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METHODOLOGY FOR ESTIMATING EMISSIONS FROM OFF-HIGHWAY MOBILE SOURCES FOR THE RAPS PROGRAM

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

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METHODOLOGY FOR ESTIMATING EMISSIONS FROM OFF-HIGHWAY MOBILE SOURCES FOR THE RAPS PROGRAM

by

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FOREWORD

The work described in this report was performed by Southwest Research Institute for the U.S. Environmental Protection Agency under Contract No. 68-02-1397, "Methodology for Estimating Emissions from Off-Highway Sources for the RAPS Program." The project grew out of RFP No. DU-74-A041 and SwRI's responding Proposal No. 11-9962, dated January 7, 1974. The project was initiated on March 12, 1974; and the technical effort was completed on September 30, 1974. It was identified at SwRI as Project No. 11-3916.

The project leader for SwRI has been Charles T. Hare, Manager, Advanced Technology, Department of Emissions Research. Overall supervision has been provided by Karl J. Springer, Director, Department of Emissions Research. Project Officer for the Environmental Protection Agency has been Charles C. Masser, National Air Data Branch.

ABSTRACT

Emissions, population, and usage data existing in the technical literature have been collected and organized for the following unregulated sources: outboard motors, snowmobiles, motorcycles, lawn and garden equipment, construction equipment, industrial equipment, and farm equipment. The investigation has been limited to mobile sources utilizing internal combustion engines and thus has not included plant processes or stationary engines.

Sources of data for individual counties have been compiled, mostly items which may have some correlation with equipment population, usage, or emissions. Data found in these sources have been restated only where necessary to other phases of the program.

Methodologies for estimating emissions and fuel consumption on a county basis have been developed for the sources noted above. They have been demonstrated for counties in the St. Louis Metropolitan Air Quality Control Region (AQCR 070), and their strengths and weaknesses have been discussed. Methods have also been developed to apportion county emissions estimates to grid elements, but they have not been demonstrated. The exhaust constituents assessed include hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NO_x), particulate, aldehydes (RCHO), and oxides of sulfur (SO_x). For outboard motors, neither particulate nor aldehyde data were available; but carbon dioxide (CO_2) emissions were included.

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I. INTRODUCTION

This study is an extension of previous work by SwRI on emissions from uncontrolled mobile sources using internal combustion engines, with emphasis on estimates for counties and smaller areas. Prior studies conducted at SwRI under Contract No. EHS 70-108 have been responsible for the development and/or publication of a substantial fraction of available data for a number of engine categories. These categories include locomotives, outboard motors, motorcycles, small utility engines, farm equipment, construction equipment, industrial equipment, gas turbine electric utility powerplants, and snowmobiles.

Of the categories noted above, seven were studied during this project (outboards, snowmobiles, motorcycles, lawn and garden, construction, industrial, and farm). The first objective was to compile and summarize all available data on emissions, population, and usage of engines in these categories. Sources consulted were reports for EPA and other agencies, technical papers, state motor vehicle registration departments, statistical publications, and others.

Another objective was to compile a list of data sources for counties and other small areas, and the results of this effort appear as Appendix B. Although a great deal of direct information on engine emissions, population, and usage is not available for counties, sufficient data were uncovered which are relatable to the desired variables to have made the effort worthwhile. The final objectives of this study were to derive methodologies for estimating emissions down to the county and grid element levels,and to demonstrate the county methodologies for AQCR 070 (St. Louis Metropolitan). Even having accomplished these tasks, the problem remains that no data are available against which the derived results can be checked.

II. SUMMARY OF NATIONAL AND STATE DATA ON EQUIPMENT POPULATIONS, USAGE, AND EMISSIONS

Engines for which emission estimation methodologies have been developed under the subject program are used in a wide variety of leisure and utilitarian applications. They represent all major non-automotive engine markets up to about the 500 horsepower class. As a consequence of this diversity in size, type, and field of application, data relating to population, usage, and emissions of the engines are widely scattered in the literature. This section of the report will summarize pertinent data found for each engine category, as a matter of convenience and for future reference.

A. OUTBOARD MOTORS

Data on the population of outboard motors or outboard boats and their distribution by state are available through the U.S. Coast Guard[1] and The Boating Industry magazine[2]. Calendar year 1973 outboard boat registrations in the 48 contiguous states plus the District of Columbia totalled 4.98 million, but some states did not register all outboard boats operating on their waters. All registration exemptions for small boats ran out at the end of 1973, however, so the 1974 registration total (available in 1975) should show a strong increase due to inclusion of a number of previously unregistered craft. The 1973 Boating Industry total for outboard motors in the same states was 7.51 million, but the exact basis for this figure is not known.

Breakdowns of the USCG[1] 1973 outboard boat registrations and the Boating Industry[2] 1973 outboard motor population by state are given in Appendix A, Tables A-1 and A-2, respectively. The reliability of boat population figures for 14 states will be in doubt until 1974 registration figures become available, but a correction for unregistered boats can be estimated using an analysis of the total U.S. outboard motor population by rated power category[3,4]. Assuming that boats in the power categories 0-6.9 hp and 7.0-19.9 hp are uniformly distributed within the categories, the correction factors shown in Table 1 can be used with corresponding state registrations to come up with more

*Numbers in parentheses indicate list of References at the end of this report.

Table 1. FACTORS TO CORRECT 1973 STATE OUTBOARD BOAT REGISTRATIONS FOR EXEMPTION OF SMALLER CRAFT

Exemption	State(s)	Calculated	
		% Unregistered	Correction factor
5 hp or below	TN, WV, WY	22.5	1.29
7.5 hp or below	MD, MO	32.5	1.48
8 hp or below	MT	33.6	1.51
9.9 hp or below	ND	37.6	1.60
10 hp or below	AR, FL, GA, LA, ME, MS, NC	37.8	1.61

representative values. Performing this correction for all the states exempting very small craft yields an additional 0.51 million outboard boats, making the estimated current total about 5.5 million.

Relatively little good information is available on usage of outboard motors or outboard boats, so estimates have been used previously[3] to compute the national impact of outboards. It is expected that climatic conditions have a strong influence on outboard usage, so the usage aspect will be handled with the emissions estimation methodology in Section IV. Several studies have been conducted on outboard motor emissions[3-6], but only the first one (References 3 and 4) has been published at this time. In examining outboard motor emissions data from all investigations, attention must be paid to segregating emissions computed or measured to be ending up in the atmosphere from those ending up in the water. Depending on the exhaust constituent of interest, fractions going through the water to the atmosphere range from 40 or 50 to nearly 100 percent. Emission factors for use in making small-scale atmospheric emission estimates are presented in Table 2, along with fuel consumption factors. It is anticipated that emission factors in grams per motor hour and fuel consumption factors in gallons per motor hour will be the most useful of those given, but factors are also given in other units for convenience.

A number of states keep data on registration of outboard boats and/or outboard motors by county, but requests for such data were not sent to all states. In the course of looking for socioeconomic data, however, a number of state statistical publications were obtained which contained boat registration data. County registrations were obtained in this manner for New York[7], Ohio[8], South Carolina[9], and Wisconsin[10]; but some of these data were out of date by as much as seven years.

Table 2. AIR POLLUTANT EMISSION FACTORS AND FUEL CONSUMPTION FOR OUTBOARD MOTORS

Fuel consumption		Atmospheric exhaust emissions					
Units	Value	Units	HC	CO	CO_2	NO_x	SO_x
g/rated hp hr	174.	g/rated hp hr	31.3	92.7	143.	0.18	0.18
gal/rated hp hr[b]	0.0622	g/motor hr[a]	769.	2,280.	3,510.	4.5	4.4
kg/motor hr[a]	4.28	g/gal fuel[b]	503.	1,490.	2,300.	3.0	2.9
gal/motor hr[a, b]	1.53						

[a]Based on average motor rated horsepower of 24.6.
[b]Based on fuel density of 6.17 lb_m/gal = 0.739 g/ml.

B. SNOWMOBILES

Registration of snowmobiles by state is summarized at least annually by the International Snowmobile Industries Association (ISIA), and the latest data available are dated March 1, 1974[11]. The total of all U.S. registrations as given in the ISIA data is 1.71 million, and an additional 0.86 million are listed for Canada. Tabulation of all the state registrations is given in Table A-3 of Appendix A. In addition to the ISIA data, the only information found on snowmobile population was registration data by county for New York[7].

Annual usage of snowmobiles is not a well-defined quantity, and all values used in the literature to date have been estimated[12-14]. The estimates used in the referenced publications were 60 hr/yr and 100 hr/yr, respectively, the former figure being based on qualitative information from a number of sources. For lack of information to the contrary, the 60 hr/yr estimate will be adopted for the purposes of this report.

Data on exhaust emissions from snowmobile engines are available from three sources[12-16], although information from Reference 12 (and Reference 13, which is based on Reference 12) is much more comprehensive and complete than that from the others. Reference 16 contains rudimentary raw data (one speed, several loads and mixtures) on one engine, and Reference 14 develops an emission factor based on the same engine. Reference 15 contains basic data (one speed, one load, several mixtures) on one engine and no real attempt at computing an emission factor. Reference 12 includes data on four engines (three 2-strokes and one rotary), each of which was operated at 29 speed/load conditions using manufacturers' recommended carburetor settings. Where possible, all these data will be taken into consideration; but it is obvious that data from Reference 12 will be relied upon most heavily.

