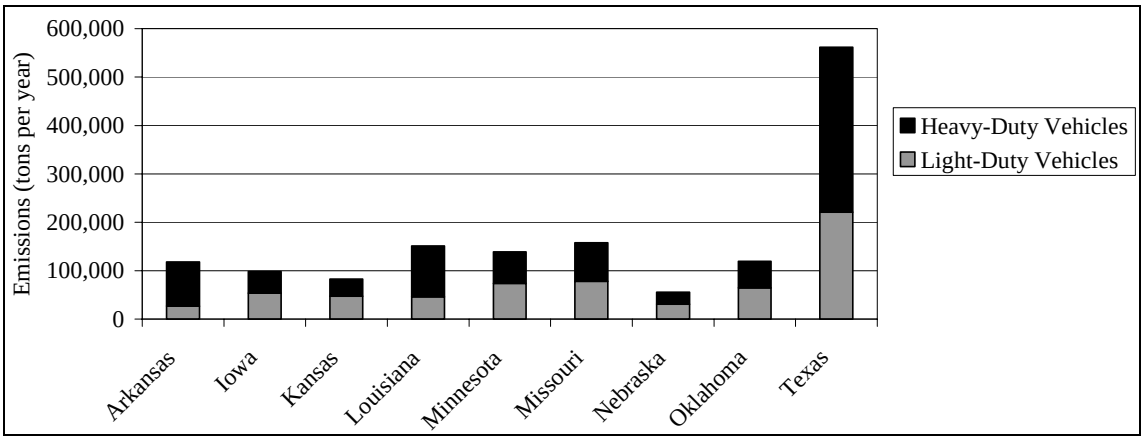


Figure 1-1. Year-2002 emissions of NO_x from on-road mobile sources in the CENRAP region.

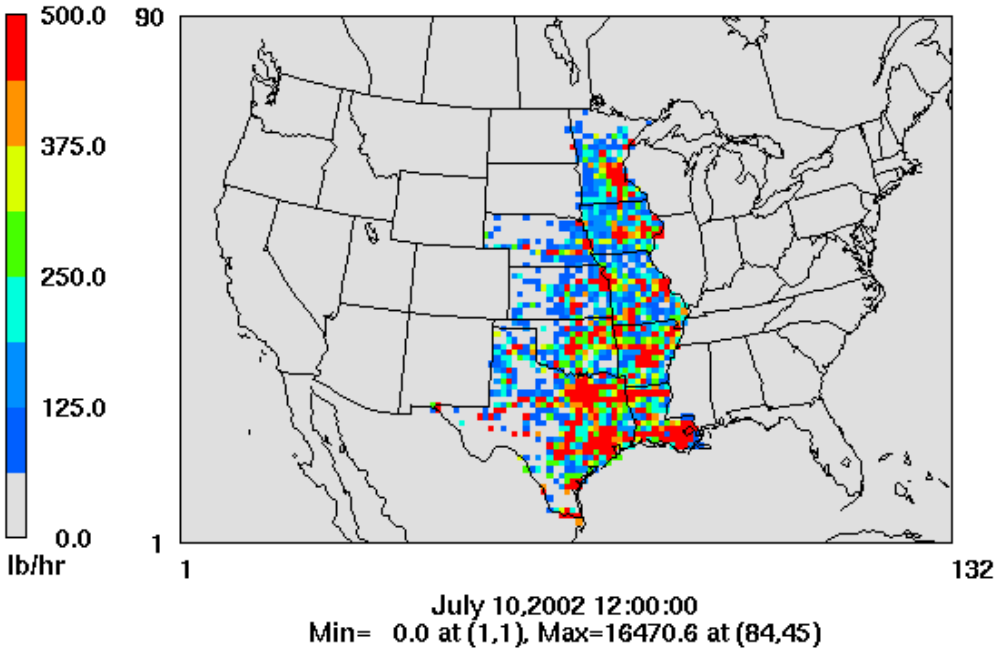


Figure 1-2. Geographic distribution of on-road mobile source emissions of NO_x in the CENRAP states on July 10, 2002.

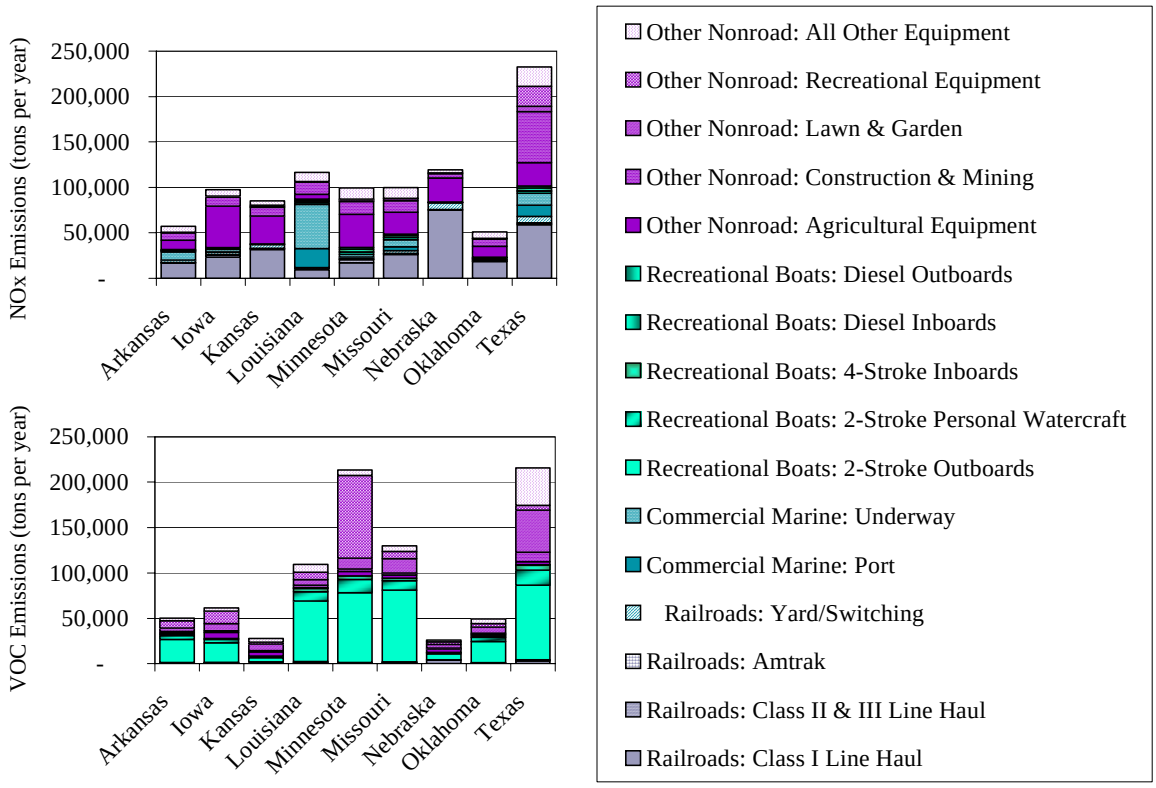


Figure 1-3. Year-2002 emissions of NO_x and VOC from non-road mobile sources in the CENRAP region.

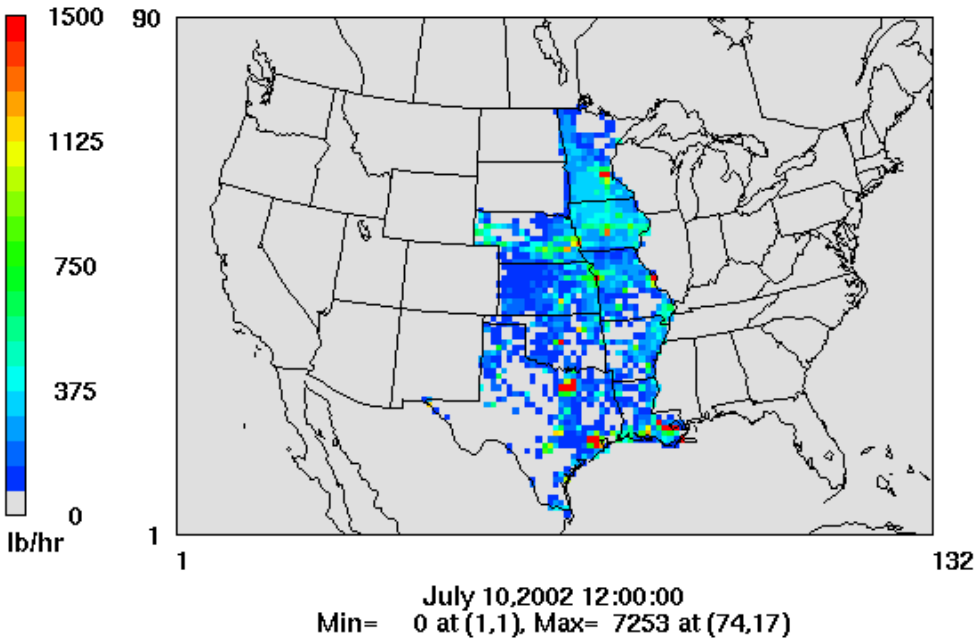


Figure 1-4. Geographic distribution of non-road mobile source NO_x in the CENRAP states on July 10, 2002.

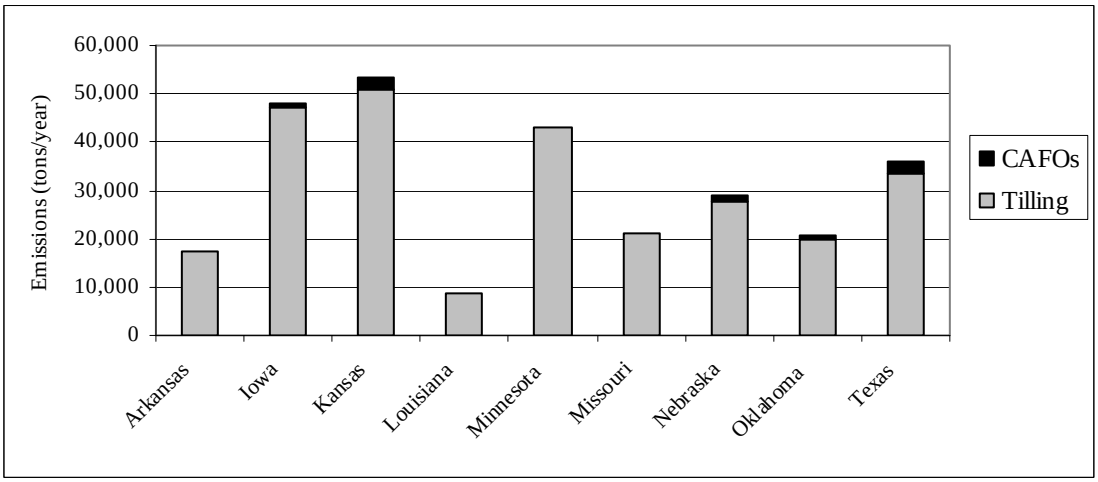


Figure 1-5. Year-2002 emissions of $PM_{2.5}$ from sources of fugitive agricultural dust in the CENRAP region.

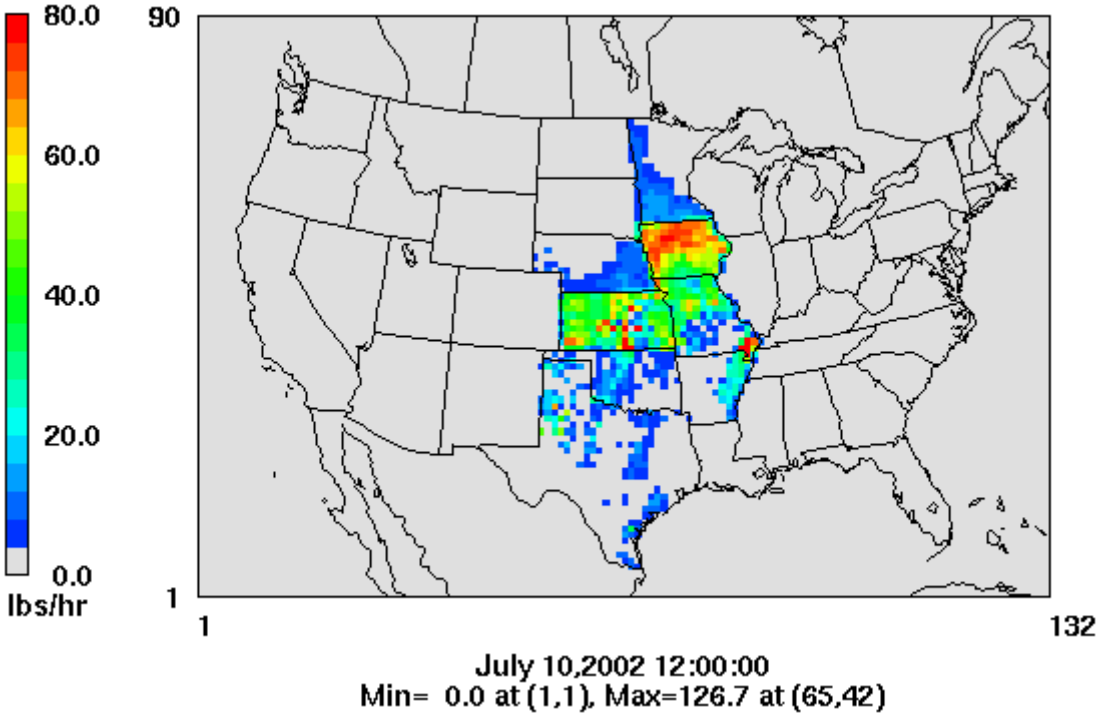


Figure 1-6. Geographic distribution of $PM_{2.5}$ emissions from sources of agricultural fugitive dust in the CENRAP states on July 10, 2002.

Of the mobile and agricultural fugitive dust sources discussed throughout this report, those that we qualitatively consider to contribute the greatest degrees of uncertainty to the emissions for the CENRAP region are agricultural fugitive dust sources and "other" non-road mobile sources.[3] The most effective strategies to improve these components of the inventory in the future would be to develop process-based emissions estimation techniques for agricultural fugitive dust sources and to prioritize and gather bottom-up activity data for "other" non-road mobile sources (as was done through this project for recreational boating). These recommendations are discussed in more detail in Section 3.

[3] "Other" non-road mobile sources include all non-road mobiles sources other than locomotives, commercial marine vessels, recreational boats, and aircraft.

2. SUMMARY AND ASSESSMENT OF THE INVENTORIES

STI calculated emissions as detailed in Appendix A, Emission Estimation Methods for Mobile Sources and Agricultural Dust Sources in the Central States, with results tabulated in Appendix B, Annual Emissions by State and Source Category. In addition, STI carried out quality assurance procedures as provided in the Quality Assurance Project Plan (QAPP) (Sullivan, 2004) and as detailed in this section. In summary, emissions from on-road mobile sources were estimated to contribute 20% and 28% of total annual emissions of VOCs and NO_x in the CENRAP region, while non-road mobile sources were estimated to contribute 23% and 18%, respectively. Agricultural dust sources were estimated to contribute 17% of total annual $PM_{2.5}$ emissions. Emissions for many of these source categories vary seasonally, daily, and hourly. Emissions of NO_x and VOC from on-road mobile sources peak in the summer with somewhat increased vehicle activity (VMT); however, emissions of CO from on-road mobile sources peak in the winter due to colder ambient temperatures. In addition, diurnal and day-of-week patterns of emissions from on-road mobile sources vary. On-road mobile emissions are generally greater on weekdays than on weekend days; and weekday driving activities track the morning and afternoon commute patterns, while weekend driving activities do not. The variation of seasonal, diurnal, and day-of-week patterns for recreational boats is even more pronounced than that for on-road mobile sources. Emissions from recreational boats are highly concentrated in the summer months (except in the warmest, most southern states) and on weekend days. Recreational boating activities peak sharply between 0700 and 1000 and decline gradually throughout the day. Emissions from commercial marine vessels also follow a seasonal pattern (except in the warmest, most southern states). Emissions from locomotives vary minimally or negligibly by season, day of week, and hour of day. Emissions from agricultural tilling operations follow seasonal patterns that are unique to each state and dependent on the climatic conditions and types of crops grown in each state.

2.1 EMISSIONS FROM ON-ROAD MOBILE SOURCES

2.1.1 Summary of Emissions from On-Road Mobile Sources

Over 525 billion VMT were estimated to have occurred in 2002 in the CENRAP region, with consequent emissions as shown in **Table 2-1** and **Figure 2-1**. **Figure 2-2** illustrates the geographic distribution of on-road mobile source emissions for a selected date.

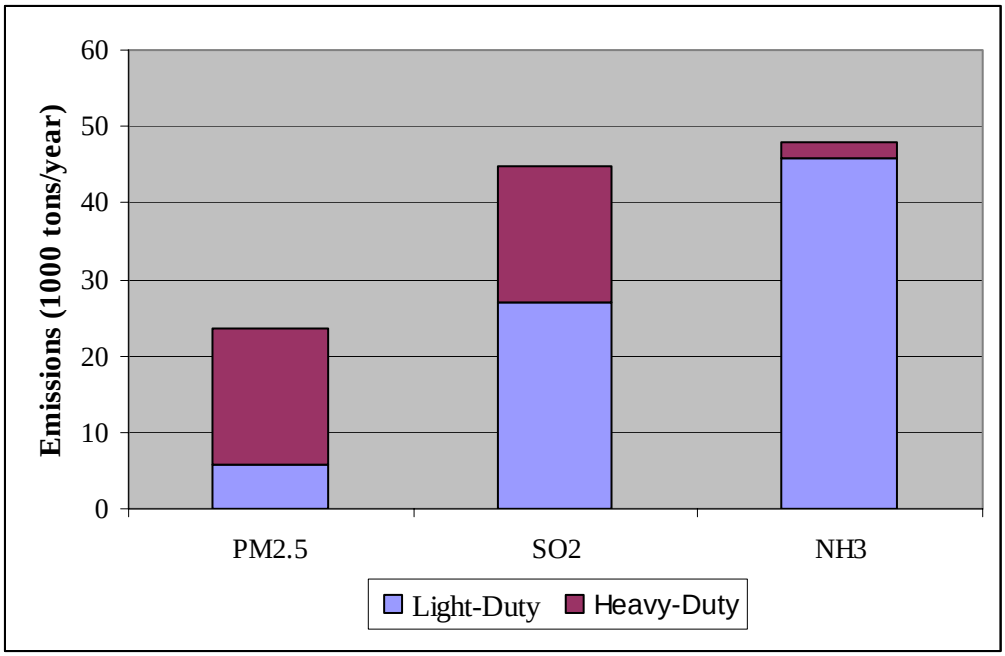
Appendix C provides graphical and tabular summaries of the activity data that were prepared for the emission inventories of on-road mobile sources, including VMT, fleet distributions, fuels characteristics, and regulatory controls. Whenever possible, VMT were acquired from local air quality agencies or metropolitan planning organizations and HPMS data were used as defaults for areas without local VMT estimates. VMT data were provided by local agencies for approximately 25% of the counties in the CENRAP region, while the remainder are from the HPMS data. Areas that were able to provide local estimates of VMT included Houston/Galveston, Texas; Beaumont/Port Arthur, Texas; Dallas-Ft. Worth, Texas; Baton Rouge, Louisiana; New Orleans, Louisiana; St. Louis, Missouri; and Lincoln, Nebraska. Metropolitan areas that have recently produced local estimates of VMT (or will do so very

shortly) include Kansas City, Minneapolis-St. Paul, and Little Rock. In the future, these locally generated VMT estimates should be used to improve the emission inventories for the CENRAP region.