Emission factors and fuel consumption for 2-stroke snowmobiles have been computed in several sets of units, and they are presented in Table 3. The emissions values obtained for a rotary snowmobile engine[12]

Table 3. EMISSION FACTORS AND FUEL CONSUMPTION FOR SNOWMOBILES WITH 2-STROKE ENGINES

	Emission factors[12]						Emission factors[14]		
Units	HC	CO	NO_x	Part.	RCHO	SO_x	HC	CO	NO_x
g/rated hp hr	23.1	35.9	0.367	1.02	0.34	0.031	29.	105.	0.32
g/unit hr	630.	978.	10.0	27.9	9.2	0.85	580.	2100.	6.40
g/gal fuel	670.	1000.	11.	30.	9.8	0.90	-	-	-
kg/unit yr	37.8	58.7	0.60	1.67	0.55	0.05	58.	210.	0.64

Fuel consumption[12]	
Units	Value
g/rated hp hr	97.
gal/rated hp hr	0.035
kg/unit hr	2.6
gal/unit hr	0.94
kg/unit yr	160.
gal/unit yr	56.

Notes:
average rated hp = 20[14] or 27.22[12]
annual usage = 100 hr[14] or 60 hr[12]
average load factor = 0.50[14] or 0.210[12]
fuel density = 6.2 lb_m/gal = 0.743 g/ml

are not included in Table 3, because they were different than 2-stroke levels in several cases. It should be noted that the values are based on tests of only one engine, a 35 hp unit, and that care must be exercised in choice of scaling factors when the data are used to represent other rotaries. Emission factors and fuel consumption for rotary-engined snowmobiles are given in Table 4 in several sets of units. Factors from both Tables 3 and 4 can be used for snowmobile populations where the fraction of each type in the population is known or can be estimated. The OMC rotaries have been on the market less than three seasons as of now (10/74); so if the population breakdown is not available, only small errors would be introduced by assuming that the population is all of the 2-stroke type and using factors from Table 3.

C. MOTORCYCLES

Motorcycle registrations by state are compiled by the U. S. Department of Transportation, Federal Highway Administration. These data are published annually in Statistical Abstract of the United States[17], Highway Statistics[22], and elsewhere. Another source for reasonably accurate state registration data is Automotive Industries[18] magazine,

Table 4. EMISSION FACTORS AND FUEL CONSUMPTION FOR ROTARY-ENGINE SNOWMOBILES[12]

Fuel consumption		Emission factors					
Units	Value	Units	HC	CO	NO_x	Part.	SO_x
g/rated hp hr	124.	g/rated hp hr	4.14	71.7	0.61	0.29	0.052
gal/rated hp hr	0.044	g/unit hr	145.	2510.	21.2	10.2	1.81
kg/unit hr	4.3	g/gal fuel	94.	1600.	14.	6.6	1.2
gal/unit hr	1.54	kg/unit yr	8.70	151.	1.27	0.61	0.11
kg/unit yr	260.						
gal/unit yr	92.						

Notes: rated hp = 35
annual usage = 60 hr
average load factor = 0.217
fuel density = 6.2 lb_m/gal = 0.743 g/ml

and this source has a shorter time lag than the official government publications. The latest registration data available now are for 1973[18], indicating total U.S. registered motorcycles to be about 4.36 million. A recent national survey[19] indicates that 21 percent of all motorcycles may be unregistered, bringing the estimated national total to 5.52 million units. The 1973 registrations by state mentioned above are tabulated in Table A-4 of Appendix A.

A great deal of information is available now regarding motorcycle usage, but none of it is without flaws. The most comprehensive sources are two statistical surveys[19, 20] conducted quite recently by a marketing research firm. The major problems with these data are: (1) that all survey participants were city residents, and (2) that the researchers used a "median average" rather than the arithmetic mean for expressing yearly mileage to compensate for what they felt to be respondent or interviewer errors resulting in high mileage figures. The influence of sampling only in cities cannot be estimated quantitatively, but a recent publication on fuel usage estimation by county[21] indicates annual light-duty vehicle mileage in rural areas may be significantly greater than that in urban areas. How well this directional generality would work for motorcycles is not known.

Annual mileage data in terms of medians and means from the two surveys[19, 20] are shown in Table 5 as functions of engine size and type. Most of the trends from the two surveys compare rather well, but the median average mileages are grossly different. This result is difficult to explain in view of the very good agreement of the overall mean averages;

Table 5. ANNUAL MILEAGE DATA[a] FOR MOTORCYCLES BY ENGINE TYPE AND SIZE

Engine size	Annual mileage by type(19)			Annual mileage by type(20)		
	2-stroke	4-stroke	All	2-stroke	4-stroke	All
90cc or less	828	1,560	1,152	620	480	560
91-190cc	1,644	1,980	1,764	1,170	1,240	1,170
191-290cc	1,968	3,000	2,232	1,630	1,300	1,570
over 290cc	2,796	4,464	3,948	2,420	2,740	2,580
All	1,896	3,456	2,280	1,420	1,870	1,590
	Mean average		3,276	Mean average		3,460

[a]"Median average" mileages except where otherwise noted.

and in combination with other mathematical and logical errors in the survey analyses, the disagreement makes strong confidence in the overall survey results impossible.

Other mileage estimates for motorcycles[22, 23] have been largely a matter of speculation, except one set of figures released in 1973 by the Motorcycle Industry Council (MIC)[24]. These estimates were 1900 miles per year for machines under 100cc, 2500 miles per year for 100-199cc units, 3000 miles per year for bikes in the 200-299cc class, and 4500 miles per year for units 300cc or larger. Even with all the information available, there is not a clear-cut choice of existing mileage data which is obviously accurate. Consequently, the estimates in Table 6 are recommended in lieu of more reliable information. The population percentages

Table 6. MILEAGE ESTIMATES RECOMMENDED FOR MOTORCYCLES AND POPULATION BREAKDOWNS

Engine size	Annual mileage	% of population(19)	% of population(19)	
			2-stroke	4-stroke
90cc or less	750	21	11	9
91- 90cc	1400	27	19	8
191-290cc	2100	11	8	3
over 290cc	3000	41	13	29
National mean	1996	Overall	51	49

[a]Computed using population percentages from Reference 19.

by engine size in Table 6 can be used for the nation as a whole, but more accurate regional size breakdowns(19) are given in Appendix A, Table A-5. The breakdown by engine type in Table 6 can be used for all areas. It should be noted that where parts of an Air Quality Control Region (AQCR) fall into two or more motorcycle "regions", it would probably be logical to use compromise population percentages by engine size for the entire area rather than use different ones on either side of a boundary.

Data on emissions from motorcycles are available from several sources(25-27), but those given in Reference 25 (and refined in Reference 26, a paper based on Reference 25) are by far the most comprehensive. Emissions data given in the Olson report(28) are not useful in computing emission factors due to the inaccuracy of the old procedures used. Factors listed by AESi in its report to the California Air Resources Board(27) are essentially equal to those developed by SwRI in its report to the Environmental Protection Agency(25) and almost equal to the refined factors(26).

If a simplified calculation of motorcycle emissions is desired, data from Table 6 can be used in conjunction with emission factors from Table 7. A more detailed analysis can be performed (by "region", as

Table 7. GENERALIZED MOTORCYCLE EMISSION FACTORS AND FUEL CONSUMPTION BY ENGINE TYPE

Application	Engine type	Data ref.	Emissions in grams per mile						Fuel, mi/gal
			HC[a]	CO	NO_x[b]	Part.	RCHO	SO_x	
on-road	2-s	25	16.	27.	0.12	0.33	0.11	0.038	-
		26	17.	30.	0.11	0.36	0.12	0.040	41
		27	16.	27.	0.12	0.33	-	-	-
	4-s	25	3.5	33.	0.24	0.046	0.047	0.022	-
		26	3.6	34.	0.23	0.048	0.050	0.023	44
		27	3.5	33.	0.24	0.04	-	-	-
off-road	2-s	27	24.	32.4	0.06	0.33	-	-	-
	4-s	27	4.0	39.6	0.36	0.04	-	-	-

[a]Includes an allowance for evaporative emissions.
[b]Does not reflect correction to new driving schedule for testing smaller (under 170cc) motorcycles(29).

defined in Table A-5) by using emission factors from Table 8 and population breakdowns from Table 6. These factors can be expressed in other units when the annual mileage estimate from Table 6 is used, and the results

Table 8. MOTORCYCLE EXHAUST EMISSION FACTORS AND FUEL CONSUMPTION PER UNIT DISTANCE BY ENGINE TYPE AND SIZE

Engine size	Emissions from 2-stroke motorcycles in grams per mile						Fuel usage, mi/gal
	HC	CO	NO_x	Part.	RCHO	SO_x	
90cc or less[a]	6	6	0.11	0.14	0.10	0.021	80
91-190cc[a]	10	12	0.10	0.19	0.11	0.025	69
191-290cc	18	30	0.04	0.35	0.13	0.043	40
over 290cc	25	50	0.04	0.55	0.14	0.057	30

Engine size	Emissions from 4-stroke motorcycles in grams per mile						Fuel usage, mi/gal
	HC	CO	NO_x	Part.	RCHO	SO_x	
90cc or less[a]	2.2	20	0.22	0.022	0.018	0.014	88
91-190cc[a]	2.6	24	0.20	0.030	0.026	0.017	74
191-290cc	3.4	32	0.17	0.045	0.044	0.022	56
over 290cc	4.8	46	0.11	0.070	0.079	0.031	40

[a]Only the NO_x values have been corrected to reflect the new smaller-bike (under 170cc) cycle[29].

are given in Table 9. Note that all the factors developed thus far <u>except</u> those given in Table 7 include no evaporative emissions. The data and method required to estimate evaporative emissions will be presented with the county motorcycle emissions estimation methodology in Section IV.