Fleet distributions were developed by acquiring records of vehicle registrations from the departments of motor vehicles in each CENRAP state. These records were decoded using the Eastern Research Group (ERG) Vehicle Identification Number (VIN) Decoder program. Fleet distributions by vehicle type, vehicle age, and fuel type were calculated on the basis of the ERG VIN Decoder outputs. In several states, the fleet distributions differed significantly from national average distributions, which correspond to MOBILE6 model defaults.

Table 2-1. 2002 VMT and emissions (tons) for on-road mobile sources in CENRAP states.

State	Annual VMT (10^6 miles)	$PM_{2.5}$	CO	NO_x	SO_2	NH_3	VOC
Arkansas							
Light-Duty	19,224	235	502,991	27,137	1,383	1,971	29,752
Heavy-Duty	9,955	2,076	102,247	90,833	2,163	313	9,786
Iowa							
Light-Duty	27,664	381	973,854	53,702	2,113	2,755	67,501
Heavy-Duty	3,701	931	30,853	44,607	884	107	2,993
Kansas							
Light-Duty	25,424	345	930,039	47,210	1,938	2,528	61,867
Heavy-Duty	3,401	855	29,686	35,520	758	98	2,979
Louisiana							
Light-Duty	34,246	416	824,585	45,929	2,396	3,485	57,283
Heavy-Duty	9,049	2,272	74,770	105,449	2,257	263	7,361
Minnesota							
Light-Duty	46,880	595	1,285,076	73,656	1,274	4,771	75,663
Heavy-Duty	6,271	1,577	43,160	65,290	1,314	182	5,255
Missouri							
Light-Duty	53,030	680	1,375,126	77,916	3,120	5,356	76,004
Heavy-Duty	7,238	1,841	52,065	79,607	1,787	209	5,491
Nebraska							
Light-Duty	15,957	246	581,402	30,649	1,229	1,581	38,788
Heavy-Duty	2,449	624	18,626	25,037	589	71	2,115
Oklahoma							
Light-Duty	39,569	509	1,194,649	64,504	2,989	3,968	81,676
Heavy-Duty	5,293	1,331	48,382	54,812	1,265	154	5,062
Texas							
Light-Duty	190,132	2,339	3,653,523	220,819	10,555	19,365	248,680
Heavy-Duty	25,989	6,276	113,949	340,992	6,667	692	14,057
Total	525,473	23,529	11,834,984	1,483,668	44,678	47,870	792,310



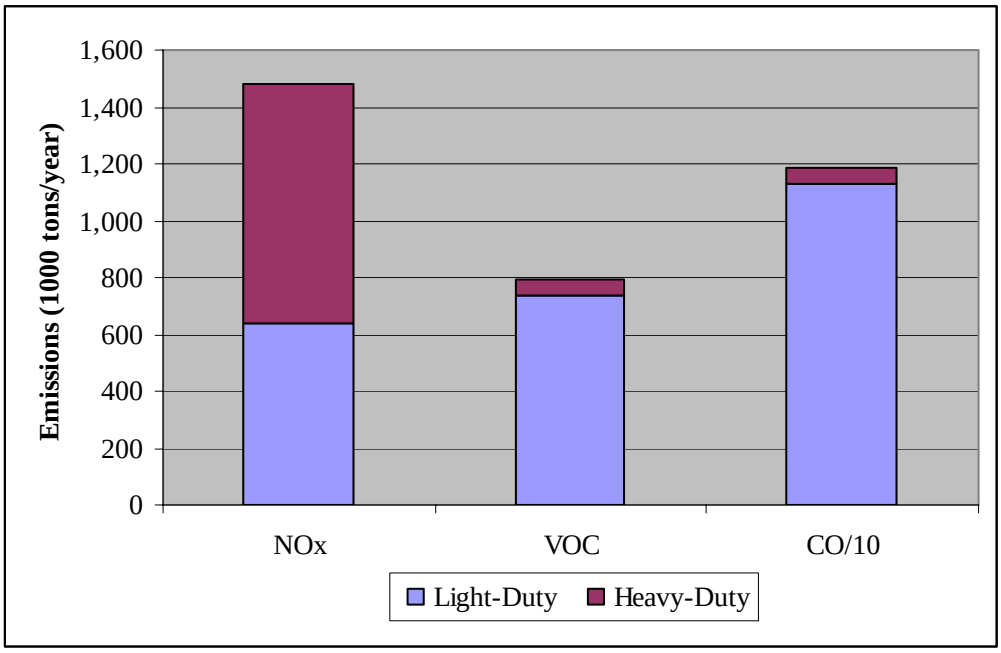


Figure 2-1. Annual on-road mobile emissions by pollutant and vehicle type (note: CO emissions have been divided by 10 for scaling purposes).

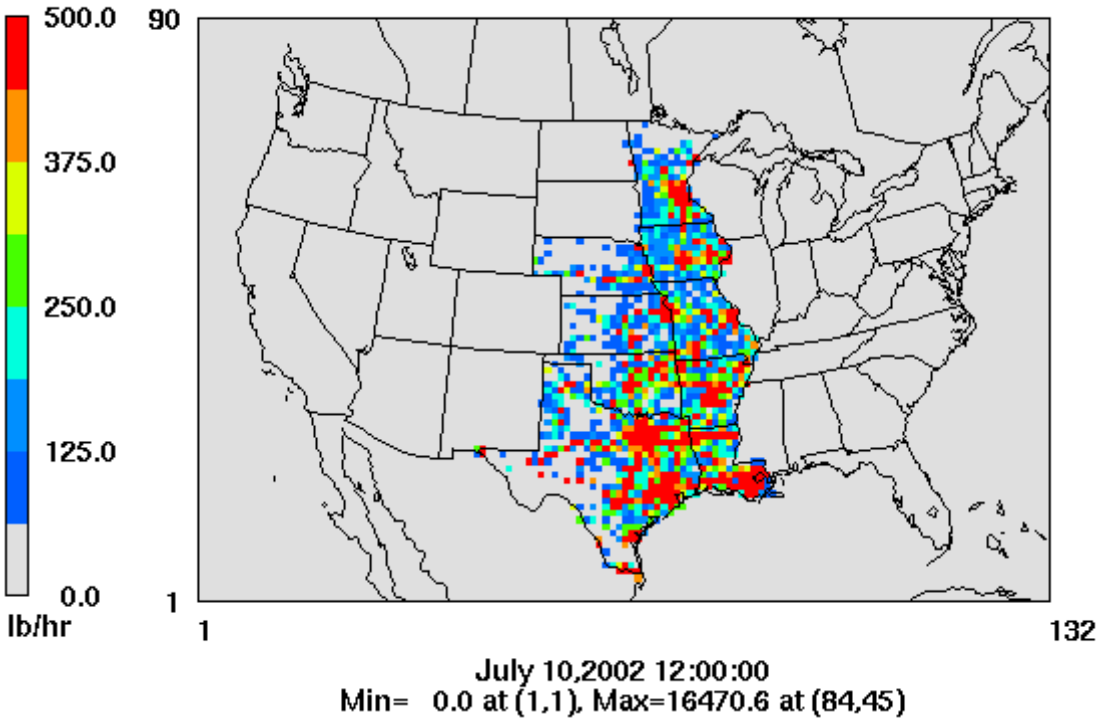


Figure 2-2. Geographic distribution of on-road mobile source emissions of NO_x in the CENRAP states on July 10, 2002.

Fuels characteristics (e.g., sulfur content, volatility, and oxygenate content) required by MOBILE6 were acquired for most CENRAP states from Northrop Grumman. However, for Kansas, Minnesota, and Missouri, data from state departments of agriculture were used because they proved to be more extensive than the Northrop Grumman data. Information on regulatory programs (such as inspection and maintenance programs) was acquired by contacting the state and local personnel involved with these programs.

MOBILE6 was run in SMOKE using gridded, hourly temperature data from meteorological files created by the Meteorology Chemistry Interface Processor (MCIP), a mesoscale model (MM5) post-processing program. Meteorological data files for all of January and July, 2002 were provided by the CENRAP Modeling Work Group, and these files were used to derive monthly average temperatures by hour so that MOBILE6 runs would be representative of entire months rather than specific episode dates.

On-road mobile source emissions were temporally allocated using temporal profiles derived from a variety of sources (see **Figures 2-3 through 2-5**). The monthly profiles for light-duty vehicles and heavy-duty vehicles were derived from national-level sales of gasoline and diesel fuels during 2002 (Energy Information Administration, 2003). SMOKE default weekly temporal profiles were used for light-duty vehicles because they were considered to be consistent with the latest research on weekday-weekend activity patterns. The weekly profile for heavy-duty vehicles was derived from traffic counts conducted in California's South Coast Air Basin

(Coe et al., 2004). County-specific data obtained from the Texas Transportation Institute and the East-West Gateway Coordinating Council were used to develop diurnal profiles for light-duty vehicles in Texas and five counties in the St. Louis area of Missouri. For the remainder of Missouri and all other states, a default SMOKE/EPA diurnal profile for weekdays was used for light-duty vehicles in urban and suburban areas, and a weekday rural profile was developed from the Texas data and applied to counties not associated with a Metropolitan Statistical Area (MSA). A weekend diurnal profile for light-duty vehicles and both a weekend and weekday profile for heavy-duty vehicles were derived from traffic counts conducted in California's South Coast Air Basin (Coe et al., 2004) and used for all CENRAP states. **Figure 2-5** shows all diurnal profiles used except county-specific profiles used for Texas and Missouri, which are detailed in Appendix C.

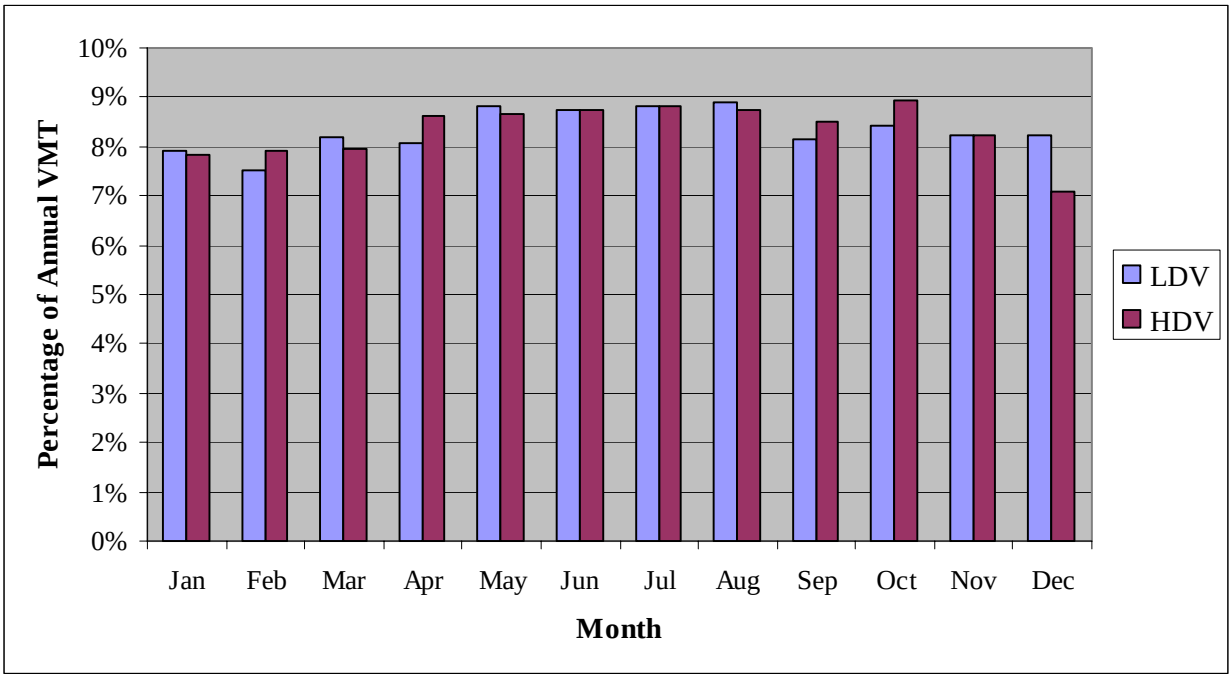


Figure 2-3. Monthly variation in on-road mobile source activity by vehicle type.

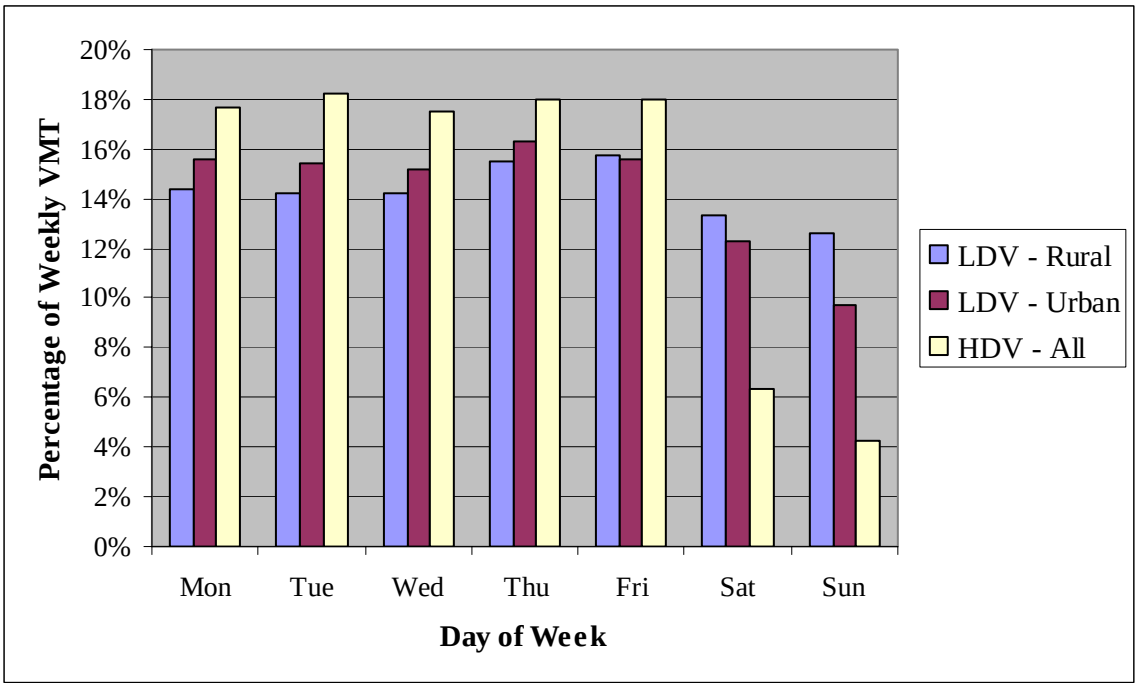


Figure 2-4. Weekly variation in on-road mobile source activity by vehicle type.

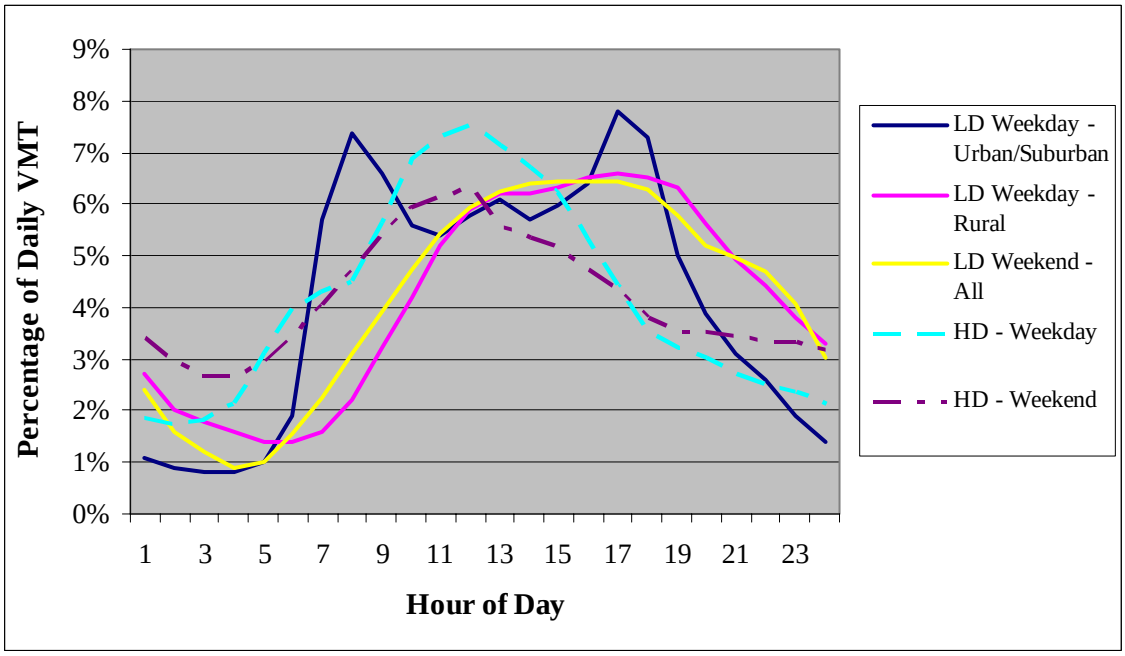


Figure 2-5. Diurnal variation in on-road mobile source emissions by vehicle type.