D. LAWN AND GARDEN EQUIPMENT

In estimating the number of small utility engines used nationwide in lawn and garden equipment, there are no registration statistics and very few reliable data on sales or production. The best estimates available at present are summarized in Table A-6 of Appendix A[14, 30, 31], and they are discussed and evaluated in a previous report to the Environmental Protection Agency[32] and a technical publication based on that report[33]. In attempting to account for utility engines used for lawn and garden applications, a major supposition is that the equipment should be distributed more or less in proportion to the number of single-unit housing structures. It has also been assumed that a rough balance should occur between extra units operated on commercial or public property and homes which have no engine-powered equipment. A good check on these assumptions is to note

Table 9. MOTORCYCLE ANNUAL EXHAUST EMISSION FACTORS AND FUEL CONSUMPTION BY ENGINE TYPE AND SIZE

Engine size	Emissions from 2-stroke motorcycles in kg per year						Fuel usage, gal/yr
	HC	CO	NO_x	Part.	RCHO	SO_x	
90cc or less[a]	4.5	4.5	0.082	0.10	0.075	0.016	9.4
91-190cc[a]	14.	17.	0.14	0.27	0.15	0.035	20.
191-290cc	38.	63.	0.08	0.74	0.27	0.090	52.
over 290cc	75.	150.	0.12	1.65	0.42	0.17	100.

Engine size	Emissions from 4-stroke motorcycles in kg per year						Fuel usage, gal/yr
	HC	CO	NO_x	Part.	RCHO	SO_x	
90cc or less[a]	1.6	15.	0.16	0.016	0.014	0.010	8.5
91-190cc[a]	3.6	34.	0.28	0.042	0.036	0.024	19.
191-290cc	7.1	67.	0.36	0.094	0.092	0.046	38.
over 290ccc	14.	140.	0.33	0.21	0.24	0.093	75.

[a]Only the NO_x values have been corrected to reflect the new smaller-bike (under 170cc) cycle[29].

that the 1970 census[17] showed 46.8 million single-unit housing structures (49.6 million projected to the present), while the population of lawnmowers (alone) projects to about 45.6 million at present. This sort of agreement is quite reasonable and tends to support the overall assumptions.

Based on data from Table A-6 and assuming a growth rate of 6 percent per year for the population of lawn and garden equipment since 1968, the equipment populations basic to this estimation methodology are presented in Table 10. Usage of lawn and garden equipment undoubtedly

Table 10. ASSUMED POPULATIONS OF LAWN AND GARDEN EQUIPMENT (10/31/74)

Engine type	Typical rated hp	Engines in service
4-stroke	3.5	50.9×10^6
2-stroke	3.0	3.5×10^6
Snowthrowers	3.5 (approx.)	1.5×10^6
Other equipment	3.5 (approx.)	52.9×10^6
Total		54.4×10^6

varies with climate, but a well-founded overall estimate of average usage is 50 hours per year[14]. A method has been developed to correct individual county emissions for climate utilizing mean frost-free days per year as basis, and it will be discussed in Section IV as the methodologies are outlined.

Data on emissions from small utility engines are available in several References[14, 16, 27, 32, 33] representing the results of three independent studies. The study reported on in References 14 and 16 was a limited laboratory investigation of 36 engines, with 29 4-stroke engines and seven 2-stroke engines in the sample. Reference 27 reports on a study in which eleven machines (eight 4-stroke and three 2-stroke) were operated through their normal tasks (cutting grass, tilling, etc.) while their exhausts were collected via a large bag or a constant-volume sampler. These data may be closer to real-life emissions than any other information available at this time. The work reported on in References 32 and 33 was an intensive laboratory study of five engines, with one 2-stroke engine and four 4-strokes in the group investigated. Some degree of effort was expended by the original researchers or by others on development of emission factors and emissions impact using each of the three studies as basis.

Hourly mass emissions and fuel consumption for the lawn and garden applications of small utility engines are given in Table 11 as

Table 11. EMISSION FACTORS FOR LAWN AND GARDEN EQUIPMENT BY TYPE OF ENGINE AND SOURCE OF INFORMATION

Engine type	Data from reference	Emissions in grams per hour						Fuel usage, gal/hr
		HC	CO	NO_x	Particulate	RCHO	SO_x	
4-stroke	16	19.	333.	5.2	-----	---	---	-----
	27	40.	380.	4.0	0.7[a]	---	---	0.177
	32	34.	380.	4.3	0.6	0.7	0.5	0.21
2-stroke	16	170.	418.	1.2	-----	---	---	-----
	27	280.	650.	2.0	10.[a]	---	---	0.400
	32	300.	670.	2.2	9.4	2.8	0.8	0.41

[a]Adopted from Reference 32 by author of Reference 27.

estimated according to each of the major studies conducted. Data from studies described in References 27 and 32 are considered to be most representative, so a compromise set of emission factors has been drawn up using these references as basis and is presented as Table 12. These factors can be used with the methodology as outlined in Section IV to estimate emissions on a county basis.

Table 12. RECOMMENDED EMISSION FACTORS AND FUEL USAGE FOR LAWN AND GARDEN EQUIPMENT

Units of factor	Engine or equipment	Emission factors						Fuel usage	
		HC	CO	NO_x	Part.	RCHO	SO_x	Value	Units
g/hr	4-s (all)	37.	380.	4.2	0.6	0.7	0.5	0.20	gal/hr
	2-s snow-thrower	350.	770.	2.4	11.	3.3	0.9	0.47	gal/hr
	Other 2-s	300.	660.	2.1	9.4	2.8	0.8	0.40	gal/hr
kg/yr[a]	4-s snow-thrower	0.19	2.0	0.02	0.00	0.00	0.00	1.1	gal/hr
	2-s snow-thrower	1.9	4.1	0.01	0.06	0.02	0.00	2.5	gal/hr
	Other 4-s	1.8	19.	0.21	0.03	0.04	0.02	10.	gal/hr
	Other 2-s	15.	33.	0.01	0.47	0.14	0.04	20.	gal/hr

[a]Assuming 40 inches snowfall for snowthrowers and a 213 day season for other equipment.

E. CONSTRUCTION EQUIPMENT

Although the project considered construction and industrial equipment as a single category, it now seems more reasonable to consider them separately and thereby reduce the risk of logical errors. In conjunction with efforts toward developing emission factors, a number of sources(27, 34-38) provide estimates of construction equipment populations. In two of these References(27, 38), the scope was limited to a single state; so populations estimated therein are not general enough for present purposes. Another study(37) made no distinction between construction and industrial equipment usage, so its population figures cannot be used here. Two more References(35, 36) do not make use of explicit equipment populations, but rather a total horsepower-hour figure, in estimating emissions impact. By elimination, Reference 34 is the only usable source of population data on construction equipment. Table 13 summarizes these estimates by equipment category, along with data from several sources on typical machine horsepower and annual usage.

Since the result required from this section for input to the county construction equipment methodology is total national construction equipment emissions, only three References(34, 35, 36) can be used for final comparison. Emission factors developed in some of the other studies, however, are useful for indicating the range of estimates available; and all the factors available are included in Table A-7 of Appendix A. Values for national construction equipment emissions are given in Table 14, including amounts estimated for earthmoving equipment as well as all equipment categories. Agreement between estimates for earthmoving equipment is reasonably good, although entirely different assumptions were made for the estimate in Reference 34 as compared to the other two.

Table 13. ESTIMATES OF CONSTRUCTION MACHINERY POPULATIONS, USAGE, AND RATED HORSEPOWER

Equipment category	Estimated population(34)	Est. usage, hr/yr Ref. 27[a]	Ref. 34	Ref. 36	Estimated power, hp Ref. 27[a]	Ref. 34
Tracklaying tractors	197,000	1350	1050	1500	140	120
Tracklaying loaders	86,000	1700	1100	2000	240	65
Motor graders	95,300	2000	830	1200	105	90
Scrapers	27,000	1000	2000[b]	2000	475	475
Off-highway trucks	20,800	2400	2000[b]	2200	420	400
Wheel loaders	134,000	1400	1140	2000	140	130
Wheel tractors	437,000	900	740	----	82	75
Rollers	81,600	700	740	----	78	75
Wheel dozers	2,700	1800	2000	----	330	300
General purpose	100,000	600	1000	----	115	120

[a]These estimates are not considered entirely independent of those in Reference 34 and are intended for California only.
[b]These estimates are not independent of those in Reference 36.

Table 14. ESTIMATES OF NATIONAL CONSTRUCTION EQUIPMENT EMISSIONS AND FUEL CONSUMPTION

Equipment categories	Fuel	Ref.	Emissions in kg/yr x 10^{-6} HC	CO	NO_x	Part.	RCHO	SO_x	Fuel, 10^6 gal/yr
All const.	Diesel	34	72.	220.	820.	63.	17.	65.	4615.
	Gasol.	34	56.	1100.	36.	2.2	1.	1.6	602.
Earth-moving	Diesel	35[a]	55.3	164.	376.	----	---	----	3609.[c]
	Diesel	36[b]	39.9	202.	567.	18.1	---	97.0	3874.[c]
	Diesel	34	57.4	160.	529.	34.8	10.	42.3	3368.