2.1.2 Assessment of On-Road Mobile Source Emissions

The emission inventories for on-road mobile sources are based on extensive region-specific information, including VMT data, fleet characteristics, temporal distributions, and regulatory program descriptions. These estimates were also strengthened by the use of gridded, hourly temperature data. The importance of using state and county-specific data can be seen in a comparison of the CENRAP's inventory with the preliminary 2002 NEI. As **Figure 2-6** shows, both inventories estimate 1.5 million tons of NO_x from on-road mobile sources for the CENRAP region as a whole. However, significant differences exist at the state level. For example, Louisiana's NO_x emissions are 27% higher than the estimates from the NEI, while Missouri's NO_x emissions are 16% lower. Differences are apparent at the CENRAP region-wide scale for VOC emissions, which are about 10% lower than those in the NEI, while region-wide $PM_{2.5}$ and SO_2 estimates are about 20% lower. These differences seem to arise primarily from the use of more localized temperature data, fuel volatility data, and fuel sulfur contents. For example, the 2002 NEI assumes an across-the-board diesel sulfur content of 500 ppmw (the regulatory limit), whereas the state-specific data used in this inventory ranged from 330-390 ppmw for the various CENRAP states. Further improvements could be made by continuing to acquire and incorporate local data. For example, improved VMT data are now available for the Kansas City metropolitan area and should be incorporated into future inventory efforts.

Further improvements to the VMT distributions for light-duty vehicle types may be feasible by applying vehicle registration data in novel ways. Many light-duty and/or diesel trucks (e.g., SUVs) are driven for similar purposes as passenger vehicles—a trend that was established in the 1990s and that continues to strengthen. Therefore, the ratio of registered SUVs to registered light-duty autos is likely to be proportional to the VMT traveled by these vehicle types. Alternatively, the VMT mix could be calculated from registration data using vehicle type-specific assumptions about annual mileage accumulation rates (AMAR), which are inherent to the MOBILE6 model. Such adjustments to the VMT distributions may be beneficial because emission factors vary significantly by light-duty vehicle class and fuel type and because MOBILE6 default VMT distributions may be out-of-date due to the rapidly increasing popularity of SUVs and light trucks.

Finally, it should be noted that an "annualized" on-road mobile source inventory was assembled as an average of SMOKE/MOBILE6 runs performed for January and July—a necessity given the current availability of meteorological data. The inventory could be improved by performing runs for all 12 months of the year as new meteorological inputs become available. However, this would likely produce only minor or insignificant changes in annual total emissions.

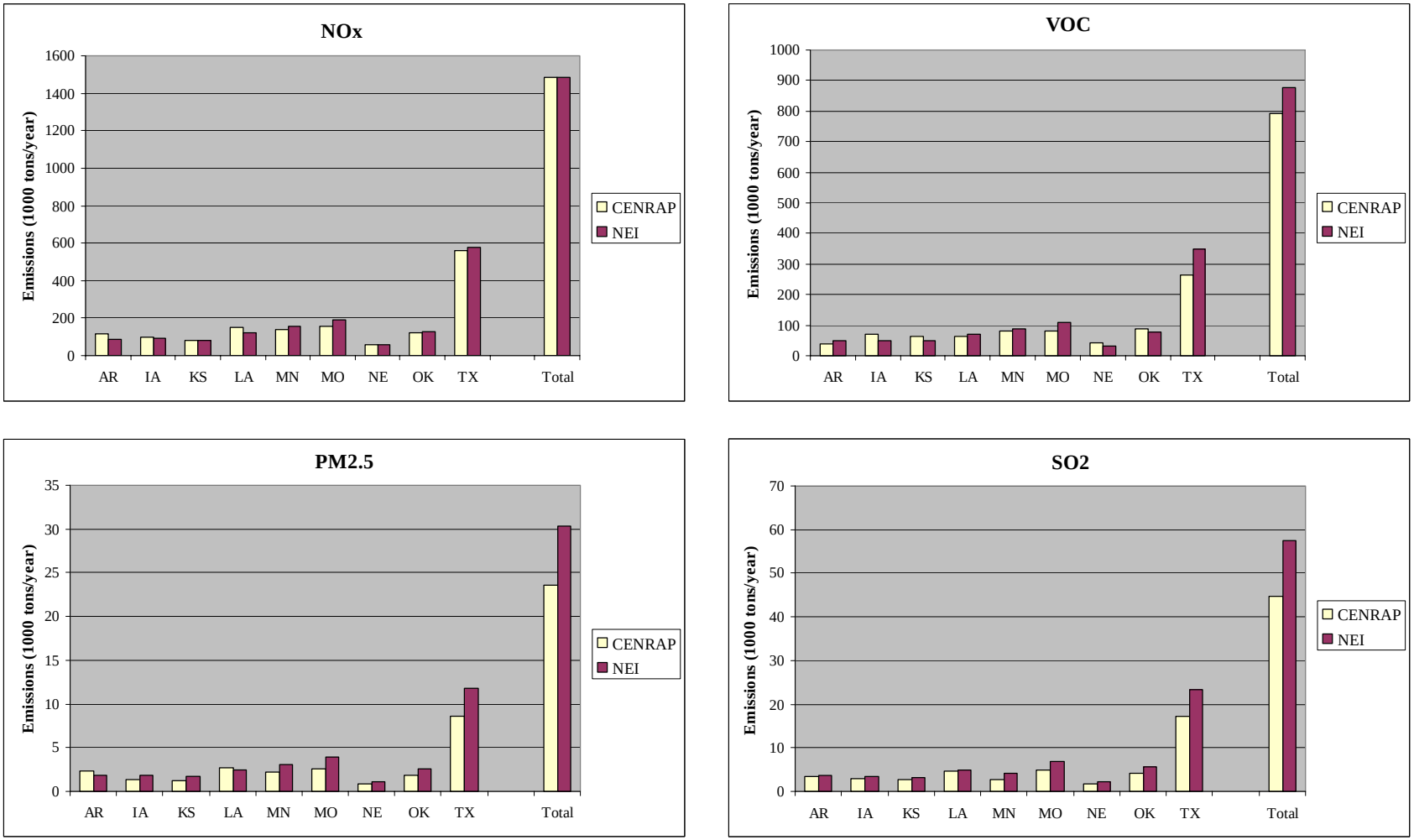


Figure 2-6. Comparison of CENRAP's emission inventories for on-road mobile source to the 2002 preliminary NEI.

2.2 EMISSIONS FROM NON-ROAD MOBILE SOURCES

2.2.1 Summary of Emissions from Locomotives

Emission estimates were generated for Class I line haul, Class II and III[4] line haul, and yard (or switching) locomotives throughout the CENRAP region using fuel consumption and traffic density data obtained from individual railroads, federal agencies, and other sources. Almost 1.5 billion gallons of diesel fuel were estimated to have been consumed by locomotives in the CENRAP region in 2002, with consequent emissions as shown in **Table 2-2** and **Figure 2-7**. **Figure 2-8** illustrates the geographic distribution of locomotive emissions for a selected date, and **Figure 2-9** shows the monthly variability in locomotive activity, which is based on weekly summaries of carloads of freight moved nationally during 2002.

Table 2-2. 2002 fuel consumption and emissions (tons) for locomotives in CENRAP states.

Page 1 of 2

State	Fuel Consumption (1000 gallons)	$PM_{2.5}$	CO	NO_x	SO_2	VOC	NH_3
Arkansas							
Class I Line Haul	79,645	530	2,334	16,769	1,434	880	7
Class II & III Line Haul	2,058	14	60	433	37	23	0
Amtrak	1,050	7	32	221	20	12	0
Yard/Switching	7,912	73	333	2,408	200	184	0
Iowa							
Class I Line Haul	110,685	738	3,243	23,304	1,992	1,224	10
Class II & III Line Haul	11,186	74	328	2,355	201	124	1
Amtrak	1,050	7	31	221	20	12	0
Yard/Switching	9,283	86	389	2,825	235	216	0
Kansas							
Class I Line Haul	150,063	1,000	4,397	31,596	2,702	1,659	14
Class II & III Line Haul	6,518	43	191	1,372	117	72	1
Amtrak	1,050	6	31	221	20	11	0
Yard/Switching	12,594	115	529	3,832	318	293	0
Louisiana							
Class I Line Haul	45,878	305	1,345	9,659	826	507	4
Class II & III Line Haul	576	4	17	121	10	6	0
Amtrak	1,500	10	43	315	27	16	0
Yard/Switching	5,556	50	233	1,691	139	129	0
Minnesota							
Class I Line Haul	80,483	536	2,358	16,946	1,449	890	7
Class II & III Line Haul	17,646	118	517	3,715	318	195	2
Amtrak	1,050	8	31	221	19	12	0
Yard/Switching	3,499	31	147	1,065	87	82	0

[4] Class I railroads operate over large areas of the country, serving many states. Class II railroads are regional in scope and serve only a few states, while Class III railroads are local and typically operate in only one state.

Table 2-2. 2002 fuel consumption and emissions (tons) for locomotives in CENRAP states.

State	Fuel Consumption (1000 gallons)	$PM_{2.5}$	CO	NO_x	SO_2	VOC	NH_3
Missouri							
Class I Line Haul	124,524	830	3,649	26,218	2,241	1,376	11
Class II & III Line Haul	3,352	22	98	706	60	37	0
Amtrak	2,400	15	70	504	42	25	0
Yard/Switching	9,463	86	398	2,880	239	220	0
Nebraska							
Class I Line Haul	357,167	2,379	10,465	75,201	6,429	3,948	33
Class II & III Line Haul	1,379	9	40	290	25	15	0
Amtrak	750	4	22	158	13	8	0
Yard/Switching	24,553	225	1,032	7,471	618	572	1
Oklahoma							
Class I Line Haul	86,879	578	2,545	18,293	1,564	961	8
Class II & III Line Haul	1,826	12	54	384	34	20	0
Amtrak	1,050	7	31	221	19	12	0
Yard/Switching	5,276	48	222	1,606	134	123	0
Texas							
Class I Line Haul	279,022	1,858	8,176	58,748	5,023	3,084	25
Class II & III Line Haul	5,539	37	162	1,166	100	61	1
Amtrak	5,250	34	155	1,105	94	57	0
Yard/Switching	23,723	220	996	7,217	600	551	1
Total	1,481,435	10,118	44,703	321,460	27,402	17,616	126

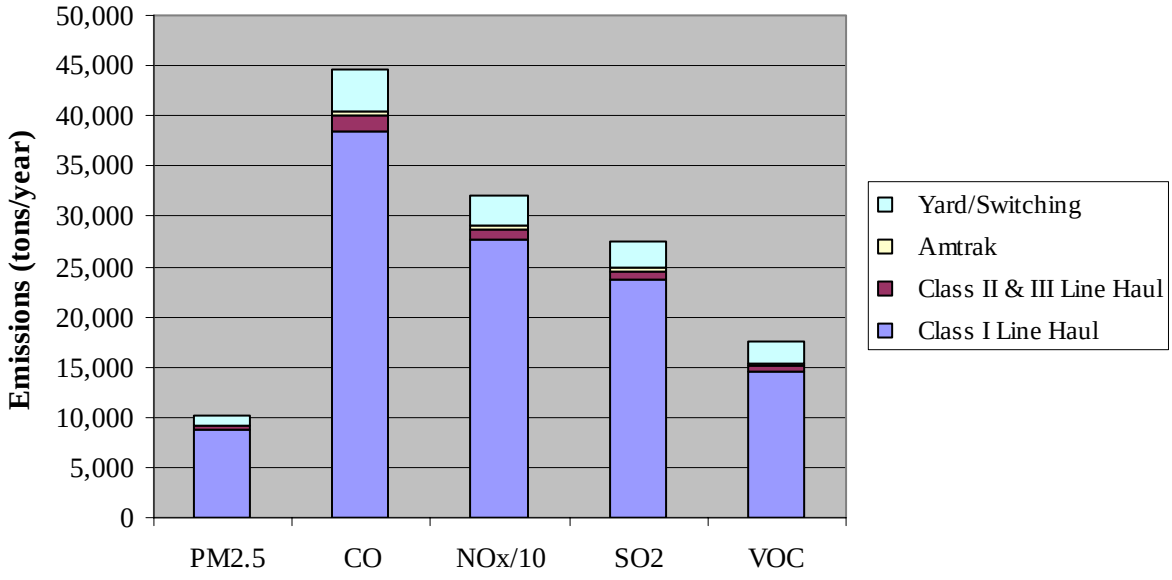


Figure 2-7. Annual locomotive emissions by pollutant and locomotive type for the CENRAP region (note: NO_x emissions have been divided by 10 for scaling purposes).

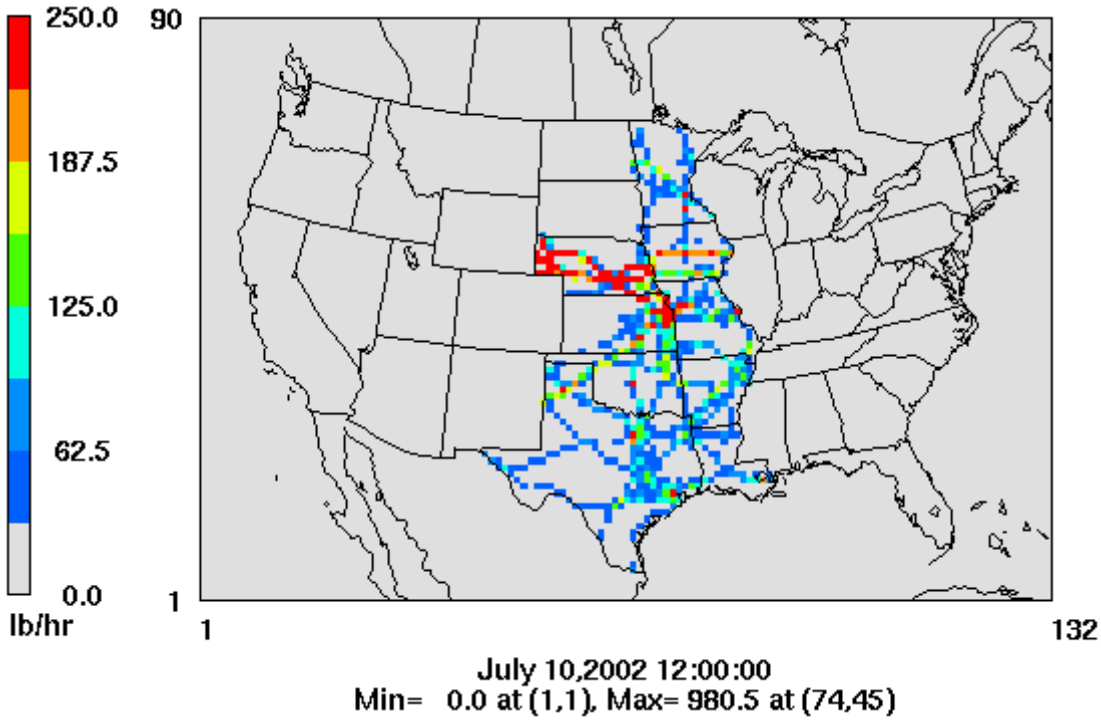


Figure 2-8. Geographic distribution of locomotive emissions of NO_x on July 10, 2002.

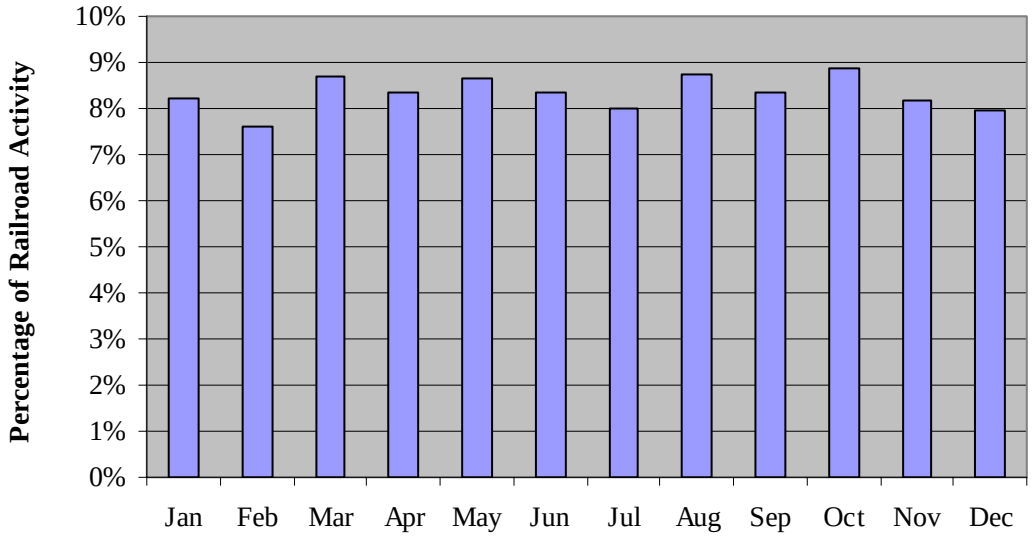


Figure 2-9. Monthly variability in locomotive activity.

2.2.2 Assessment of Emissions from Locomotives

Most of the effort of emission inventory development for locomotives was directed toward Class I railroads, which, though small in number, typically account for over 90% of the annual fuel consumption by railroads in the United States (U.S. Environmental Protection Agency, 1998a). Fuel consumption and traffic density data for 2002 were obtained for all eight Class I railroads operating in the CENRAP states, and this information was used to generate county-level emission estimates. Although less effort was expended on smaller railroads, representative bottom-up data sets were collected, including 2002 fuel consumption data for six of the 14 Class II railroads, and either fuel consumption data or yard locomotive fleet sizes for 35 of the 113 Class III and switching railroads that operate in the CENRAP region. Overall, of 1.48 billion gallons of fuel consumed by railroads in the CENRAP region for 2002, 1.44 billion gallons (or 97%) were directly reported by individual railroads, while the remainder were extrapolated from activity patterns. Therefore, the vast majority of the emission inventory for locomotives is based on directly reported, bottom-up activity data.

Figure 2-10 compares the CENRAP's inventory with the 2002 preliminary NEI inventory. CENRAP's emission estimates for most pollutants are about 50% higher than those in the NEI with the exception of NO_x, for which the CENRAP and NEI emission estimates are roughly equal. "Uncontrolled" emission factors were applied across the board for the 2002 NEI, which offset a corresponding underestimate of locomotive activity levels in the CENRAP area. CENRAP's NO_x inventory for locomotives reflects existing federal emission standards for locomotives. These emission standards, which took effect with the 1973 model year, predominately affect NO_x emissions. Therefore, although activity levels estimated for the CENRAP inventory were higher than those estimated for the NEI, the resultant NO_x emissions are about the same.

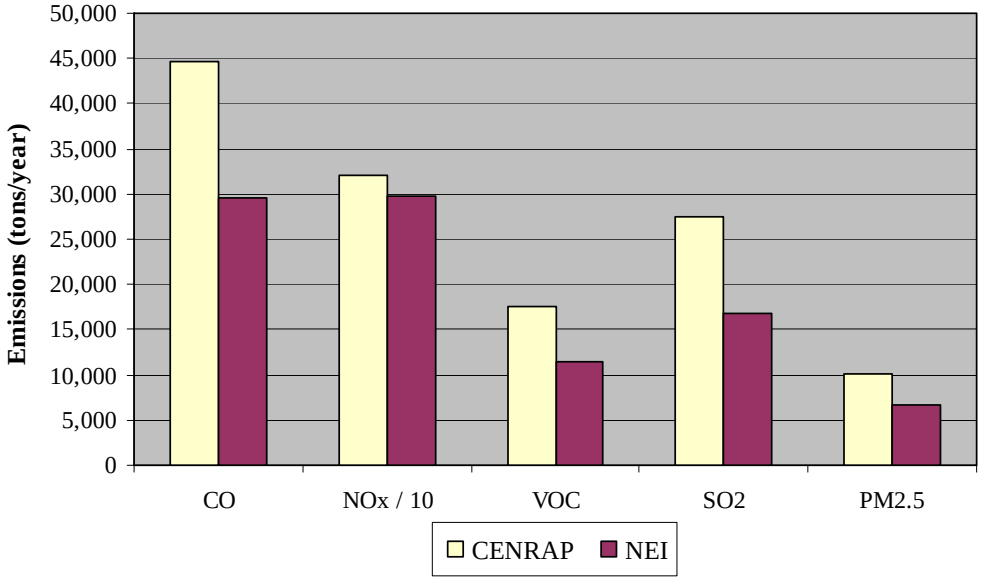


Figure 2-10. Comparison of locomotive emissions estimates with results from the 2002 preliminary NEI (note: NO_x emissions have been divided by 10 for scaling purposes).

Use of 2002 railroad-specific fuel consumption estimates and emission factors reflective of existing emissions standards greatly improved the degree of certainty in the CENRAP region-wide emission inventory above that associated with the preliminary 2002 NEI. Additional survey work could improve the accuracy of the inventory, but this improvement would likely be significant only at county or metropolitan scales where railroad activities are dominated by Class II or III railroads. In addition, local data would likely be more representative of variances in local activity patterns than the national-level data that were used to create a monthly temporal profile.

2.2.3 Summary of Emissions from Commercial Marine Vessels

Emission estimates were generated for commercial marine vessels operating in commercially active waterways in the CENRAP region, including inland river systems, Lake Superior, and the Gulf Intracoastal Waterway (GIWW). County-level emissions were designated as either "in-port" or "underway", as shown in **Table 2-3** and **Figure 2-11**. **Figure 2-12** illustrates the geographic distribution of commercial marine emissions for a selected date, and **Figure 2-13** shows the monthly variability in commercial marine activity by state, with profiles based on monthly summaries of freight movements through selected locks and ports for 2002.

Table 2-3. 2002 commercial marine vessel emissions (tons) in CENRAP states.

State	Type	CO	NOx	VOC	SO2	PM2.5	NH_3
Arkansas	Port	13	68	1	6	1	0
	Underway	1,783	9,274	193	889	197	4
Iowa	Port	55	286	6	27	6	0
	Underway	534	2,776	58	266	59	1
Kansas	Port	2	9	0	1	0	0
	Underway	4	22	0	2	0	0
Louisiana	Port	2,719	20,772	739	5,369	693	6
	Underway	6,912	48,574	999	7,082	1,221	7
Minnesota	Port	211	1,533	57	230	37	1
	Underway	492	2,822	65	484	79	1
Missouri	Port	585	4,281	170	443	84	2
	Underway	1,472	7,656	159	734	163	3
Nebraska	Port	1	3	0	0	0	0
	Underway	5	27	1	3	1	0
Oklahoma	Port	1	5	0	0	0	0
	Underway	97	505	10	48	11	0
Texas	Port	1,613	12,300	423	4,315	526	3
	Underway	1,882	13,009	300	5,778	686	3
Total		18,381	123,922	3,182	25,677	3,764	32

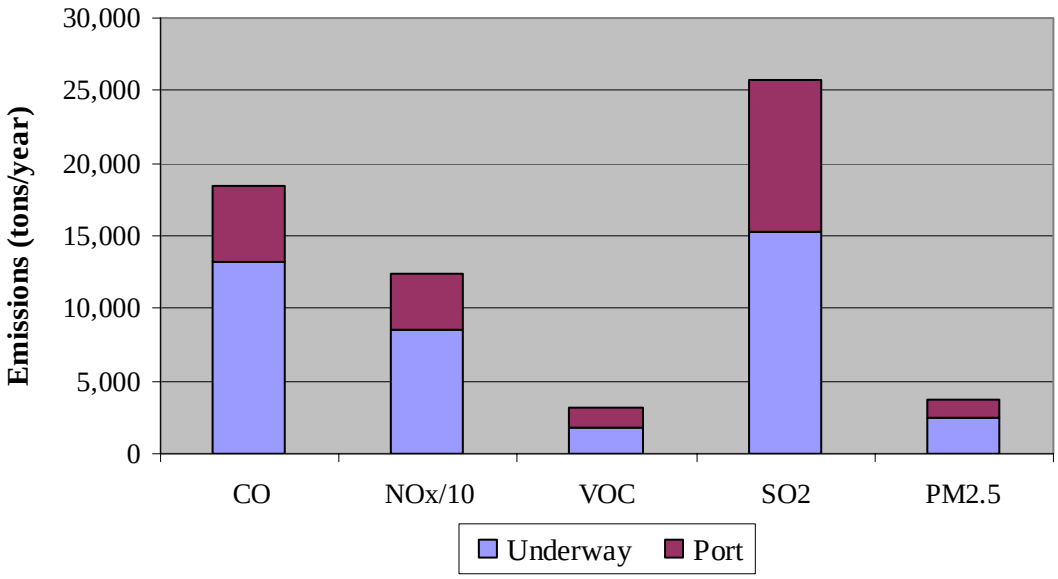


Figure 2-11. Annual commercial marine vessel emissions by pollutant and source type for the CENRAP region (note: NO_x emissions have been divided by 10 for scaling purposes).

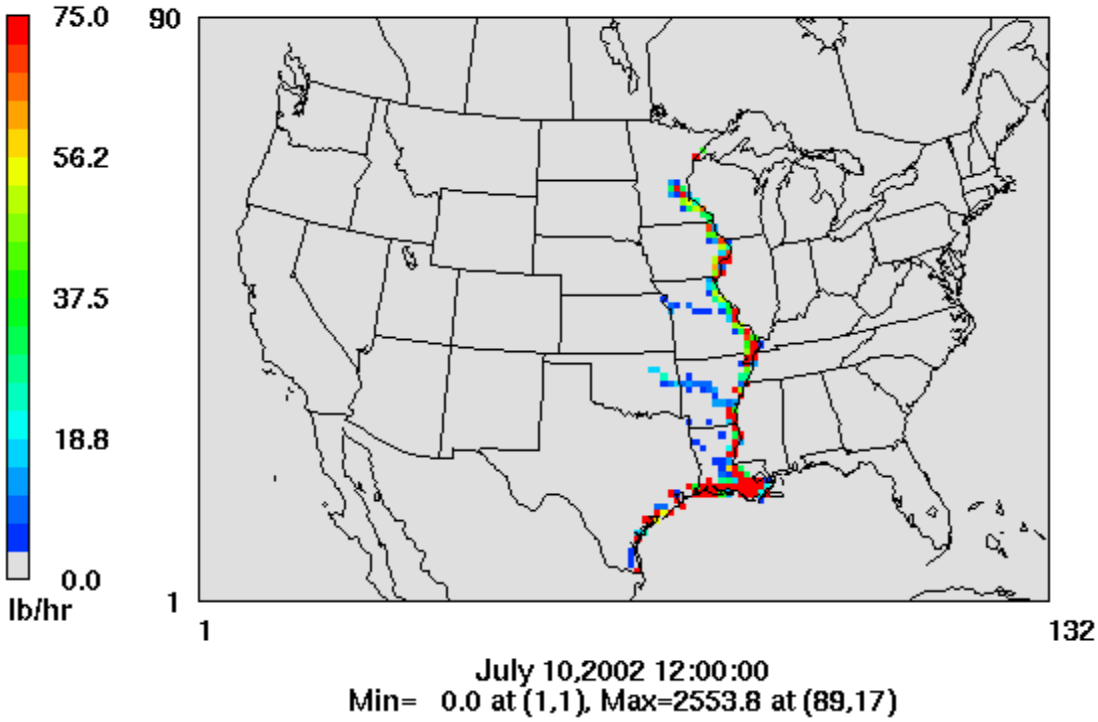


Figure 2-12. Geographic distribution of commercial marine emissions of NO_x in the CENRAP states on July 10, 2002.

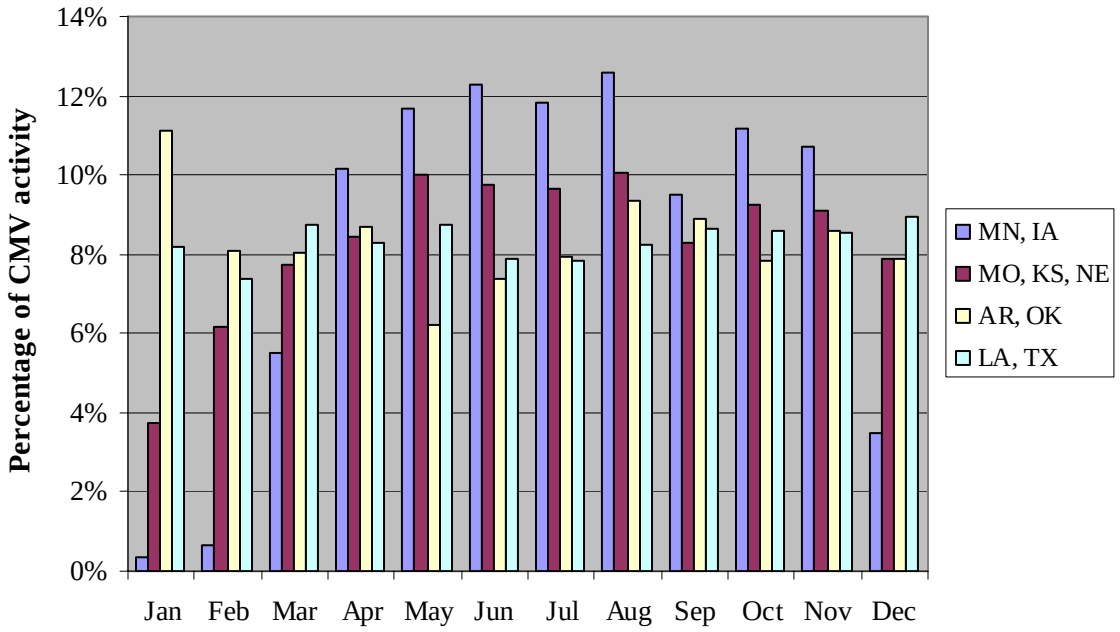


Figure 2-13. Monthly variability in commercial marine vessel activity.

2.2.4 Assessment of Emissions from Commercial Marine Vessels

Emission estimates for this inventory differ significantly from those found in the preliminary 2002 NEI. CENRAP's emissions are lower by approximately a factor of 3 for all pollutants (see **Figure 2-14**). Emissions in Louisiana and Texas account for most of the emissions and much of the overall difference, as seen in **Figure 2-15**.

For inland river systems in the CENRAP region, emission estimates were based on bottom-up fuel consumption data derived from the Tennessee Valley Authority (TVA) Barge Costing Model. This model was developed to estimate fuel usage by inland river segment for fuel tax purposes, and annual model results have varied from actual tax receipts by an average of only 1.5% since 1996. The results indicate that the activity data used to estimate emissions for most of the CENRAP region (including all of Arkansas, Iowa, Kansas, Missouri, Nebraska, and Oklahoma) have a high degree of certainty.

However, the TVA model does not cover fuel consumption by "deep-draft" (oceangoing) vessels, harbor tugs, and other vessels that operate around ports in the Great Lakes or the Gulf Inland Waterway of Louisiana and Texas. In these cases, emission estimates were prepared using work-based (rather than fuel-based) emission factors and a complex array of activity data, including the number of vessel calls at specific ports, vessel speeds, and vessel characteristics (such as engine horsepower, load factors, etc.). Although detailed information was available for several important ports in the CENRAP region, including St. Louis, Baton Rouge, New Orleans, South Louisiana, and Corpus Christi, a complete survey of ports in Louisiana, Texas, and Minnesota was not possible within the scope of this project. Therefore, data from "known" ports were extrapolated to "unknown" ports using techniques outlined in a two-volume report produced by ARCADIS on behalf of the EPA (U.S. Environmental Protection Agency, 1999a).

Improvements to the inventory could be made at local scales by gathering more detailed data on individual ports within a county or region.

The difference between the CENRAP inventory and the preliminary 2002 NEI is most likely due to the use of top-down methods to develop the 2002 NEI, for which national-level emissions were calculated from estimated annual hours of operation and fuel consumption for the U.S. commercial marine fleet, then disaggregated to port and underway emissions based on the simplifying assumption that 75% of distillate fuel and 25% of residual fuel is consumed "in-port". National-scale, in-port emissions were then assigned to the largest 150 ports in the country based on the amount of freight handled by each, and the remaining "underway" emissions were assigned to active shipping lanes based on traffic density patterns (U.S. Environmental Protection Agency, 1999b). These methods seem to have resulted in significantly overestimated emissions at large ports, as seen in **Table 2-4**, which compares "in-port" emissions from the 2002 NEI for the counties containing the Port of Baton Rouge and the Houston-Galveston Port with other estimates of emissions for these same ports. CENRAP's emission inventories for these ports are more closely aligned with previous estimates prepared by Booz Allen Hamilton (1991) and Eastern Research Group & Starcrest (2003), both of whom also applied bottom-up activity data to prepare their inventories.

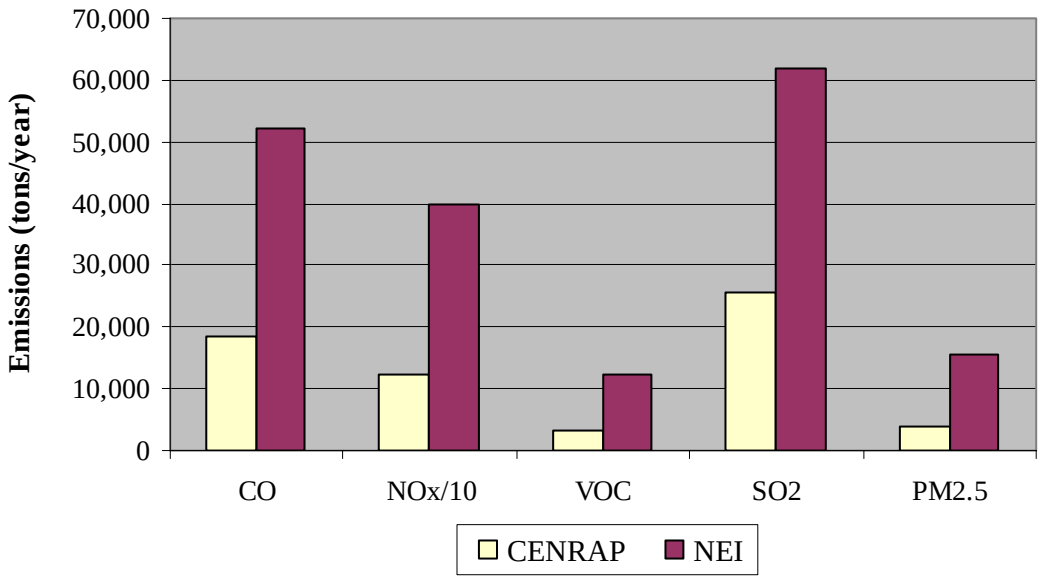


Figure 2-14. Comparison of commercial marine emissions estimates with results from the 2002 preliminary NEI (note: NO_x emissions have been divided by 10 for scaling purposes).