[a]Estimate for 1969 made in 1970.
[b]Estimate for 1969 made in 1972.
[c]Assuming a BSFC of 0.44 lb_m/hp hr = 200 g/hp hr, fuel density = 0.86 g/ml.

F. INDUSTRIAL EQUIPMENT

This category of engines includes a relatively large number of small utility engines similar to those used in lawn and garden equipment and a much smaller number of more durable, more expensive engines of the heavy-duty type. Treating the heavy-duty class first, it includes items such as fork lift engines, auxillary engines used on mobile equipment, engines used in the mineral industries, and pump and generator engines used by airports and utilities. The major source of information on this class of equipment is a previous report to the Environmental Protection Agency[34], in which engine populations and size distributions were estimated on the basis of engine shipments and their value. These estimates are presented in Table 15 along with assumptions on annual engine usage which are about one-half the numbers of hours estimated earlier for comparably-sized construction equipment.

Table 15. ESTIMATES OF HEAVY-DUTY INDUSTRIAL ENGINE POPULATION, RATED POWER, AND ANNUAL USAGE[34]

Engine type	Typical rated hp	Annual usage, hr/yr	Population
Diesel	125	600	417,000
Gasoline	55	300	990,000

The light-duty gasoline engines used in industry are assumed to be the relatively inexpensive air-cooled type. The population of these engines can be estimated by extending the method used in Reference 34 and by assuming that: (1) useful life of these engines averages 600 hours and (2) annual usage averages 100 hours. The resulting population estimate for light-duty industrial gasoline engines is 5.8 million units, and average rated horsepower is estimated at 3.86[34].

Information on emissions from one or more types of industrial engines is found in several of the same sources already utilized[27, 33, 34, 37]. Reference 37 is limited in scope to industrial tractors only, but the specific emissions data are useful for comparison. Reference 27 contains original emissions data only on light duty gasoline engines. Emissions data from these sources are summarized in Table 16 along with fuel consumption estimates and a compromise figure is given for emissions from the light-duty class of industrial engines. The total of estimated annual emissions can be used with the methodologies developed in Section IV to estimate county and grid emissions totals.

Table 16. EMISSIONS AND FUEL CONSUMPTION OF INDUSTRIAL ENGINES

Engine type	Ref.	Units	Emissions HC	CO	NO_x	Part.	RCHO	SO_x
Heavy-duty diesel	34	g/hp hr	1.12	3.03	14.0	1.00	0.21	0.931
	37[a]	g/hp hr	2.7	6.5	8.3	-	-	-
	34	10^6 kg/yr	18.2	49.3	228.	16.2	3.4	15.1
Heavy-duty gasoline	34	g/hp hr	6.68	199.	5.16	0.327	0.22	0.268
	37[a]	g/hp hr	2.8	163.	7.8	-	-	-
	34	10^6 kg/yr	86.5	1690.	43.8	2.8	1.9	2.3
Light-duty gasoline	27[b]	g/hr	50.0	600.	10.0	0.7	-	-
	33	g/hr	29.2	386.	7.68	0.68	0.72	0.60
	c	g/m	32.	400.	7.3	0.68	0.72	0.60
	c	10^6 kg/yr	19.	230.	4.2	0.39	0.42	0.35

Engine type	Ref.	Fuel Units	Value
Heavy-duty diesel	34	g/hp hr	211.
	37[a]	g/hp hr	193.
	34	10^6 gal/yr	1067.
Heavy-duty gasoline	34	g/hp hr	312.
	37[a]	g/hp hr	243.
	34	10^6 gal/yr	941.
Light-duty gasoline	27[b]	gal/hr	0.300
	33	gal/hr	0.25
	c	gal/hr	0.23
	c	10^6 gal/yr	133.

[a]Industrial wheel tractors only.
[b]Category called "home utility" in reference.
[c]Compromise between estimates given in References 27 and 33, based on 3.86 average engine hp.

G. FARM EQUIPMENT

The population of farm equipment is quite well defined down to the county level due to the availability of the Census of Agriculture[39]. This reference can be considerably out of date, since it is published at five-year intervals, but the equipment populations change slowly enough so that most of the data remain reasonably accurate. The edition used in preparing this report was for 1969, and a new one (dated 1974) should be out in 1976. Data given in this reference are much too voluminous to be included here, but copies of the whole document are available in most libraries.

Farm equipment usage information is available in the form of estimates from several sources(33, 34, 37, 38), but accurate survey data are not available. The estimates are summarized in Table 17, along with

Table 17. SUMMARY OF MOTORIZED FARM EQUIPMENT ANNUAL USAGE ESTIMATES

Type of equipment	Ref.	Estimated annual usage, hours	Typical power, hp	Typical load factor
Diesel tractor	34	490	80.2[a]	0.57
	37	432	78.4[a]	0.43
	38[b]	600	80.4	0.57
Gasoline tractor	34	291	40.9[a]	0.57
	37	282	39.7[a]	0.36
	38[b]	500	50.5	0.57
Self-propelled combine	34	73	110.	0.52
	38[b]	100	120/105[c]	0.52
Pull combine	34	52	25.	0.52
	38[b]	100	120/105[c]	0.52
Balers	34	24	40.	0.52
	38[b]	60	70/50[c]	0.52
Forage harvesters	34	120	140.	0.52
	38[b]	100	150/110[c]	0.50
Miscellaneous heavy-duty	34	50	30.	0.52
	38[b]	50	60/30[c]	0.50
Miscellaneous light-duty	34	50	3.5	0.40

[a]Flywheel hp
[b]California only
[c]Estimates for diesel/gasoline equipment.

values for the typical horsepower and load factor of each category of equipment. Estimates given in References 34 and 37 for tractors are in very good agreement, but those in Reference 38 show much higher usage. It should also be noted that tractor horsepower estimates in Reference 38 apparently do not include a correction for power train losses. It is recommended that the values of usage and horsepower from Reference 34 be used when computing emissions from a given area due to their consistent availability, but estimates for tractors could be made using Reference 37 with little change in overall values. Usage of estimates from Reference 38 should at least be restricted to California, and the power loss correction noted above should be made for any calculation involving tractors.

In order to be usable in the emissions estimation methodology without modification, farm equipment emission factors should be expressed in kg/hr. This step is presented as Table 18 for data from several references, along with information on fuel consumption. Hourly emission factors from all the sources are in reasonably good agreement for diesel tractors, and the disagreements for gasoline tractors stem primarily from the variation in load factors shown by Table 17 (these comments also apply to fuel consumption). Since the emission factors from Reference 38 are derived mainly from those in Reference 34, the more complete documentation of Reference 34 makes it the logical choice over Reference 38 for all categories. Making a choice between References 34 and 37 in the gasoline tractor category, however, is a more difficult problem. For hydrocarbons, the choice would have to be Reference 34 due to the greater accuracy of the analytical method used (FID rather than NDIR). A compromise between values given in References 34 and 37 for CO, NO_x, and fuel consumption would probably be most appropriate, resulting in factors of 2.86, 0.134, and 5.08 kg/hr, respectively.

Table 18. EMISSION FACTORS AND FUEL CONSUMPTION FOR FARM EQUIPMENT

Equipment type	Ref.	Emission factors, kg/hr						Fuel[a], kg/hr
		HC	CO	NO_x	Part.	RCHO	SO_x	
Diesel tractor	34	0.078	0.154	0.429	0.059	0.016	0.040	9.06
	37	0.092	0.221	0.282	-----	-----	-----	8.06
	38	0.063	0.139	0.426	0.050	-----	0.040	8.23
Gasoline tractor	34	0.208	3.34	0.155	0.008	0.007	0.006	6.30
	37	0.041[b]	2.38	0.113	-----	-----	-----	3.86
	38	0.197	4.11	0.190	0.010	-----	0.007	6.94
Self-propelled combine	34	0.300	6.37	0.408	0.054	0.015	0.034	15.3
	38	0.259	6.50	0.417	0.055	-----	0.033	12.6
Pull combine	34	0.116	2.83	0.068	0.005	0.003	0.004	4.25
Baler	34	0.183	4.53	0.109	0.008	0.005	0.006	6.80
	38	0.179	5.33	0.148	0.012	-----	0.007	6.34
Forage harvester	34	0.122	0.297	0.657	0.110	0.022	0.067	15.2
	38	0.171	2.25	0.612	0.098	-----	0.060	14.3
Miscellaneous heavy-duty	34	0.082	1.73	0.112	0.015	0.004	0.009	4.17
	38	0.079	1.70	0.175	0.025	-----	0.015	4.71
Miscellaneous light-duty	c	0.029	0.363	0.007	0.001	0.001	0.001	0.58

[a]Where necessary, densities assumed were 0.731 g/ml for gasoline and 0.851 g/ml for diesel fuel.
[b]Based on NDIR data.
[c]Based on factors for light-duty industrial engines, Table 16.