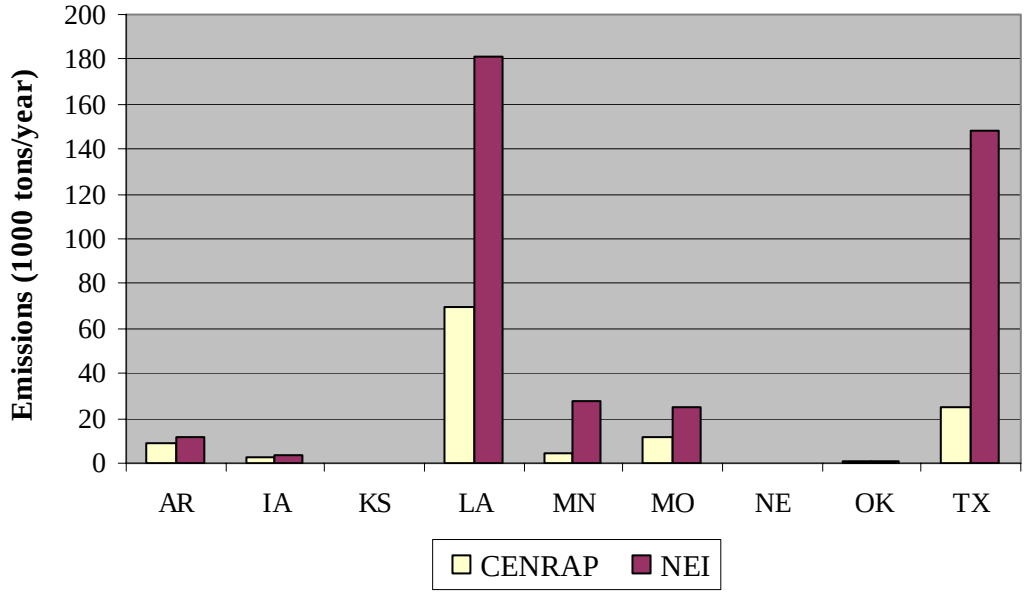


Figure 2-15. State-by-state comparison of commercial marine NOx emissions.

Table 2-4. Comparison of inventories for selected ports in the CENRAP region (emissions in tons/year).

Port	Inventory	$PM_{2.5}$	NO_x	CO	VOC	SO_2
Baton Rouge	1991 Booz-Allen Hamilton	129	2,187	449	203	928
	2002 CENRAP	196	5,355	737	170	1,562
	2002 NEI	1,407	36,088	4,756	1,128	5,291
Houston-Galveston	1991 Booz-Allen Hamilton	887	14,977	2,131	1,391	6,554
	2000 Starcrest	-----	7,336	1,022	219	-----
	2002 CENRAP	318	7,232	943	245	2,610
	2002 NEI	2,955	75,787	9,989	2,370	11,111

2.2.5 Summary of Emissions from Recreational Boats

Emissions from recreational boats were calculated with the latest version of the EPA's NONROAD model (NONROAD 2004). NONROAD produces county-level emission estimates for several categories of recreational boats using national equipment populations, which are disaggregated to the county level on the basis of the total water surface area in a given county. NONROAD also relies on broad assumptions related to boating activity (such as annual hours of operation, engine load factors, and temporal variations in activity). These assumptions vary by equipment type but not geographic area. The activity data files used by the NONROAD model were updated for the CENRAP inventory with information gathered through a bottom-up survey of representative groups of recreational boat owners. The survey was designed to gather data on vessel characteristics, hours of use, fuel consumption, engine loads, and temporal and geographic

usage patterns in each of the CENRAP states. Data assembled through this survey were then incorporated into the NONROAD model, along with state-specific data on temperatures and fuels characteristics.[5] The more significant survey results showed that boating activities varied substantially by state in most respects, including types of boats used, diurnal patterns of boating, seasonal patterns of boating, and hours of boat use.

One of the challenges associated with conducting the recreational boating survey and analyzing results was the tendency of survey respondents to generally over-report their use of recreational boats. This phenomenon, called "reporting bias", often occurs when survey respondents have non-neutral attitudes about the behaviors they report. Under-reporting of illicit behaviors (such as use of illegal drugs or driving above posted speed limits) and over-reporting of positive behaviors (such as exercising regularly or volunteering for charity) are commonly observed, unless surveys are designed to control or eliminate these biases. The CENRAP recreational boating survey was designed to control for reporting bias. Respondents were asked about their "typical" usage pattern, but they were also asked about their specific usage pattern for the preceding week—information that is much more likely to be reported accurately. The average usage pattern for the preceding week was used to adjust reported "typical" usage patterns, which greatly reduced the effects of over-reporting by factors of 1.5 to 2.0. In addition, respondents were asked about the quantities of fuel purchased for their recreational boats—information that could be used as a second check of reporting bias. On the basis of reported fuel consumptions, recreational boating usage was further reduced for over-reporting bias by a factor of 0.3 (with a range of uncertainty from 0.0 to 0.5). The resulting database of activity levels in the CENRAP region indicates greater usage of recreational boats than the NONROAD 2004 defaults by a factor of approximately 2. In spite of this large difference, the uncertainty in the overall survey results is judged to be approximately only ±25%. Notably, geographic areas in which subsistence fishing is prevalent exhibited the least evidence of over-reporting bias, while owners of personal watercraft over-reported usage to a greater extent than owners of other types of watercraft. This is consistent with the theory that recreational activities tend to be over-reported more often than non-recreational activities.

Emission estimates for recreational boating vary widely from state to state, as shown in **Table 2-5** and **Figures 2-16 and 2-17**. Louisiana, Minnesota, Missouri, and Texas account for almost 80% of the annual NO_x emissions from recreational boating in the CENRAP region, while Nebraska and Kansas combined contribute less than 4% of the total NO_x emissions. Emissions also vary widely across the months of the year, days of the week, and hours of the day, as shown in **Figures 2-18 through 2-20**. Recreational boating activity peaks during the summer months for each state, and this peak is more pronounced for the four northern states of Minnesota, Nebraska, Kansas, and Iowa. Activity peaks also occur on the weekends and during morning to midday hours.

[5] See Section 2.1.1 for a discussion of sources of information on fuels characteristics.

Table 2-5. Recreational boating emissions (tons) by state and boat type.

State	Category	PM2.5	NOx	VOC	SO2	CO	NH3
Arkansas	2-Stroke Outboards	1,662	803	25,604	63	69,155	6
	2-Stroke Personal Watercraft	204	115	4,253	10	11,469	1
	4-Stroke Inboards	8	785	1,430	21	19,809	1
	Diesel Inboards	10	570	21	10	90	0
	Diesel Outboards	0	2	0	0	1	0
	Total	1,884	2,274	31,309	103	100,524	8
Iowa	2-Stroke Outboards	1,418	682	21,346	54	58,835	5
	2-Stroke Personal Watercraft	192	108	3,944	9	10,777	1
	4-Stroke Inboards	7	738	1,000	20	18,380	1
	Diesel Inboards	9	536	20	9	85	0
	Diesel Outboards	0	2	0	0	1	0
	Total	1,626	2,066	26,310	92	88,079	7
Kansas	2-Stroke Outboards	266	123	4,581	10	10,940	1
	2-Stroke Personal Watercraft	72	41	1,495	3	4,069	0
	4-Stroke Inboards	3	293	431	7	6,919	0
	Diesel Inboards	3	202	8	3	32	0
	Diesel Outboards	0	1	0	0	0	0
	Total	345	660	6,515	24	21,962	2
Louisiana	2-Stroke Outboards	4,341	2,107	66,542	165	180,909	15
	2-Stroke Personal Watercraft	509	286	10,608	24	28,589	2
	4-Stroke Inboards	20	1,928	3,598	52	49,469	3
	Diesel Inboards	25	1,420	53	26	225	1
	Diesel Outboards	0	5	1	0	3	0
	Total	4,895	5,746	80,803	267	259,196	21
Minnesota	2-Stroke Outboards	5,113	2,462	77,086	69	211,905	17
	2-Stroke Personal Watercraft	710	402	14,580	12	39,829	3
	4-Stroke Inboards	27	2,807	3,666	26	67,462	4
	Diesel Inboards	34	1,982	74	34	314	1
	Diesel Outboards	1	6	2	0	5	0
	Total	5,886	7,659	95,409	142	319,514	26
Missouri	2-Stroke Outboards	5,397	2,671	79,005	207	226,163	18
	2-Stroke Personal Watercraft	502	283	10,360	23	28,213	2
	4-Stroke Inboards	19	1,892	2,899	51	48,478	3
	Diesel Inboards	25	1,401	52	26	222	1
	Diesel Outboards	0	4	1	0	3	0
	Total	5,943	6,251	92,318	308	303,079	24

Table 2-5. Recreational boating emissions (tons) by state and boat type.

State	Category	PM2.5	NOx	VOC	SO2	CO	NH3
Nebraska	2-Stroke Outboards	414	198	6,366	16	17,146	1
	2-Stroke Personal Watercraft	60	34	1,243	3	3,382	0
	4-Stroke Inboards	2	247	355	6	5,727	0
	Diesel Inboards	3	168	6	3	27	0
	Diesel Outboards	0	1	0	0	0	0
	Total	479	648	7,971	28	26,282	2
Oklahoma	2-Stroke Outboards	1,462	695	23,269	55	60,589	5
	2-Stroke Personal Watercraft	226	127	4,709	11	12,702	1
	4-Stroke Inboards	9	874	1,588	23	21,922	1
	Diesel Inboards	11	631	24	11	100	0
	Diesel Outboards	0	2	0	0	1	0
	Total	1,708	2,330	29,590	100	95,314	7
Texas	2-Stroke Outboards	5,095	2,422	81,866	192	211,147	17
	2-Stroke Personal Watercraft	795	447	16,620	37	44,684	3
	4-Stroke Inboards	31	2,947	5,890	81	78,276	5
	Diesel Inboards	39	2,219	83	39	352	1
	Diesel Outboards	1	7	2	0	5	0
	Total	5,960	8,043	104,461	350	334,464	26
All States	2-Stroke Outboards	25,167	12,166	385,666	832	1,046,790	84
	2-Stroke Personal Watercraft	3,270	1,843	67,812	131	183,714	14
	4-Stroke Inboards	126	12,511	20,858	288	316,441	19
	Diesel Inboards	159	9,128	342	162	1,447	6
	Diesel Outboards	3	29	7	0	21	0
	Total	28,725	35,676	474,685	1,413	1,548,413	122

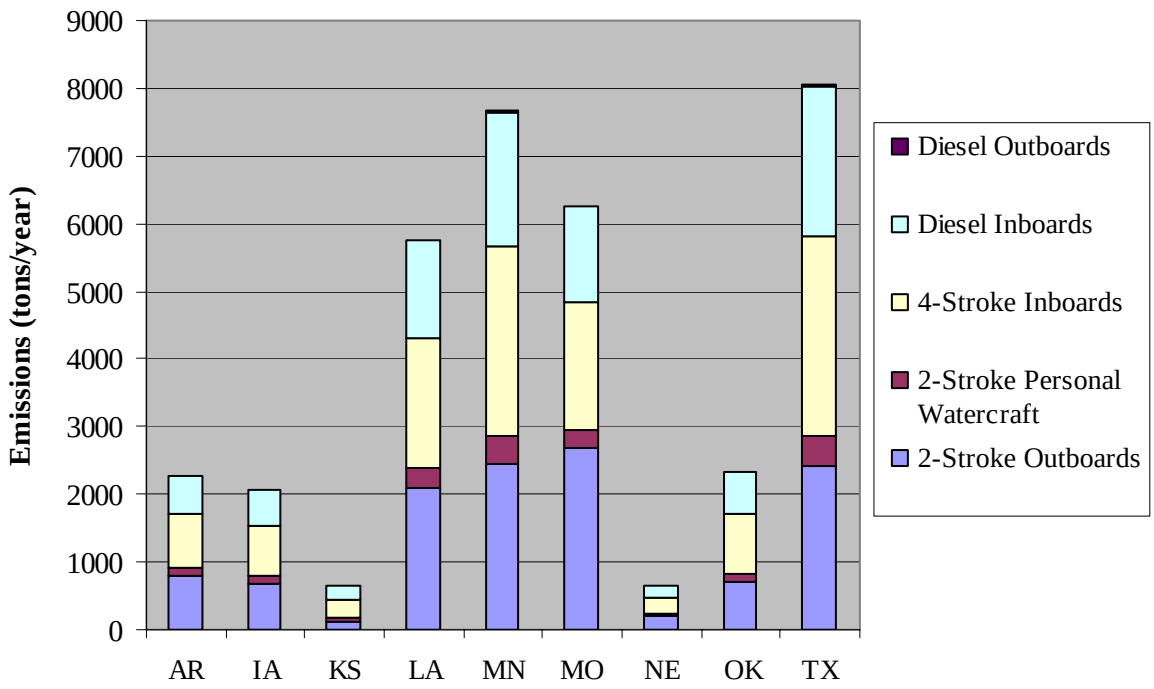


Figure 2-16. Annual NO_x emissions from recreational boating activities by state and boat type.

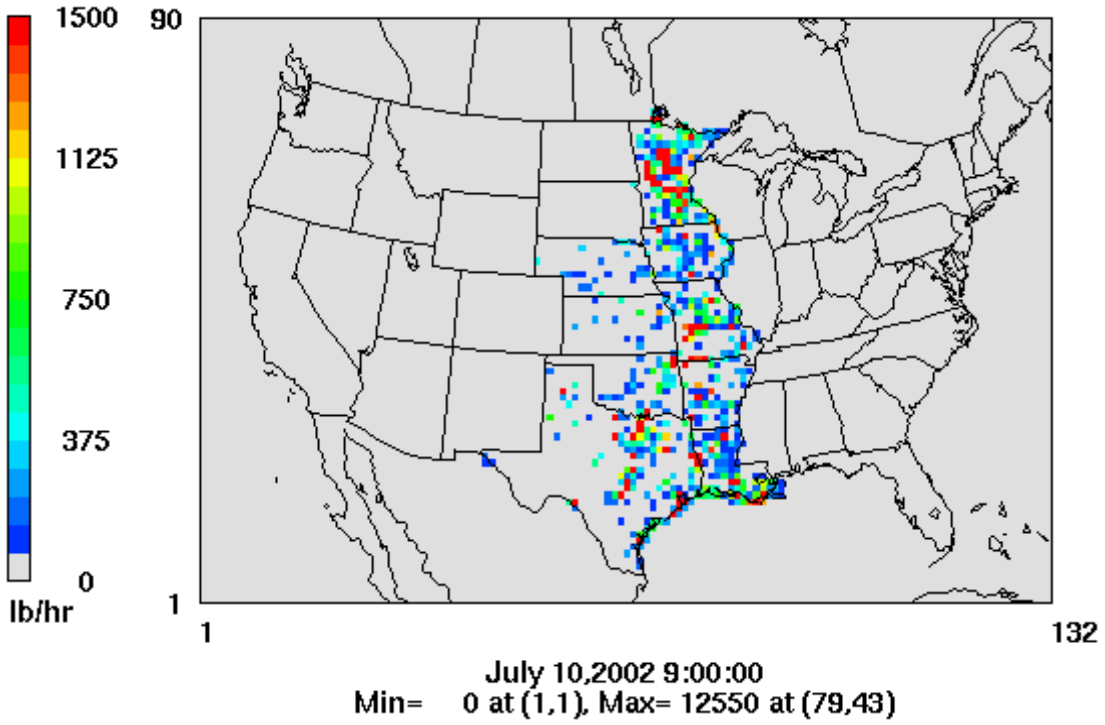


Figure 2-17. Geographic distribution of recreational boating emissions of NO_x in the CENRAP states on July 10, 2002.

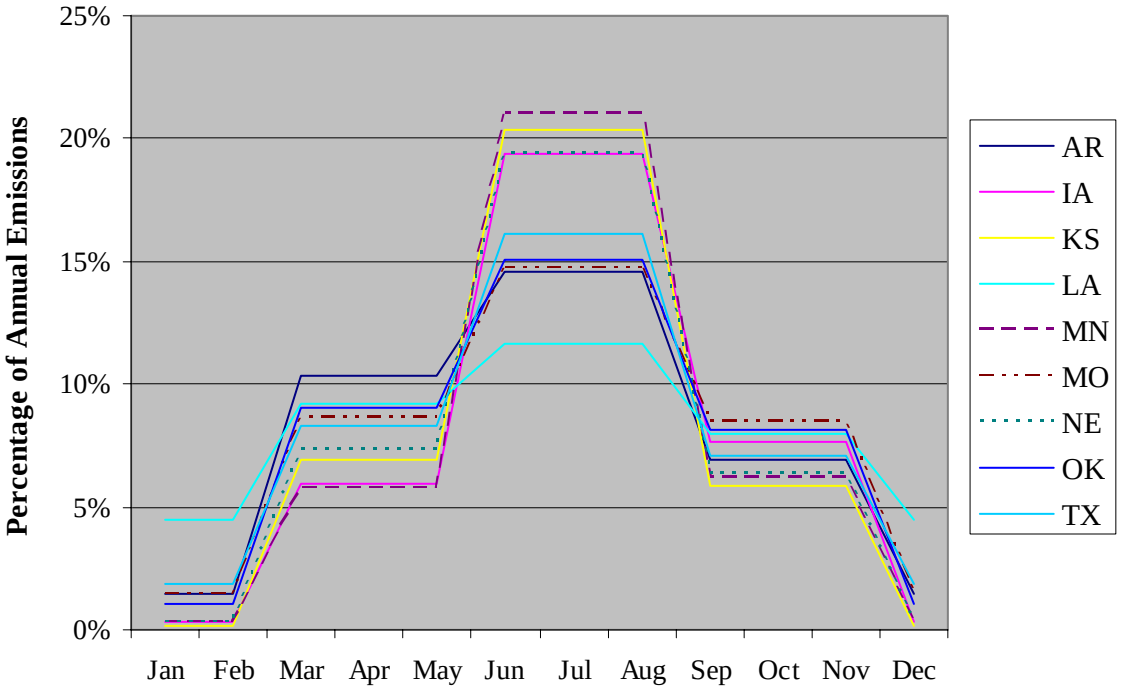


Figure 2-18. Monthly variability in recreational boating emissions by state.

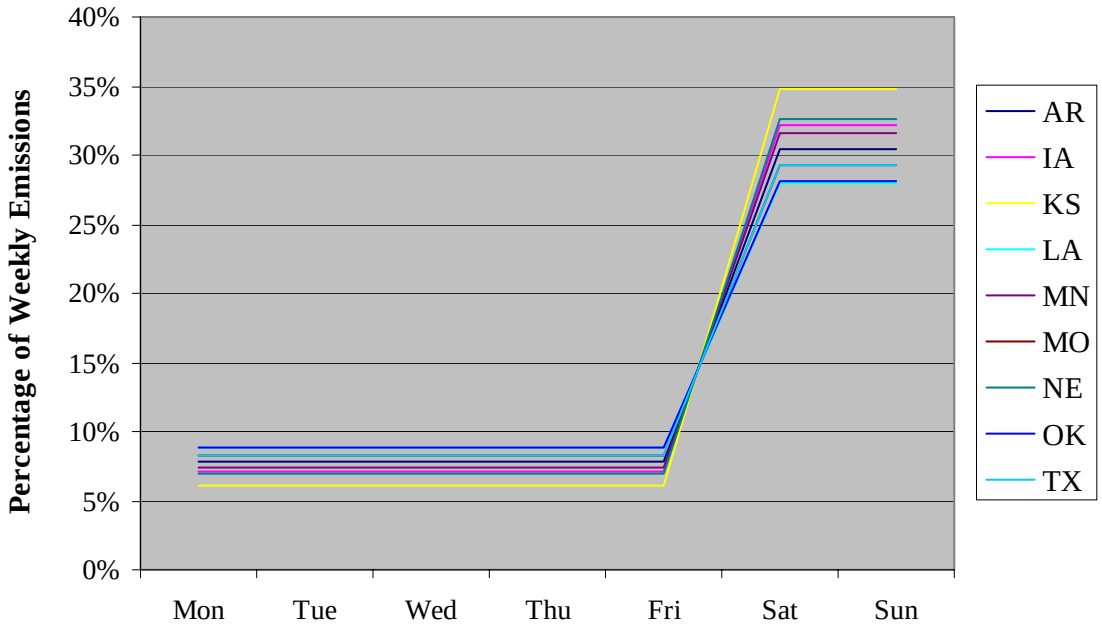


Figure 2-19. Day-of-week variability in recreational boating emissions by state.

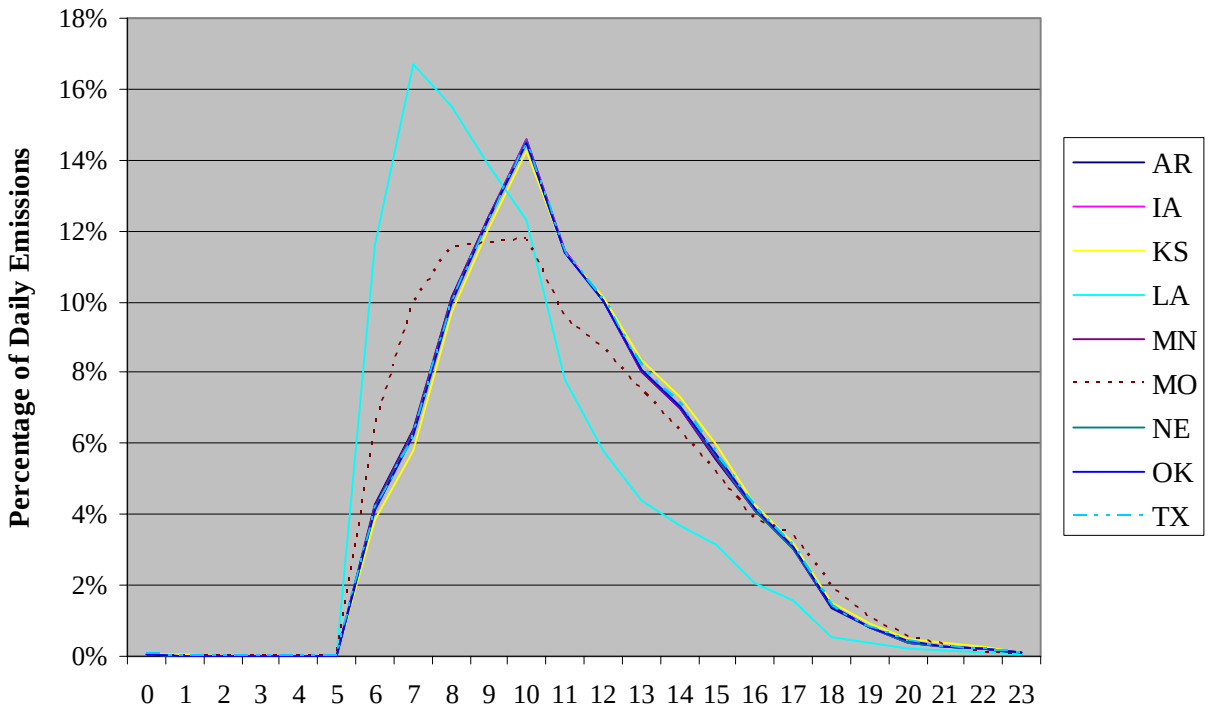


Figure 2-20. Diurnal variability in recreational boating emissions by state.

2.2.6 Assessment of Emissions from Recreational Boats

The CENRAP's emission inventory for recreational boating represents a significant improvement over existing inventories and NONROAD default activity data. Surveys of representative groups of boat owners in each of the CENRAP states made possible the replacement of NONROAD default data with state-specific information that more accurately represents recreational boating activity in the CENRAP region. The improved activity data resulted in emission estimates 2 to 4 times greater than estimates from the preliminary 2002 NEI (see **Figure 2-21**). The scale of the differences may seem surprising; however, we believe that they are reasonably accurate and reliable because care was taken to control over-reporting bias (as discussed in Section 2.2.5) and to ensure the representativeness of the survey results.

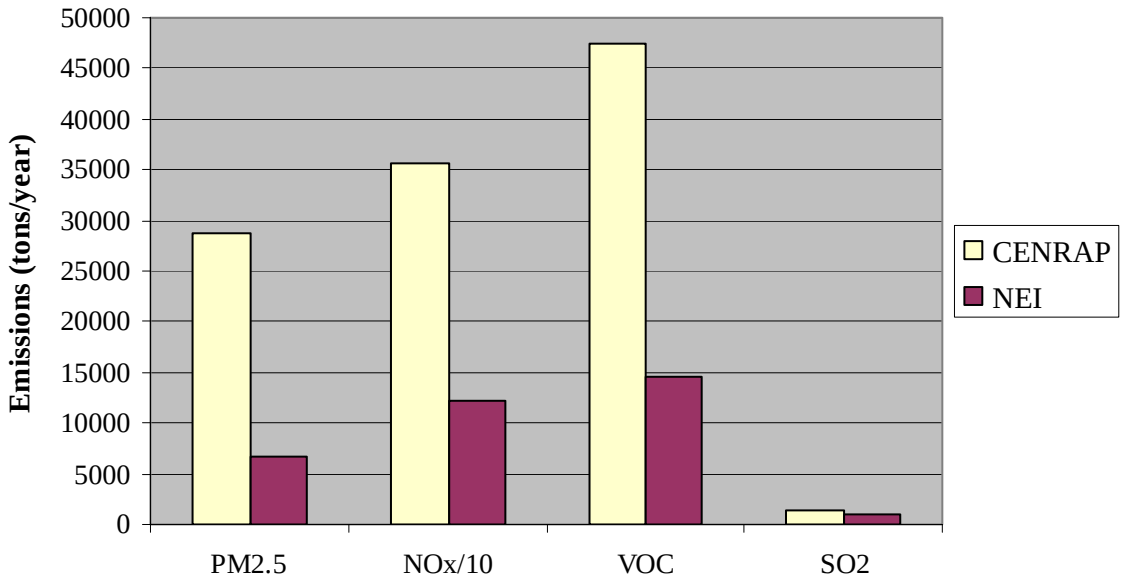


Figure 2-21. Comparison of recreational boating emissions estimates with results from the 2002 preliminary NEI (note: NO_x emissions have been divided by 10 for scaling purposes).

Figure 2-22 illustrates a county-by-county comparison of the CENRAP emission inventory with an inventory produced by running NONROAD 2004 with default inputs. The inventories differ significantly throughout the CENRAP region with respect to quantities of pollutants emitted and spatial distributions of emissions. The differences are due to the improved activity data, which were more representative of the scale and geographic distribution of recreational boating activities than NONROAD 2004 defaults. **Figure 2-23** provides a side-by-side comparison of the spatial distributions that resulted from NONROAD 2004 defaults and from the CENRAP recreational boating survey results. The CENRAP spatial allocation represents the usage patterns reported by survey respondents and is, therefore, highly representative of real-world behavior. The NONROAD spatial allocation was achieved by allocating statewide emissions proportionally to each county's water surface area. This technique overallocates emissions to areas that are unpopular with recreational boaters due to boating restrictions, remoteness from population centers, or other reasons.

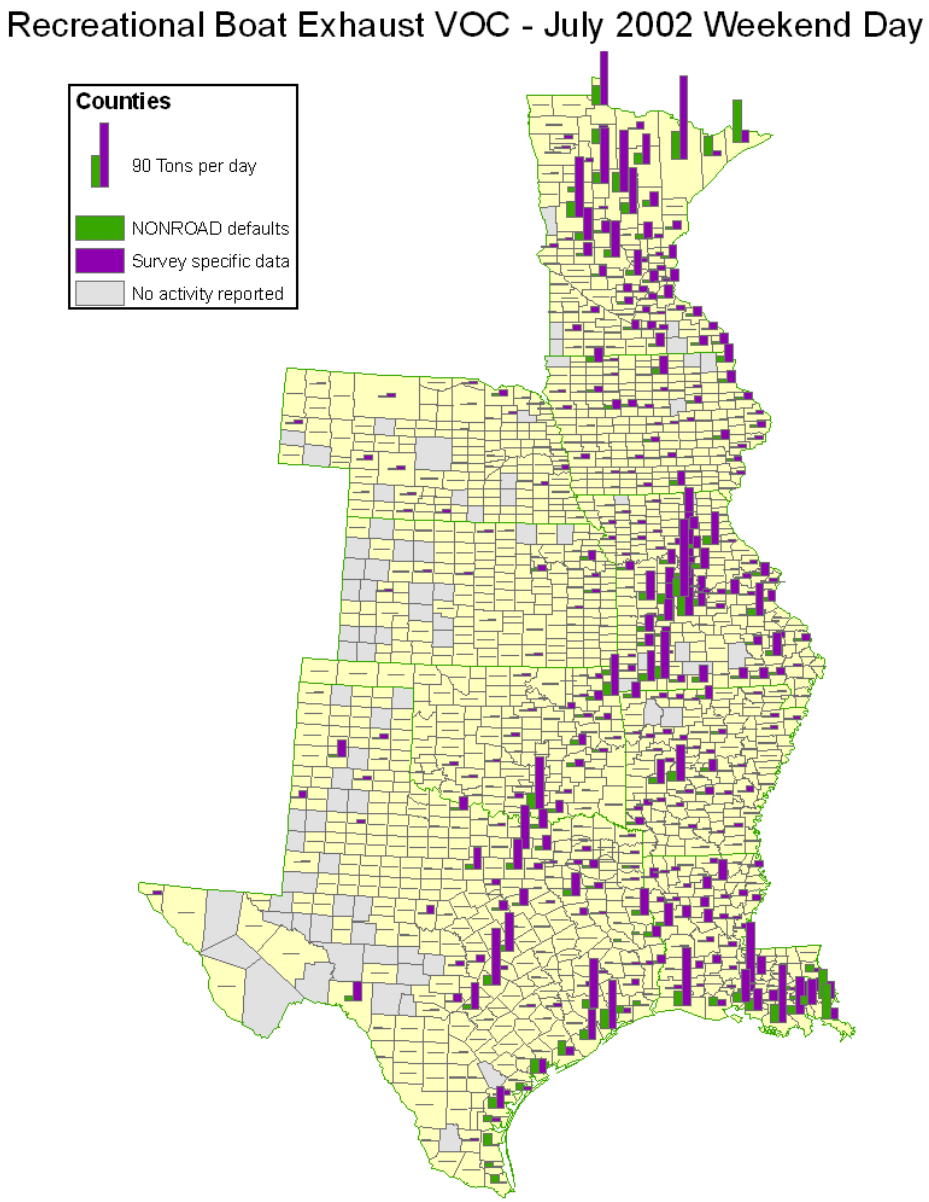


Figure 2-22. Comparison of county-level exhaust VOC emissions estimates with results obtained using NONROAD model defaults.

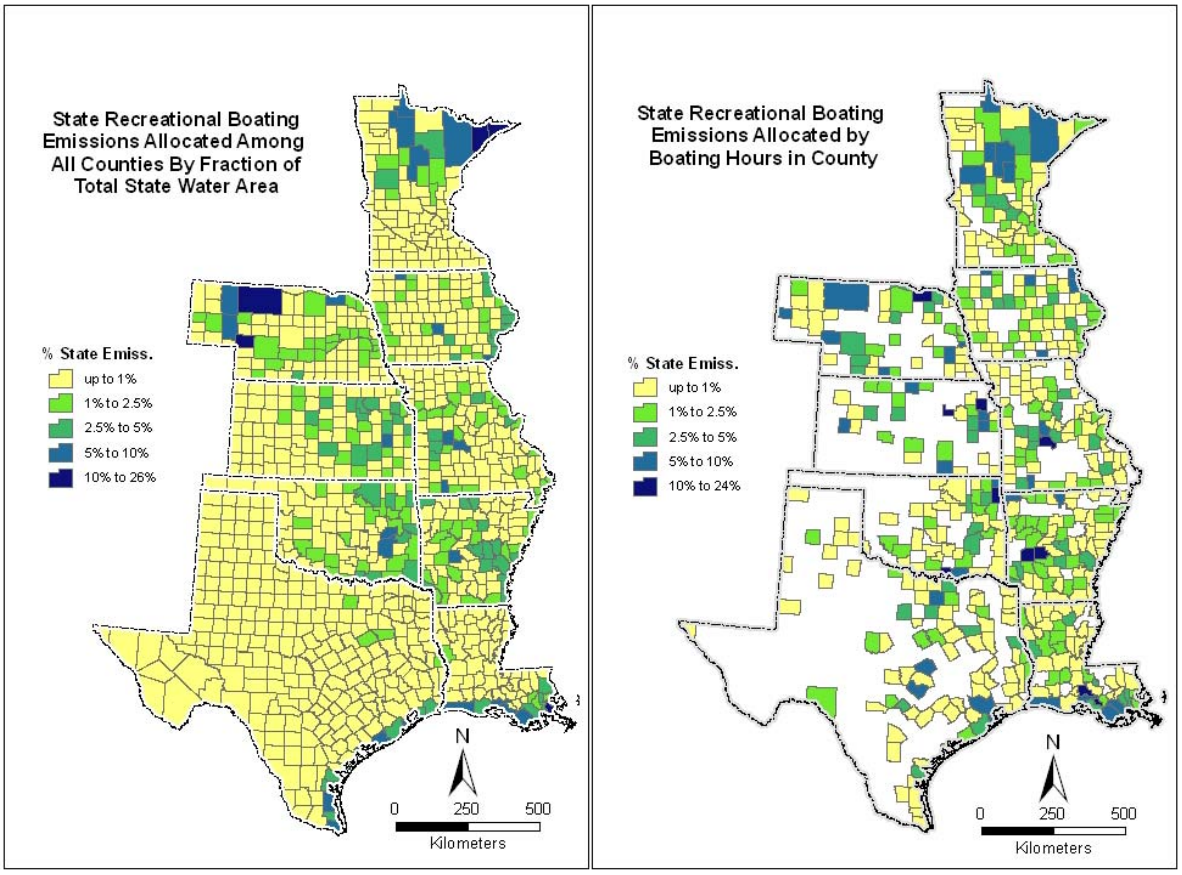


Figure 2-23. Comparison of county-level spatial allocation factors with NONROAD model defaults.

2.2.7 Summary of Emissions from Other Non-Road Mobile Sources

An initial prioritization of efforts related to non-road mobile sources indicated that commercial marine vessels, locomotives, and recreational boats represent at least two-thirds of the non-road primary and precursor emissions in counties containing or adjacent to Class I areas in the CENRAP region.[6] Therefore, these source categories were selected for bottom-up treatment, and emissions from remaining non-road mobile sources were estimated with the best available top-down methods. The EPA's NONROAD model is the approved method for estimating emissions from these sources, and the latest version of the model was run with default activity data, but with region-specific fuels characteristics and temperatures as appropriate.

Table 2-6 lists emissions for non-road mobile source categories not previously treated in earlier sections of this report—i.e., excluding emissions from locomotives, commercial marine vessels, recreational boats, and aircraft. The table lists the five largest $PM_{2.5}$ sources in each state. Agricultural equipment and construction and mining equipment, which are largely fueled

[6] The final CENRAP inventory indicates that these sources are even more substantial contributors to emissions in these areas than the initial prioritization first indicated.

by diesel fuel, tend to be the largest sources of NO_x, SO_2, and $PM_{2.5}$ for the CENRAP states, whereas recreational and lawn and garden equipment (predominantly gasoline-powered) are the largest sources of VOC. A geographic distribution of emissions for a selected date can be seen in **Figure 2-24**.

Table 2-6. "Other" non-road mobile source emissions (tons) by state and equipment type (not including emissions for locomotives, commercial marine vessels, recreational boats, and aircraft).

State	Category	$PM_{2.5}$	NO_x	VOC	SO_2	CO	NH_3
Arkansas	Agricultural Equipment	1,127	10,344	1,480	166	12,372	6
	Construction & Mining	677	8,285	1,508	152	12,639	5
	Recreational Equipment	253	177	8,041	15	26,894	1
	Industrial Equipment	132	4,954	1,222	33	19,657	1
	Lawn & Garden	92	426	3,713	18	57,637	1
	Other	135	1,666	1,866	34	41,660	9
	Total	2,415	25,852	17,830	418	170,860	22
Iowa	Agricultural Equipment	4,961	45,544	6,428	731	53,863	26
	Construction & Mining	808	9,893	1,789	181	15,007	5
	Recreational Equipment	322	227	13,516	36	51,872	3
	Lawn & Garden	229	1,088	8,190	42	127,060	2
	Commercial Equipment	142	1,775	2,314	36	58,916	1
	Other	145	5,198	1,270	35	20,234	1
	Total	6,607	63,725	33,506	1,062	326,950	38
Kansas	Agricultural Equipment	3,337	30,673	4,346	452	36,410	17
	Construction & Mining	785	9,622	1,744	161	14,608	5
	Lawn & Garden	206	909	7,155	35	106,296	2
	Commercial Equipment	124	1,535	2,033	30	52,119	1
	Industrial Equipment	112	4,024	977	26	15,550	1
	Other	101	618	3,125	13	19,689	72
	Total	4,665	47,382	19,381	716	244,673	98
Louisiana	Construction & Mining	1,095	13,383	2,436	260	20,482	8
	Agricultural Equipment	589	5,402	773	91	6,469	3
	Recreational Equipment	261	170	8,285	15	26,223	1
	Lawn & Garden	158	713	6,177	31	95,753	2
	Commercial Equipment	156	1,854	2,564	40	66,691	2
	Other	320	8,128	5,939	98	59,742	508
	Total	2,579	29,650	26,173	536	275,361	525
Minnesota	Agricultural Equipment	3,954	36,320	5,125	577	42,761	21
	Recreational Equipment	2,024	924	91,180	87	262,747	21
	Construction & Mining	1,161	14,209	2,571	259	21,446	8
	Lawn & Garden	329	1,613	11,938	26	184,758	4
	Industrial Equipment	236	8,807	2,152	55	34,390	2
	Other	275	3,492	3,880	49	94,248	4
	Total	7,979	65,365	116,847	1,052	640,351	59

Table 2-6. "Other" non-road mobile source emissions (tons) by state and equipment type (not including emissions for locomotives, commercial marine vessels, recreational boats, and aircraft).