III. SOURCES OF DATA ON COUNTIES

Amid all the information available in the literature on subjects which bear on this study, very little is available for the county level. The major sources of county data utilized are given in Table 19, along

Table 19. MAJOR SOURCES OF DATA ON COUNTIES

Source	Type of data contributed
County and City Data Book 1972[39]	Demographic, business, agricultural
1969 Census of Agriculture[40]	Agricultural equipment populations (1969)
Area Measurement Reports[41]	Land and water areas (1960)
New York State Statistical Yearbook - 1973[7]	Outboard and snowmobile registration data
Statistical Abstract of Ohio - 1969[8]	Outboard registration data
South Carolina Statistical Abstract - 1973[9]	Outboard registration data
Wisconsin Statistical Abstract - Third Edition - June 1974[10]	Outboard registration data
Secretary of State, State of Illinois[42]a	Motorcycle registration data
Missouri Department of Revenue[43]	Motorcycle and outboard registration data

[a]Two examples of sources for motorcycle registration data - the other states were not contacted.

with descriptions of the types of data obtained. In some cases, of course, the data contributed by a given source to this project constitute only a small portion of the data available from that source; and there may be a great many more sources (e. g., state motor vehicle departments) which provide equally useful data.

A number of other sources contain a lesser amount of data for counties, and these sources are listed (along with those given in Table 19) in Appendix B. Another source of county data useful to this effort has been county maps of the type prepared and distributed by state highway departments. These maps normally include not only roads but also bodies of water, boundaries and populations of incorporated places, rural dwellings, and many other features. The maps used during this project were on a scale of one-half inch equals one mile (1:126, 720), but larger-scale maps are usually available and should be used for any serious effort at making county and grid emissions estimates.

IV. METHODOLOGY FOR COUNTY EMISSIONS ESTIMATES

Availability of data and the applicability of specific items and techniques varies among the emissions sources being considered here, so each source will be considered in a separate subsection. Before arriving at the methodologies presented, experimentation was conducted with a number of alternatives for some of the source categories. Documentation of this research is provided in Appendix C, although the methods presented in the text are recommended as preferable overall.

A. OUTBOARD MOTORS

As a consequence of the Federal Safety Act of 1971, most states are currently registering all power boats operating within their borders; but a few states still exempt very small craft (common exemption limit is under 10 horsepower). Statistics for 1974 (available in 1975) should have registrations for all power boats, since the exemptions are no longer approved by the Coast Guard after calendar year 1973. A number of states tabulate boat registrations by county as well as total for the state, but county tabulations are not required for Coast Guard approval.

For the states in which boat registrations are available by county, the county boat population will be assumed to equal registrations plus any applicable correction for boats not registered. It would be worth expending considerable effort to find boat registrations by county or to extract such values from available data, because registrations by county are not easily projected from other generally-available county data.

Data from four states (New York(7), Ohio(8), South Carolina(9), and Wisconsin(10)) confirm that boat registrations correlate strongly with population on a county basis. Simple regression analysis shows correlation coefficients r^2 from 0.70 to 0.99 for individual states, and around 0.75 for the four states taken together. New York data(7) also show that, except for inland counties having no surface water usable for boating ("dry" counties), boats used correlate strongly with boats registered (r^2 over 0.9). To be recorded by the Bureau of the Census(41), ponds must be at least 40 acres (0.16 km^2) in area and streams must be at least 1/8 mile (0.20 km) wide. The best estimate of boats used in a county, therefore, is to apportion total state boat registrations (corrected for boats not registered, if any) by population. Adjustments for individual inland counties can be made if no inland water usable for boating exists by simply neglecting outboard emissions. Care should be exercised, however, to make certain that a given county really has no water usable for boating; because many reservoirs have been constructed since these area measurements were made (1960 or earlier). A correction for disproportionately low registrations and usage in densely populated counties can also be made according to the empirical relationship (based on four-state data[7-10])

$$\text{percent of state boat total used in county} = 31.6\,(\text{population density, inhabitants/mi}^2)^{-0.5} \times (\text{percent of state population in county})$$

for counties having population densities over 1000 inhabitants/mi^2.

The general equation to be used for outboard emissions is

$$\text{county emissions (kg/yr)} = (\text{boats used in county}) \times (\text{emission factor, kg/unit year}).$$

The emission factor is a function of the mixture of boats in the boat population (sizes and types) as well as annual operating time. Although it would be desirable to use a specific mixture of boat sizes and types for each county, such data are not available; so it will be necessary to assume a "typical" mixture[3] in order to proceed with calculations.

Annual boat usage has been estimated to average 75 hours nationwide[3], but usage undoubtedly varies with climatic conditions. For the purposes of this methodology, annual usage will be estimated by the equation

$$\text{annual boat usage (hr)} = 10C_2;$$

where C_2 = number of months during which "monthly normal" temperature exceeds:

45°F for counties in the north region (43°N latitude and northward)
48°F for counties in the central region (37°N latitude to 43°N latitude)
55°F for counties in the south region (south of 37°N latitude).

The temperatures were computed by assuming that the annual period of usage averages six months in the north region, seven months in the central region, and eight months in the south region. "Monthly normal" temperatures are averages of daytime highs and lows averaged over each month of the year for a long period of time (typically 30 years or more). Such data are usually compiled for all weather stations, and data for the nearest weather station can be used. The expression for the yearly average emission factor thus becomes

$$\text{emissions in kg/unit yr} = 0.01\ C_2\ (\text{emissions in g/unit hr}).$$

It is understood that the emissions under consideration are air pollutants only, so the factors should not include pollutants expected to remain in the water phase.

B. SNOWMOBILES

Snowmobiles are used mainly in the north central and northeast states, and good state registration data are available(11). Registrations by county, however, were found only for New York(7); and they correlate very well with snowmobiles used in each county (r^2 over 0.99). In order to predict usage of snowmobiles by county where county data are not available, urban and non-urban counties should be separated. For non-urban counties in New York (population density under 1000 inhabitants per square mile), multiple regression analysis yielded the following relationship ($r^2 = 0.66$):

$$\text{percent of state snowmobiles used in county} = -2.345 + 1.560\ (\text{percent of state population in county}) + 0.0325\ (\text{percent snowfall at state geographic center}).$$

Other variables with which experimentation was conducted, such as number of developed trails and number of large farms, exhibited very weak correlation with snowmobile usage. The percentages resulting from the equation above can be used with state snowmobile registrations to compute the number of snowmobiles operating in each county.

For urban areas where population density is 1000 inhabitants per square mile or more, snowmobile usage decreases as a function of population density. It appears that usage drops to zero when population density reaches about 3000 per square mile, so it will be assumed that usage in urban areas follows the relationship

$$\text{percent of state snowmobiles used in county} = C_4 \left[1.5 - 0.0005\ (\text{county population density, inhabitants/mi}^2)\right] \times (\text{percent of state population in county}),$$

where C_4 = 1 for densities from 1000 to 3000 per square mile and C_4 = 0 for densities above 3000 per square mile.

The general equation used to estimate snowmobile emissions on a county basis is

$$\text{county emissions (kg/yr)} = \text{(total national emissions, kg/yr)} \frac{\text{(snowmobiles operating in county)}}{\text{(national snowmobile registrations)}}.$$

C. MOTORCYCLES

The methodology for motorcycles is one of the least complicated of those under consideration, because registration data for motorcycles are available by county. Registrations only tell part of the story, however, since some motorcycles are always unregistered in each part of the country. The general relationship to be used for motorcycle emissions is

$$\text{county emissions (kg/yr)} = \left[\text{(county registrations)} / \text{(1 - fraction units unregistered)}\right] \times \text{(emission factor, kg/unit yr)}.$$

The county registration data are available from individual state motor vehicle departments, and the fraction of units unregistered is available on both national and regional bases from a recent statistical survey[19]. The emission factor for the population of motorcycles under consideration is computed for each pollutant by

$$\text{factor, kg/unit yr} = (0.001) \sum_{i=i}^{8} F_i \left[\left(\text{emissions, g/mi} \times \frac{\text{mi}}{\text{yr}}\right) + C_1 \left(\text{riding season, days}\right) \left(\text{tank volume}, \ell\right) \left(\frac{0.53 \text{ g HC}}{\ell \text{ tank volume day}}\right)\right]_i,$$

where i = individual motorcycle type/size (e.g., 2-stroke, 91-190 cm^3 displacement)

F_i = fraction of motorcycle population under consideration which is classified in category i

C_1 = 1.0 for hydrocarbons, 0.0 for other pollutants.

The factors F_i and distances travelled annually are available from the same statistical survey mentioned above[19] on both national and regional bases. Length of the riding season in days is available as a national average from another survey[20], and a method has been devised to correct the riding season for specific locations by making use of monthly normal temperatures for U.S. Cities[44]. This correction simply involves counting the number of months during which monthly normal temperature was 38°F or higher for the location of interest and converting those months to days. Fuel tank volumes can be estimated at 2.0 gallons (7.6 ℓ) for bikes of 90 cc or less, 2.5 gallons (9.5 ℓ) for those in the 91-190 cc range, 3.0 gallons (11.4 ℓ) for those in the 191-290 cc range, and 3.5 gallons (15.2 ℓ) for those over 290 cc.

D. LAWN AND GARDEN EQUIPMENT

Emissions from individual small utility engines of the types used in lawn and garden equipment have been studied thoroughly(32, 30), and estimates of national emissions have been made using these emissions results as basis(32, 31). To allocate emissions from lawn and garden equipment by county, however, consideration will be given to areas where these machines are used and to seasonal factors. Lawn and garden equipment is used predominantly around homes, so it seems reasonable that equipment population should correlate well with number of one-unit housing structures(39). This data item will be the basic criterion by which emissions from lawn and garden engines are allocated to counties.

An additional factor for lawn and garden equipment is the highly seasonal nature of its use. Data on occurrence of freezing conditions(17) can be used to predict the length of season for use of mowers, edgers, and tillers. Usage of snowthrowers is predominantly limited to relatively few states, where snowfalls of one inch or more are recorded 10 or 15 times per year (or more frequently). This usage can be evaluated by assuming that no snowthrowers are in service where annual snowfall is under 30 inches and that each snowthrower operates eight minutes for each inch of snowfall. These assumptions are based on a "typical" snowfall of 2.5 inches and a typical usage time of 20 minutes per snowfall. The criterion of 30 inches annual snowfall leads to an (approximate) dividing line of 40°N latitude separating the region of snowthrower operation from generally warmer climates. The distribution of snowthrowers will be assumed to follow the distribution of population in those areas where they are likely to be in service.

The general relationship for lawn and garden equipment emissions is

$$\text{county emissions (kg/yr)} = (\text{nat'l emissions except snowthrowers, kg/yr}) \times \left(\frac{\text{average operating year}}{\text{213 days}}\right)\left(\frac{\text{county mean freeze-free days}}{\text{year}}\right) \times \left(\frac{\text{county one-unit housing structures}}{\text{national one-unit housing structures}}\right) + C_3\left(\frac{\text{county population}}{\text{heavy snow zone population}}\right) \times (\text{national snowthrower population})\left(\frac{\text{one hour operation}}{\text{7.5 inches snowfall}}\right) \times (\text{county snowfall, in/yr})(\text{emission factor, kg/hr});$$

where C_3 = 0 for counties having less than 30 inches annual snowfall, and
C_3 = 1 for counties having 30 inches annual snowfall or more.

The "heavy snow zone population" is the sum of populations of 19 states plus half the populations of three additional states, totalling 83.98 million (1970 census). County snowfall can be assumed equal to that recorded at the nearest reporting station, either inside or outside the county.

E. CONSTRUCTION EQUIPMENT

Nationwide emissions from construction equipment have been estimated by several individual efforts[34, 35, 36], and there is reasonably good agreement on the totals. Allocation of these emissions will be made first to the states, based on construction dollar volume[45]. Allocation to counties will then be made by population.

The construction volume data to be used are available at intervals of six months in the open literature and probably at smaller intervals by consulting directly with the source. The data are broken into three major categories: heavy construction, highways and bridges, and building construction (not including homebuilding). The first two categories make use of more engine-powered equipment per dollar of construction performed than building construction does, so construction dollars in the first two categories will be weighted by a factor of 3 as compared to those spent in building construction. The relationship used to calculate county emissions from construction equipment (based on the above considerations) is

$$\text{county emissions (kg/yr)} = \\ \text{(national emissions, kg/yr)}\,\frac{\text{(state const. volume) (county population)}}{\text{(nat'l const. volume) (state population)}}\,.$$

Emissions due to homebuilding and other light construction are considered negligible compared to emissions from larger (contracted) construction jobs.

F. INDUSTRIAL EQUIPMENT

Based on rather minimal information, emissions from industrial engines have been estimated on a national basis[34]. This category includes engine applications such as: fork-lifts, generators, pumps, and other machinery used by manufacturing concerns; refrigeration units, auxillary engines, and material-handling machinery used in wholesale trade; and machinery used in mining and quarrying. The method used in this case will be to apportion emissions to counties directly from national estimates by the relationship county emissions(kg/yr) =

$$(\text{national emissions kg/yr}) \frac{\text{county } (A + B + C)}{\text{national } (A + B + C)};$$

where A = value added by manufacturing establishments,
B = sales of wholesale trade establishments, and
C = value of shipments and receipts of mineral industries.

In some cases it will be necessary to estimate these quantities by apportioning state data according to number of establishments of each type in the county. Such estimation will be necessary to a greater extent for item "C" than for the others, but it is (for most counties) a relatively small contributor to the sum of A, B, and C.

G. FARM EQUIPMENT

Emissions from motorized farm equipment can be estimated quite accurately due to availability of good data on machine populations[40] and well-documented estimates of annual machine usage[34, 37, 38, 32]. Population data are available for farm tractors, garden tractors used on farms, combines, motorized balers, and motorized forage harvesters. Population estimates for large miscellaneous engines (mostly used in irrigation), small utility engines, and small utility engines used specifically on lawn and garden equipment can also be made.

The large (mostly water-cooled) general purpose engines in service nationwide number about 27 percent of the tractor population[46]. It will be assumed that these engines number 5 percent of the tractor population in non-irrigated areas and 30 percent in irrigated areas. General-purpose small utility engines (used on augers, sprayers, etc.) will be assumed to number 1.5 per farm (class 1-5 farms only). These assumptions are based on the ratio of engines in service in agriculture nationwide to total number of farms and consideration of typical farm requirements. Annual usage of all these items of equipment and applicable emission factors have been developed sufficiently for use in this methodology.

The basic relationship for calculating emissions from farm equipment is

$$\text{county emissions (kg/yr)} = \sum (\text{equipment population}) \times (\text{annual usage}) (\text{emission factor, kg/hr}),$$

where the summation is taken over the types of equipment used.

The number of class 1-5 farms in each county is also available from the Census of Agriculture[40], along with specific data on machinery populations.

V. DEMONSTRATION OF COUNTY EMISSIONS ESTIMATION METHODOLOGIES

The methodologies presented in Section IV are demonstrated in this section for the 12 counties in the St. Louis Metropolitan Air Quality Control Region (AQCR 070). While most aspects of the methodologies can be demonstrated well for these particular counties, special situations restricting applicability or accuracy will be identified. It should be noted, however, that unforeseen circumstances are very likely to occur if the methodologies are applied widely in the field, creating a need for sound judgment and good knowledge of the area under study.

A. OUTBOARD MOTORS

Referring back to Section IV.A., certain data are needed for each county to compute the emissions impact of outboard motors. These data are summarized in Table 20 for the counties in AQCR 070. Before the Missouri outboard registration data can be used, they must be multiplied by the appropriate correction factor from Table 1 (1.48) to account for unregistered small craft. To convey an idea of the accuracy of the registration data under discussion, the Missouri total (corrected for unregistered units) is 227,450 motors as determined by the Department of Revenue, while other sources show 196,000 motors(2) and 105,013 outboard boats(3). It is likely that the last figure is low due to non-inclusion of small boats (it would correct to 155,419), but there is still a considerable amount of disagreement. The figure considered most reasonable for outboard boats in Illinois is listed in Table A-1 of Appendix A, and for the end of 1973 this figure is 182,120.

The value of C_2 listed in Table 20 is seven (months), so annual boat usage for AQCR 070 is estimated at $10C_2$ = 70 hours. The formula for annual emissions becomes

emissions in kg/unit yr = 0.07 (emissions in g/unit hr).

Table 20. COUNTY DATA TO BE USED IN DETERMINING OUTBOARD MOTOR EMISSIONS IMPACT

State	County	Outboard regist.	% state popul.	Population density, inhab./mi^2	Inland water, mi^2	C_2
Illinois	Bond	------[a]	0.126	37	3.0[c]	7
	Clinton	------	0.255	65	38.4[d]	7
	Madison	------	2.26	342	12.5	7
	Monroe	------	0.170	49	9.1	7
	Randolph	------	0.282	53	12.2	7
	St. Clair	------	2.57	424	2.2	7
	Washington	------	0.124	24	0.6	7
Missouri	Franklin	2,536[b]	1.18	59	8.3	7
	Jefferson	5,108[b]	2.25	158	3.4	7
	St. Charles	4,468[b]	1.99	169	35.0	7
	St. Louis	23,488[b]	20.3	1,907	17.6	7
	St. Louis City	12,121[b]	13.3	10,201	3.8	7

[a]Not available for Illinois.
[b]Includes only boats with motors of 7.5 hp or more.
[c]Shown on county road map - 0.0 mi^2 in 1960 tabulation[41].
[d]Shown on county road map - only 0.1 mi^2 in 1960 tabulation[41].

Based on 1973 Illinois total boat registrations apportioned according to population and corrected Missouri registrations by county, Table 21 shows county emissions and fuel consumption of outboard motors using factors from Table 2. These values will be combined later with emissions from the other categories of interest to determine totals for counties and AQCR 070. In terms of season, the outboard emissions are expected to occur during the months of April through October, inclusive.