State	Category	$PM_{2.5}$	NO_x	VOC	SO_2	CO	NH_3
Missouri	Agricultural Equipment	2,643	24,252	3,435	421	28,831	14
	Construction & Mining	1,045	12,766	2,314	254	19,485	7
	Lawn & Garden	439	2,031	15,731	83	244,136	5
	Recreational Equipment	256	259	8,067	18	39,236	1
	Industrial Equipment	242	8,701	2,120	64	33,917	2
	Other	270	3,319	3,997	69	101,239	4
	Total	4,895	51,328	35,664	909	466,845	33
Nebraska	Agricultural Equipment	2,870	26,356	3,733	423	31,201	15
	Construction & Mining	417	5,107	924	93	7,728	2
	Lawn & Garden	120	533	4,219	20	62,304	1
	Recreational Equipment	83	99	2,824	8	17,152	0
	Commercial Equipment	82	1,020	1,342	20	34,191	1
	Other	73	2,441	607	18	9,401	3
	Total	3,644	35,556	13,650	582	161,977	23
Oklahoma	Agricultural Equipment	1,277	11,731	1,679	188	14,025	6
	Construction & Mining	655	8,016	1,459	147	12,213	4
	Lawn & Garden	172	776	6,348	32	97,477	2
	Recreational Equipment	129	124	4,106	9	18,720	1
	Commercial Equipment	126	1,532	2,097	31	53,592	1
	Other	184	5,383	3,157	53	34,267	250
	Total	2,543	27,563	18,846	460	230,294	265
Texas	Construction & Mining	4,610	56,355	10,274	1,049	86,597	36
	Agricultural Equipment	2,791	25,621	3,676	414	30,877	14
	Lawn & Garden	1,393	5,908	46,403	240	708,712	16
	Commercial Equipment	794	9,459	13,202	199	340,914	10
	Industrial Equipment	671	21,938	5,264	167	82,994	5
	Other	983	11,728	28,062	201	190,438	1,362
	Total	11,241	131,009	106,881	2,271	1,440,533	1,444
Total – All States and Sources		46,568	477,429	388,778	8,006	3,957,843	2,507

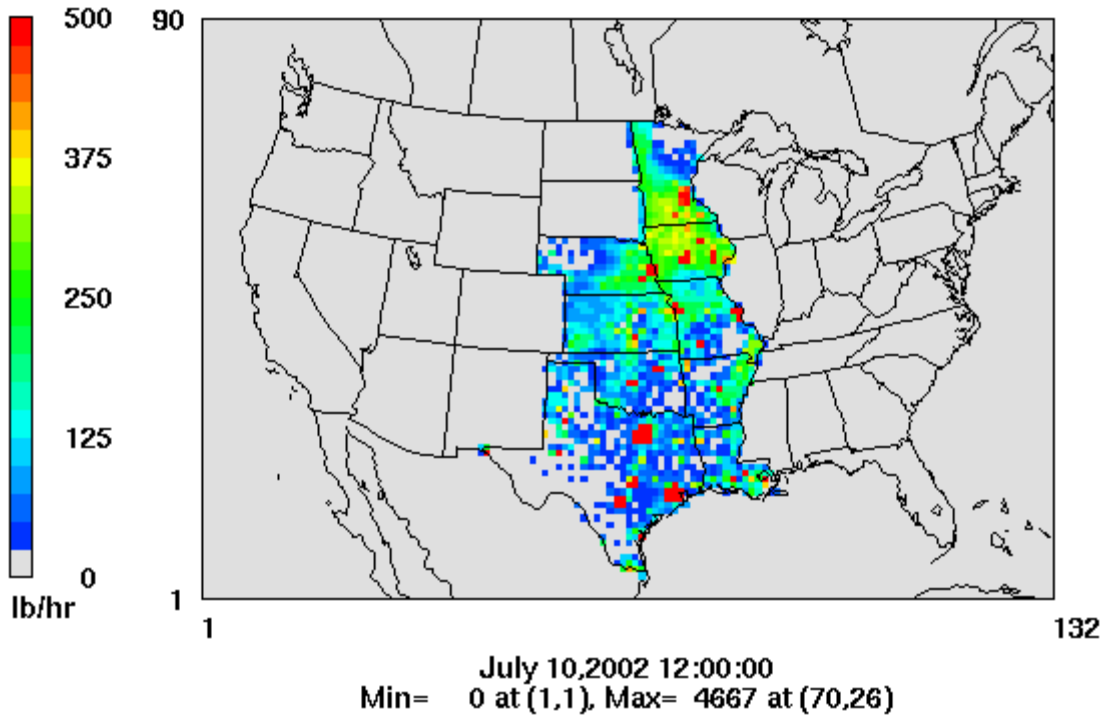


Figure 2-24. Geographic distribution of "other" non-road mobile source emissions of NO_x in CENRAP states on July 10, 2002.

2.2.8 Assessment of Emissions from Non-Road Mobile Sources

Emissions estimates for non-road mobile sources represent an improvement over existing inventories due to the use of region-specific fuels characteristics. **Figure 2-25** shows a comparison of the CENRAP inventory and the preliminary 2002 NEI. A significant difference in SO_2 emissions and a modest difference in VOC emissions are apparent. These differences are due to the use of state-specific diesel sulfur contents and gasoline volatilities for the CENRAP inventory. However, further improvements could be made by gathering bottom-up activity data (as was done for recreational boating). Based on a review of the emissions totals, the priority categories for further study are agricultural equipment and construction and mining equipment, which account for 75% of the total NO_x, $PM_{2.5}$, and SO_2 emissions from "other" non-road mobile sources and/or recreational or lawn and garden equipment, which dominate VOC emissions.

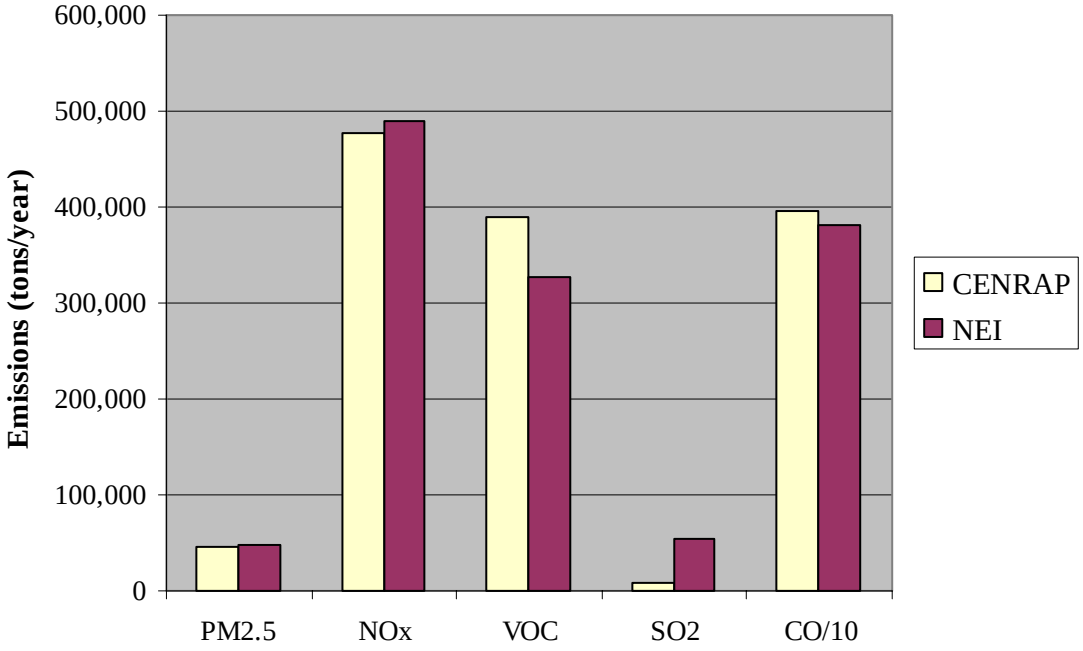


Figure 2-25. Comparison of non-road mobile source emissions with results from the preliminary 2002 NEI (note: CO emissions have been divided by 10 for scaling purposes).

2.3 EMISSIONS FROM SOURCES OF AGRICULTURAL DUST

2.3.1 Summary of Emissions from Agricultural Tilling Operations

Particulate matter (PM) emissions from agricultural tilling operations in the CENRAP region were estimated combining a constant emission factor with county-level activity data, including the silt content of surface soils, the number of tillings performed in a year for each crop type, the acres of each crop type, and information about conservational tillage practices. (Conservational tilling practices, such as no-till, mulch-till, and ridge-till, reduce the number of tilling passes performed in a year.) Total PM_{10} emissions from agricultural tilling operations in the CENRAP region were estimated to be over 1.3 million tons per year, with $PM_{2.5}$ emissions contributing about 270,000 tons to this total (see **Table 2-7** and **Figure 2-26**). A geographic distribution of county-level $PM_{2.5}$ emissions appears in **Figure 2-27**. Temporal variations in $PM_{2.5}$ emissions by month, day-of-week, and hour-of-day appear in **Figures 2-28 through 2-30**.

Table 2-7. Particulate matter emissions (tons) from agricultural tilling operations by state.

State	PM_{10}	$PM_{2.5}$
Arkansas	87,895	17,579
Iowa	236,520	47,304
Kansas	253,850	50,769
Louisiana	42,443	8,489
Minnesota	215,070	43,013
Missouri	104,530	20,905
Nebraska	138,850	27,770
Oklahoma	100,160	20,033
Texas	167,420	33,484
Total	1,346,738	269,346

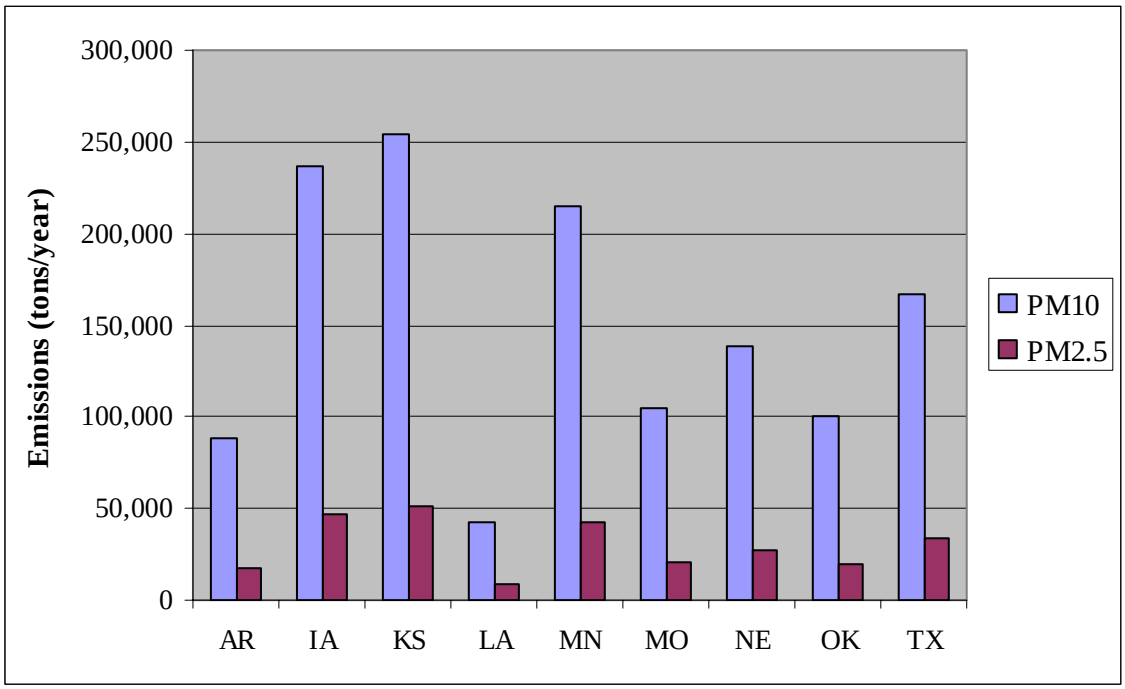


Figure 2-26. Particulate matter emissions from agricultural tilling operations by state.

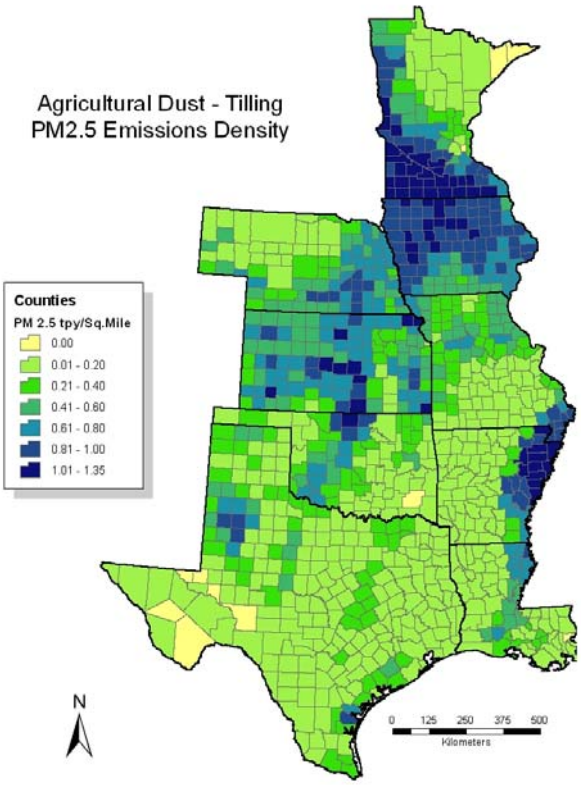


Figure 2-27. County-level $PM_{2.5}$ emission estimates for agricultural tilling operations.

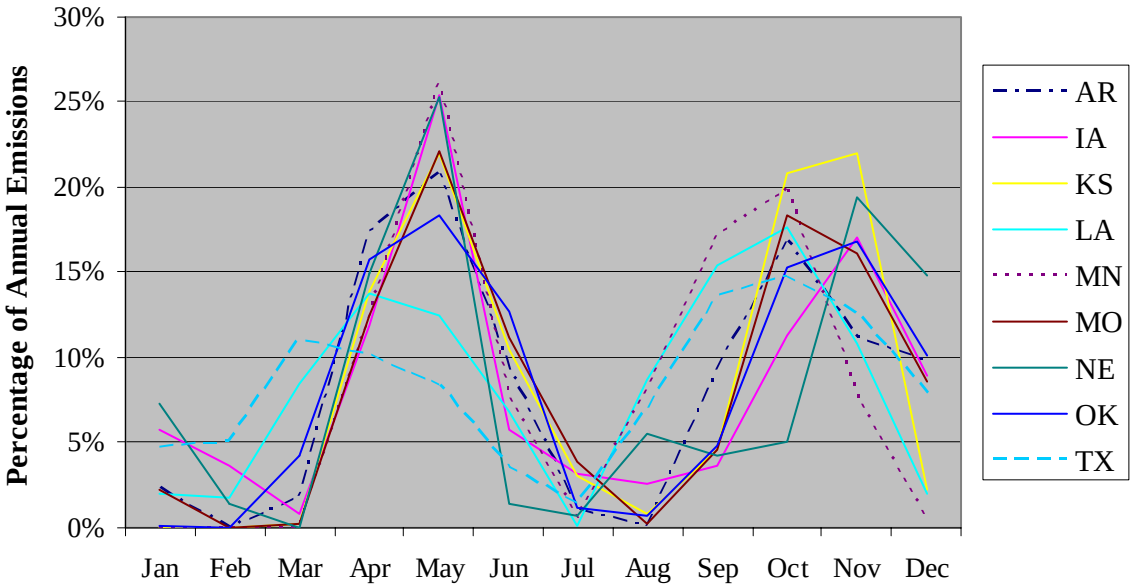


Figure 2-28. Monthly variability in agricultural tilling emissions by state.

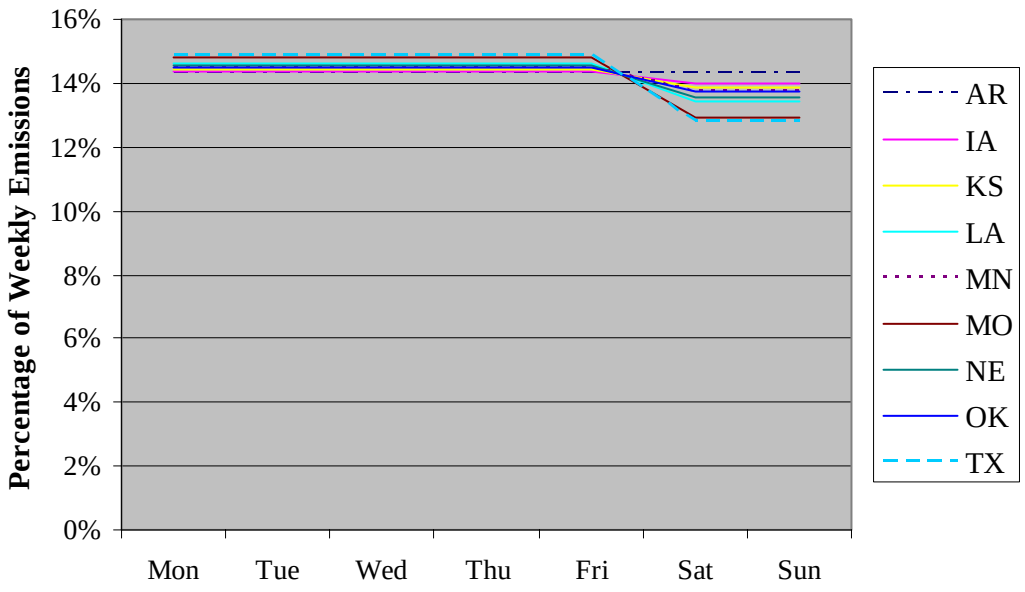


Figure 2-29. Day-of-week variability in agricultural tilling emissions by state.