B. SNOWMOBILES

As shown by data in Table A-3 of Appendix A, no snowmobiles are registered in Missouri; and 34,500 are registered in Illinois. Using the method developed in Section IV.B. for apportioning the snowmobile population to counties, the equation for Illinois counties becomes

$$\begin{aligned} \text{snowmobiles in county} &= -809. + 538. \,(\text{\% of state popul. in county}) \\ &\quad + 11.1\,(77.7) \\ &= 53 + 538 \,(\text{\% of state popul. in county}) \end{aligned}$$

assuming that average snowfall at the state geographic center is 22.0 inches per year. All emissions from snowmobiles, of course, would

Table 21. EMISSIONS AND FUEL CONSUMPTION OF OUTBOARD MOTORS FOR COUNTIES IN AQCR 070

State	County	Outboard boats used	Emissions, 10^3 kg/yr					Fuel used, 10^3 gal/yr
			HC	CO	CO_2	NO_x	SO_x	
Illinois	Bond	229	12.3	36.5	56.3	0.072	0.071	24.5
	Clinton	464	25.0	74.1	114.	0.146	0.143	49.7
	Madison	4,116	222.	657.	1,010.	1.30	1.27	441.
	Monroe	310	16.7	49.5	76.2	0.098	0.096	33.2
	Randolph	514	27.7	82.0	126.	0.162	0.158	55.0
	St. Clair	4,680	252.	747.	1,150.	1.47	1.44	501.
	Washington	226	12.2	36.1	55.5	0.071	0.070	24.2
Missouri	Franklin	3,753	12.2	36.1	55.5	0.071	0.070	402.
	Jefferson	7,560	407.	1,210.	1,860.	2.38	2.33	810.
	St. Charles	6,613	356.	1,060.	1,620.	2.08	2.04	708.
	St. Louis	34,762	1,870.	5,550.	8,540.	11.0	10.7	3,720.
	St. Louis City	17,939	966.	2,860.	4,410.	5.65	5.53	1,920.
Total AQCR 070		81,166	4,370.	13,000.	19,900.	25.6	25.0	8,690.

occur in the winter months (December through March, in this case). Snowmobile populations, emissions, and fuel consumption are summarized in Table 22 for the counties of AQCR 070 where they are computed to occur. It is probable that the error of estimate in this case makes these values higher than actual, due to the rather minimal snowfall in the area for lengthy snowmobile operation.

C. MOTORCYCLES

Emissions from motorcycles are estimated using the method in Section IV. C. and data from Section II. C. The breakdown according to engine size and type is taken from Table 6, and the riding season is computed to be nine months (March through November) or 275 days. The computation of emission factors (in kg/unit year) and fuel consumption is outlined in Table 23, with the results for AQCR 070 appearing as "weighted composites" at the bottom of the table.

Table 23. COMPUTATION OF EMISSION FACTORS AND FUEL CONSUMPTION FOR MOTORCYCLES IN AQCR 070

Motorcycle size	i	Fi	Emissions in kg/unit year						Fuel usage, gal/yr
			HC	CO	NO_x	Part.	RCHO	SO_x	
4-s/0-90cc	1	0.109	2.7	15.	0.16	0.016	0.014	0.010	8.5
4-s/91-190cc	2	0.127	5.0	34.	0.28	0.042	0.036	0.024	19.
4-s/191-290cc	3	0.058	8.8	67.	0.36	0.094	0.092	0.046	38.
4-s/over 290cc	4	0.231	16.	140.	0.33	0.21	0.24	0.093	75.
2-s/0-90cc	5	0.098	5.6	4.5	0.082	0.10	0.075	0.016	9.4
2-s/91-190cc	6	0.115	15.	17.	0.14	0.27	0.15	0.035	20.
2-s/191-290cc	7	0.053	40.	63.	0.08	0.74	0.27	0.090	52.
2-s/over 290cc	8	0.208	77.	150.	0.12	1.65	0.42	0.17	100.
Weighted composite			26.	79.	0.20	0.50	0.19	0.074	50.

Calculation of emissions by county requires registration data, which are available[42, 43], and an assumption of the percentage of unregistered motorcycles in the total population (15 percent for AQCR 070)[19]. Emissions and fuel consumption for counties are shown in Table 24, as well as a total for AQCR 070. As already mentioned, these emissions would occur during the March through November period; and they appear to be concentrated in the more urban counties.

D. LAWN AND GARDEN EQUIPMENT

This category is divided into two classes, namely snowthrowers and other equipment. According to criteria suggested in Section IV.D.,

Table 22. SNOWMOBILE EMISSIONS AND FUEL CONSUMPTION, COUNTIES IN AQCR 070

State	County	Snowmobiles in use	Emissions, 10^3 kg/yr						Fuel used, 10^3 gal/yr
			HC	CO	NO_x	Part.	RCHO	SO_x	
Illinois	Bond	121	4.57	7.10	0.073	0.202	0.067	0.006	6.78
	Clinton	190	7.18	11.2	0.114	0.317	0.10	0.010	10.6
	Madison	1269	48.0	74.5	0.761	2.12	0.70	0.065	71.1
	Monroe	144	5.44	8.45	0.086	0.240	0.079	0.007	8.06
	Randolph	205	7.75	12.0	0.123	0.342	0.11	0.010	11.5
	St. Clair	1436	54.3	84.3	0.862	2.40	0.79	0.073	80.4
	Washington	120	4.54	7.04	0.072	0.200	0.066	0.006	6.72
Total AQCR 070		3485	132.	205.	2.09	1.9	5.82	0.178	195.

Table 24. EMISSIONS AND FUEL CONSUMPTION OF MOTORCYCLES, COUNTIES IN AQCR 070

State	County	Motorcycles[a] in use	Emissions, 10^3 kg/yr						Fuel used, 10^3 gal/yr
			HC	CO	NO_x	Part.	RCHO	SO_x	
Illinois	Bond	555	14.	44	0.11	0.28	0.11	0.04	28.
	Clinton	713	19	56	0.14	0.36	0.14	0.05	36.
	Madison	6,080	160	480	1.2	3.0	1.2	0.45	300.
	Monroe	500	13	40	0.10	0.25	0.10	0.04	25.
	Randolph	1,012	26	80	0.20	0.51	0.19	0.07	51.
	St. Clair	4,969	130	390	0.99	2.5	0.94	0.37	250.
	Washington	295	8	23	0.06	0.15	0.06	0.02	15.
Missouri	Franklin	1,608	42	130	0.32	0.80	0.31	0.12	80.
	Jefferson	3,320	86	260	0.66	1.7	0.63	0.25	170.
	St. Charles	3,492	91	280	0.70	1.7	0.66	0.26	170.
	St. Louis	14,392	370	1,100	2.9	7.2	2.7	1.1	720.
	St. Louis City	10,084	260	800	2.0	5.0	1.9	0.75	500.
Total AQCR 070		47,020	1,200	3,700	9.4	24.	8.9	3.5	2,400.

[a]Assuming 15 percent of motorcycles unregistered(19)

only an insignificant number of snowthrowers should be operating in the St. Louis area; so they will be omitted from this analysis. National emissions and fuel consumption of equipment other than snowthrowers are computed using data from Tables 10 and 12, assuming 2.7 million 2-stroke engines and 50.2 million 4-stroke engines. The other data required for this computation are the mean freeze-free days per year (205)[17] and the numbers of one-unit housing structures in the individual counties and the nation[39]. The number of one-unit housing structures in the nation is approximately 46.8 million, and emissions apportioned to counties using this variable are shown in Table 25 along with fuel consumption and calculated county engine populations. Emissions from lawn and garden equipment occurring in AQCR 070 are about 1 percent of the national total emissions from this engine category.

E. CONSTRUCTION EQUIPMENT

Emissions from construction equipment are given in Table 14 (along with fuel consumption) as national totals, and the construction dollar volume data required for apportioning the national totals to states can be obtained from Reference 29 (August 1974 issue in this case). Computation of the percentage of national construction equipment emissions allocated to the two states within which AQCR 070 falls (Illinois and Missouri) is presented in Table 26. These percentages are equal to the weighted averages of construction dollar percentages given in the last column of Table 26.

Table 26. COMPUTATION OF ILLINOIS AND MISSOURI CONSTRUCTION EQUIPMENT EMISSIONS AS PERCENTAGES OF NATIONAL TOTALS

Area or state	Heavy const.		Highway const.		Building const.[a]		Avg.[b]
	10^6 dol.	%	10^6 dol.	%	10^6 dol.	%	%
U.S.[c]	11,140	100	4,385	100	13,097	100	100
Illinois	395	3.55	297	6.77	834	6.37	5.33
Missouri	214	1.92	148	3.38	348	2.66	2.65

[a]Excluding homebuilding.
[b]Weighted using method in Section IV.E.
[c]Excluding Alaska and Hawaii.

The state percentages can be divided further to make county estimates by apportioning according to population. Percentages of state populations for each county in AQCR 070 were given in Table 20, and they are used with percentages from Table 26 and national totals from

Table 25. LAWN AND GARDEN ENGINE EMISSIONS AND FUEL CONSUMPTION FOR COUNTIES IN AQCR 070

State	County	One-unit housing structures	Computed engine populations 4-stroke	Computed engine populations 2-stroke	Fuel used 10^3 gal/yr
Illinois	Bond	4,490	4,820	259	53.4
	Clinton	7,788	8,350	449	92.5
	Madison	65,533	70,300	3,780	779.
	Monroe	5,383	5,770	311	63.9
	Randolph	8,624	9,250	498	102.
	St. Clair	68,769	73,800	3,970	817.
	Washington	4,848	5,200	280	57.6
Missouri	Franklin	15,882	17,000	916	188.
	Jefferson	27,593	29,600	1,590	328.
	St. Charles	21,631	23,200	1,250	257.
	St. Louis	235,303	252,000	13,600	2790.
	St. Louis City	81,784	87,700	4,720	971.
Total AQCR 070		547,628	587,000	31,600	11,750.