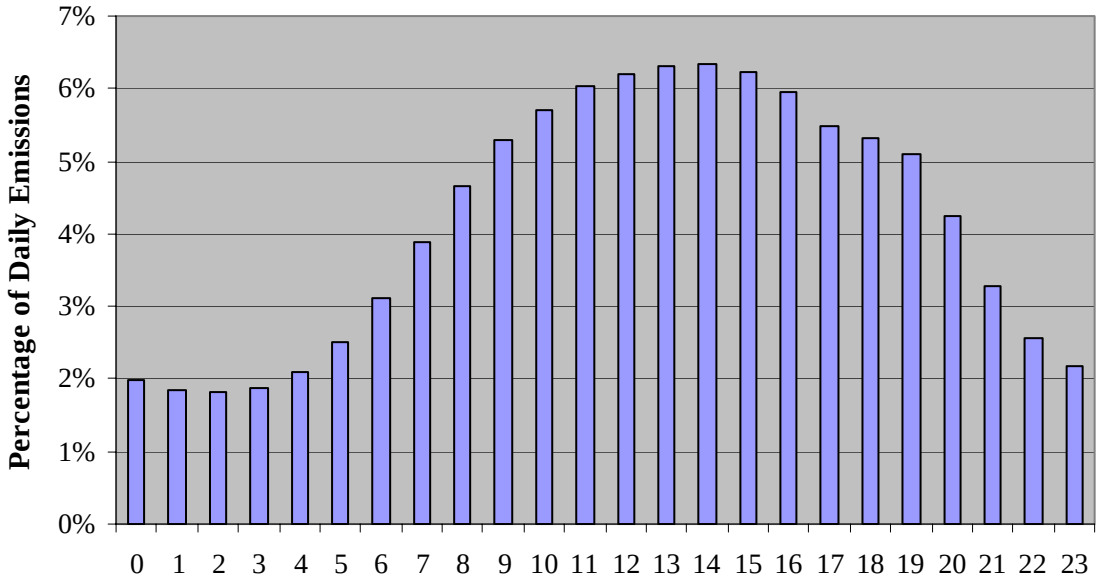


Figure 2-30. Diurnal variability in agricultural tilling emissions (same for all states).

2.3.2 Assessment of Emissions from Agricultural Tilling Operations

The use of locally representative activity information in the development of emission inventories for agricultural tilling operations permitted a significant improvement over the inventory compiled for the preliminary 2002 NEI. The most significant improvements included county-level soil silt contents and locally reported tilling practices (reported as the number of

tilling passes completed for each crop type), which were found to correlate with the actual prevalence of conservational tilling practices. Emission estimates from this inventory are generally about 25% to 30% lower than corresponding estimates from the preliminary 2002 NEI, although the comparison varies from state-to-state (see **Figure 2-31**). These reductions seem primarily due to the incorporation of local information on tilling practices because the reported number of tilling passes for each crop type was often less than indicated by EPA guidance. A likely explanation is that conservational tilling practices have become more prevalent in recent years, particularly in Texas, where the most dramatic differences between the preliminary 2002 NEI and the CENRAP inventory are apparent.

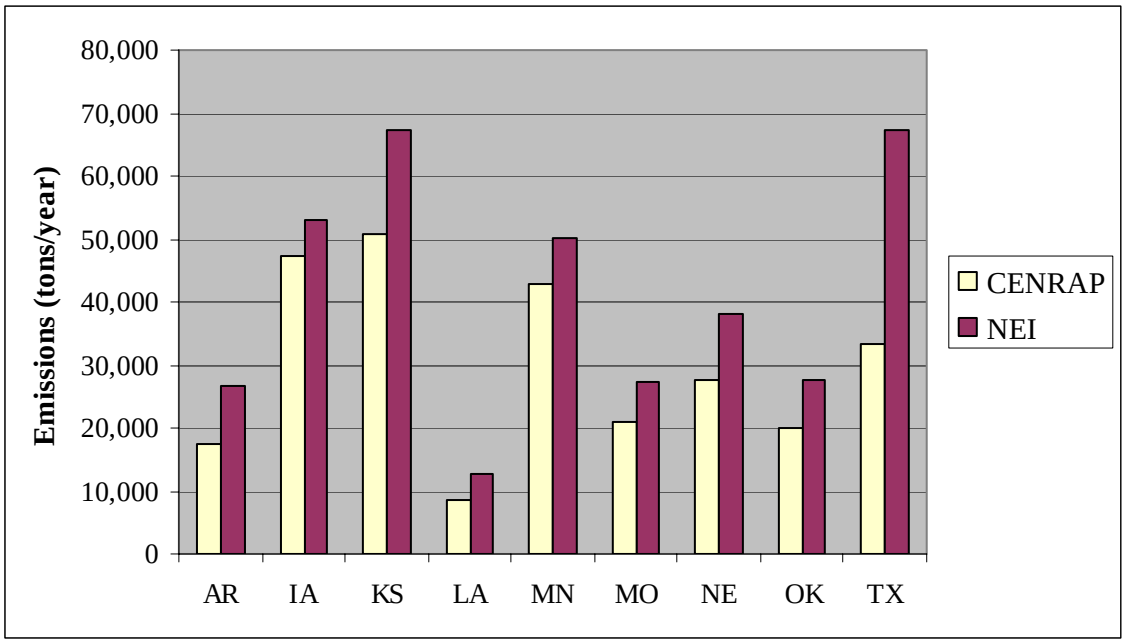


Figure 2-31. State-by-state comparison of $PM_{2.5}$ emissions from agricultural tilling operations.

2.3.3 Summary of Emissions from Livestock Operations

PM emissions from livestock operations in the CENRAP region were estimated using a PM_{10} emission factor and a $PM_{2.5}$ size fraction selected after a literature review. These factors were applied to facility-specific annual populations for beef cattle feedlots and dairies. Because facility locations were also acquired, emissions from livestock operations were treated as point sources and assigned to the specific location coordinates of each facility. Total PM_{10} emissions from livestock operations in the CENRAP region were estimated to be 51,000 tons per year, with $PM_{2.5}$ emissions contributing about 7,700 tons to this total (see **Table 2-8** and **Figure 2-32**). A geographic distribution of county-level PM_{10} emissions appears in **Figure 2-33**.

Table 2-8. Particulate matter emissions (tons) from livestock operations by state.

State	Facility Type	PM_{10}	$PM_{2.5}$
Arkansas	Beef Cattle Feedlot	0.0	0.0
	Dairy	3.9	0.6
Iowa	Beef Cattle Feedlot	4,314.0	647.1
	Dairy	40.8	6.1
Kansas	Beef Cattle Feedlot	18,378.5	2,756.8
	Dairy	142.7	21.4
Louisiana	Beef Cattle Feedlot	15.9	2.4
	Dairy	0.0	0.0
Minnesota	Beef Cattle Feedlot	252.6	37.9
	Dairy	35.6	5.3
Missouri	Beef Cattle Feedlot	109.3	16.4
	Dairy	9.7	1.5
Nebraska	Beef Cattle Feedlot	8,732.9	1,309.9
	Dairy	15.4	2.3
Oklahoma	Beef Cattle Feedlot	3,390.4	508.6
	Dairy	22.5	3.4
Texas	Beef Cattle Feedlot	15,673.8	2,351.1
	Dairy	152.2	22.8
Total		51,290.2	7,693.6

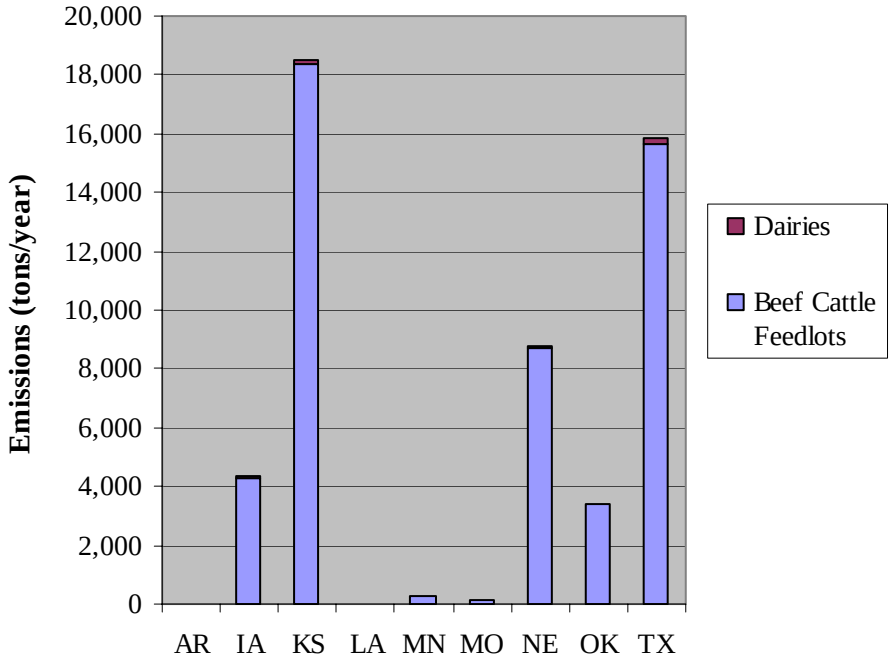


Figure 2-32. PM_{10} emissions from livestock operations by state and facility type.

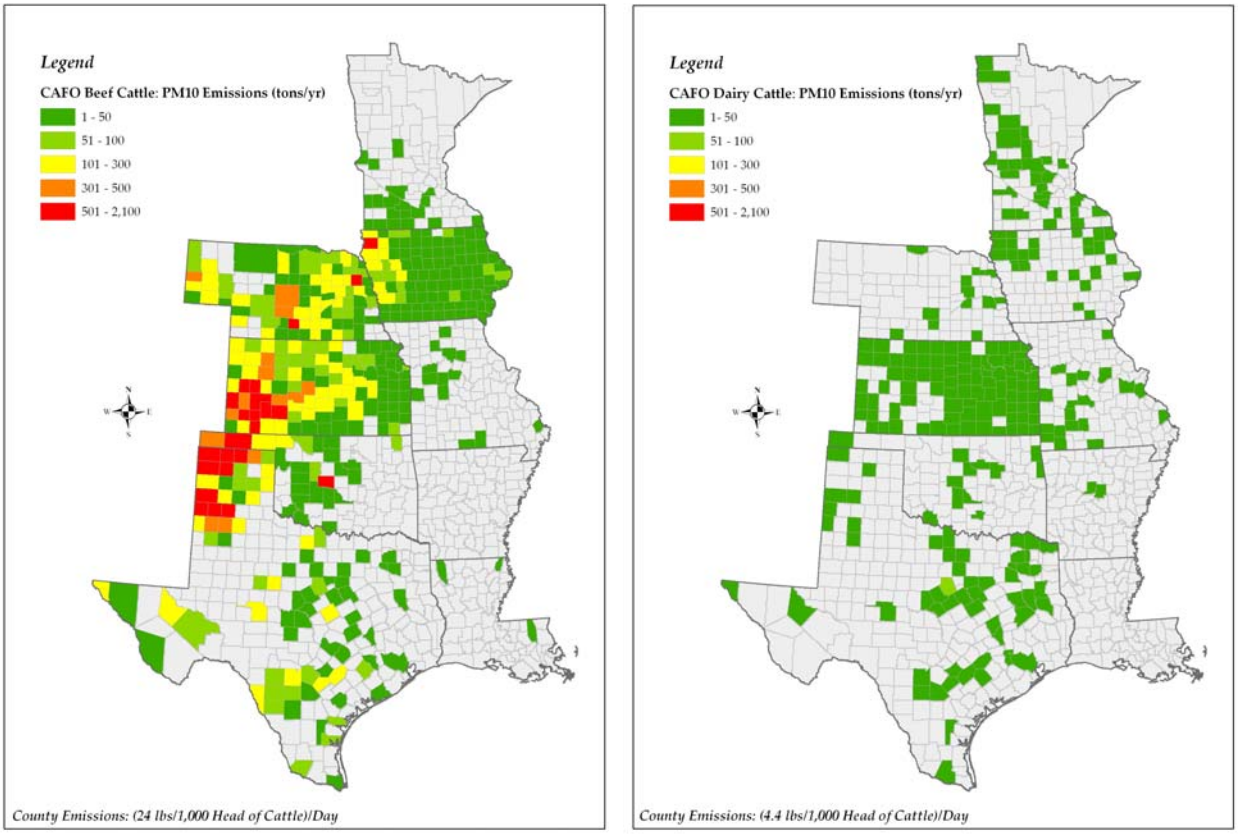


Figure 2-33. County-level PM_{10} emission estimates for beef cattle feedlots (left) and dairies (right).

2.3.4 Assessment of Emissions from Livestock Operations

The methods used to develop emission inventories for livestock operations represent a significant improvement over existing inventories, both in terms of the total annual emissions calculated and the geographic distribution of those emissions. The 1999 NEI[7] included an estimated 270,000 tons per year of PM_{10} emissions from CAFOs in the CENRAP region—a figure more than five times higher than that estimated for the CENRAP inventory. A literature search indicated that the emission factor of 17 tons per 1000 animals per year, which was used during development of the 1999 NEI, was too high for this source category. Ultimately, an emission factor of 4.4 tons per 1000 animals per year was selected for beef cattle and an emission factor of 0.8 tons per 1000 animals per year was used for dairy cows.

In addition, the use of facility coordinates greatly enhanced the spatial distribution of emissions. For the 1999 NEI, a simplifying assumption was used that the number of cattle housed at CAFOs is approximately 10% of the total number of beef cattle in each county, regardless of feedlot locations or local animal husbandry practices. As a result, emissions were assigned to many counties in which no feedlots operate, as illustrated by **Figure 2-34**, which

[7] Particulate emissions from animal feedlots are not yet included in the 2002 version of the NEI.

contrasts the geographic distribution of emissions in the 1999 NEI with known feedlot locations and animal populations. Side-by-side comparison of these figures shows that the 1999 NEI registers high emissions densities in eastern Texas, Oklahoma, western Missouri, and northwestern Nebraska—areas where very few CAFOs exist. In reality, most CAFOs in the CENRAP region accumulate in a band that reaches from the Texas panhandle, across Kansas and southeastern Nebraska, and across the state of Iowa.

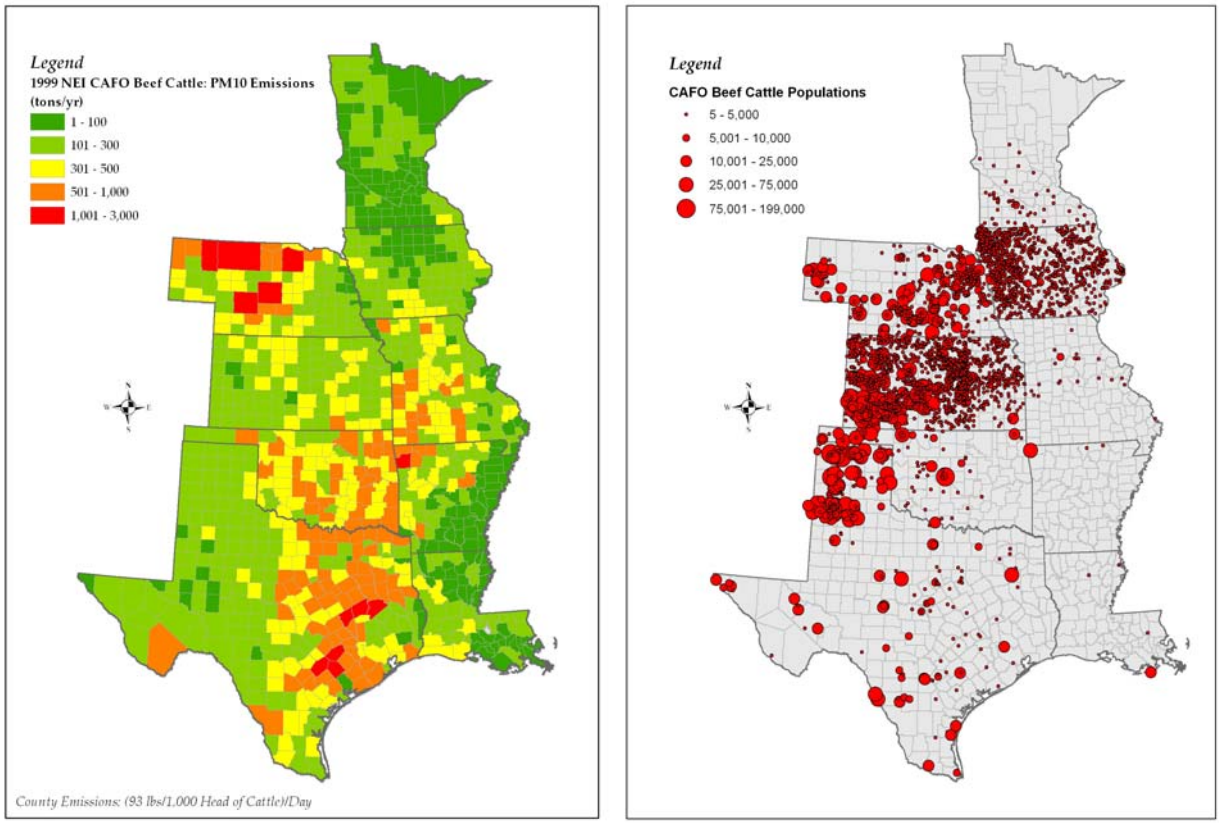


Figure 2-34. NEI county-level PM_{10} emissions for beef cattle feedlots vs. actual beef cattle feedlot locations and populations.