State	County	Emissions, 10^3 kg/yr HC	CO	NO_x	Part.	RCHO	SO_x
Illinois	Bond	12.6	100.	1.01	0.27	0.23	0.11
	Clinton	21.8	174.	1.76	0.46	0.40	0.19
	Madison	183.	1,460.	14.8	3.89	3.3	1.56
	Monroe	15.1	120.	1.22	0.32	0.27	0.13
	Randolph	24.1	192.	1.95	0.51	0.44	0.20
	St. Charles	192.	1,530.	15.5	4.08	3.5	1.63
	Washington	13.6	108.	1.09	0.29	0.25	0.12
Missouri	Franklin	44.4	354.	3.59	0.94	0.81	0.38
	Jefferson	77.1	615.	6.23	1.64	1.4	0.66
	St. Charles	60.5	482.	4.88	1.28	1.1	0.51
	St. Louis	658.	5,240.	53.1	14.0	12.	5.59
	St. Louis City	229.	1,820.	18.5	4.85	4.2	1.94
Total AQCR 070		1,530.	12,200.	124.	32.5	28.	13.0

Table 14 to compute county emissions as shown in Table 27. As expected, this category has a much larger fuel consumption and loading of NO_x emissions than any of the others examined thus far.

F. INDUSTRIAL EQUIPMENT

Fuel consumption and emissions of industrial engines are given in Table 16 as national totals, and information required to apportion emissions according to the method outlined in Section IV.F. is presented in Reference 39. These latter data are summarized in Table 28 for the counties in AQCR 070, indicating that a range from about 0.002 percent to 0.8 percent of national industrial engine emissions occur within individual counties. Using national emissions and fuel consumption data from Table 16 in conjunction with percentage distributions from Table 28, industrial engine emissions by county for AQCR 070 have been

Table 28. COMPUTATION OF INDUSTRIAL EQUIPMENT POPULATION PERCENTAGES FOR COUNTIES IN AQCR 070

Area or state	County	Millions of dollars: A = value added	B = wholesale sales	C = minerals	$\left(\frac{\text{County A+B+C}}{\text{U.S. A+B+C}}\right)$
U.S.	All	261,983.8	459,475.967	25,848.7	1.0
Illinois	Bond	13.2	14.583	-------[a]	3.72×10^{-5}
	Clinton	17.1	17.391	-------[a]	4.62×10^{-5}
	Madison	645.2	229.629	2.8	1.17×10^{-3}
	Monroe	0.9	12.829	-------[a]	1.84×10^{-5}
	Randolph	30.3	14.394	18.4	8.44×10^{-5}
	St. Clair	267.3	519.297	-------[a]	1.05×10^{-3}
	Washington	2.3	15.643	2.8	2.78×10^{-5}
Missouri	Franklin	56.0	25.699	-------[a]	3.44×10^{-5}
	Jefferson	66.4	17.333	3.0	1.12×10^{-4}
	St. Charles	44.8	33.644	-------[a]	1.05×10^{-4}
	St. Louis	1,285.8	3,065.356	9.8	5.84×10^{-3}
	St. Louis City	1,793.5	4,518.156	0.7	8.45×10^{-3}
Total AQCR 070		4,222.8	8,483.954	37.5	1.71×10^{-2}

[a]Negligible

calculated and appear as Table 29. The population of industrial engines is more heavily weighted toward gasoline-fueled units than the population of construction equipment, so it produces more HC and CO and less NO_x than does construction equipment on a soecific basis.

Table 27. CONSTRUCTION EQUIPMENT EMISSIONS AND FUEL CONSUMPTION FOR COUNTIES IN AQCR 070

State	County	% national emissions	Emissions, 10^3 kg/yr						Fuel used, 10^3 gal/yr[a]
			HC	CO	NO_x	Part.	RCHO	SO_x	
Illinois	Bond	0.00672	8.60	88.7	57.5	4.38	1.2	4.48	351.
	Clinton	0.0136	17.4	180.	116.	8.87	2.4	9.06	710.
	Madison	0.120	154.	1,580.	1,030.	78.2	22.	79.9	6,260.
	Monroe	0.00906	11.6	120.	77.6	5.91	1.6	6.03	473.
	Randolph	0.0150	19.2	198.	128.	9.78	2.7	9.99	783.
	St. Clair	0.137	175.	1,810.	1,170.	89.3	25.	91.2	7,150.
	Washington	0.00661	8.46	87.3	56.6	4.31	1.2	4.40	345.
Missouri	Franklin	0.0313	40.1	413.	268.	20.4	5.6	20.8	1,630.
	Jefferson	0.0596	76.3	787.	510.	38.9	11.	39.7	3,110.
	St. Charles	0.0527	67.5	696.	451.	34.4	9.5	35.1	2,750.
	St. Louis	0.538	689.	7,100.	4,610.	351.	97.	358.	28,100.
	St. Louis City	0.352	451.	4,650.	3,010.	230.	63.	234.	18,400.
Total AQCR 070		1.342	1,720.	17,700.	11,500.	875.	240.	894.	70,000.

[a] 88.5 percent of gallons are diesel fuel, 11.5 percent gasoline.

Table 29. INDUSTRIAL ENGINE EMISSIONS AND FUEL CONSUMPTION FOR COUNTIES IN AQCR 070

State	County	Emissions, 10^3 kg/yr						Fuel used, 10^3 gal/yr[a]
		HC	CO	NO_x	Part.	RCHO	SO_x	
Illinois	Bond	4.60	73.3	10.3	0.72	0.2	0.66	79.6
	Clinton	5.71	91.0	12.8	0.90	0.3	0.82	98.9
	Madison	145.	2,300.	323.	22.7	6.7	20.8	2,504.
	Monroe	2.28	36.2	5.1	0.36	0.1	0.33	39.4
	Randolph	10.4	166.	23.3	1.64	0.5	1.50	181.
	St. Clair	130.	2,070.	290.	20.4	6.0	18.6	2,250.
	Washington	3.44	54.7	7.7	0.54	0.2	0.49	59.5
Missouri	Franklin	4.26	67.7	9.5	0.67	0.2	0.61	73.7
	Jefferson	13.9	221.	30.9	2.17	0.6	1.99	240.
	St. Charles	13.0	207.	30.0	2.04	0.6	1.86	225.
	St. Louis	722.	11,500.	1,610.	113.	33.	104.	12,500.
	St. Louis City	1,050.	16,600.	2,330.	164.	48.	150.	18,100.
Total AQCR 070		2,120.	33,700.	4,720.	332.	96.	304.	36,600.

[a]49.8 percent of gallons are diesel fuel, 50.2 percent gasoline.

G. FARM EQUIPMENT

To compute emissions and fuel consumption of farm equipment by county, data from Reference 40 on equipment populations are used with information from Tables 17 and 18 on annual equipment usage and emission rates. To simplify the calculations, composite emission and fuel consumption factors can be used for all tractors (both gasoline and diesel). These factors (in kg/hr) are 0.153 HC, 1.71 CO, 0.259 NO_x, 0.030 Particulate, 0.011 RCHO, 0.020 SO_x, and 6.77 fuel. In addition, the composite annual tractor usage is 352 hours and fuel used in tractors is 53.1 percent diesel fuel by volume. A similar analysis for combines yields factors (in kg/hr) of 0.281 HC, 6.00 CO, 0.372 NO_x, 0.049 Particulate, 0.014 RCHO, 0.031 SO_x, and 14.1 fuel. Composite annual combine usage is 70 hours, and fuel used in combines is 34.2 percent diesel fuel by volume. Looking at the other farm application made up of both diesel and gasoline engines, fuel used in miscellaneous heavy-duty engines is 35.4 percent diesel fuel by volume.

Equipment populations for the counties in AQCR 070 (1969) are listed in Table 30 along with totals for the region. These data can be

Table 30. FARM EQUIPMENT POPULATIONS FOR COUNTIES IN AQCR 070[40]

State	County	Population by type of equipment (1969)					
		Tractors	Combines	Balers	Forage harv.	Misc. heavy duty	Misc. light duty
Illinois	Bond	1,967	379	291	104	98	1,140
	Clinton	2,946	527	586	303	147	1,602
	Madison	4,513	782	751	157	226	2,234
	Monroe	2,244	454	256	72	112	1,068
	Randolph	2,948	484	537	151	147	1,480
	St. Clair	3,746	785	478	141	187	1,878
	Washington	2,980	674	509	185	149	1,580
Missouri	Franklin	3,128	190	726	149	156	1,400
	Jefferson	1,312	91	382	49	66	514
	St. Charles	2,700	472	358	93	135	1,242
	St. Louis	1,179	154	125	16	59	554
	St. Louis City	------	-----	-----	-----	-----	------
Total AQCR 070		29,663	4,992	4,999	1,420	1,482	12,692

used with emission and fuel consumption factors given above in the text and in Table 18 to calculate total emissions by county. To avoid

Table 31. FARM EQUIPMENT EMISSIONS AND FUEL CONSUMPTION FOR COUNTIES IN AQCR 070

State	County	Emissions, 10^3 kg/yr						Fuel used[a] 10^3 gal/yr
		HC	CO	NO_x	Part.	RCHO	SO_x	
Illinois	Bond	118.	1,410.	199.	23.7	8.4	15.6	1,770.
	Clinton	179.	2,110.	309.	37.3	13.	24.5	2,730.
	Madison	268.	3,190.	448.	53.0	19.	35.0	3,980.
	Monroe	134.	1,600.	224.	26.5	9.5	17.5	1,990.
	Randolph	175.	2,080.	296.	35.2	12.	23.2	2,620.
	St. Clair	225.	2,690.	376.	44.6	16.	29.4	3,350.
	Washington	181.	2,180.	306.	36.6	13.	24.1	2,730.
Missouri	Franklin	180.	2,080.	305.	36.1	13.	23.8	2,690.
	Jefferson	75.8	885.	127.	15.0	5.4	9.9	1,130.
	St. Charles	160.	1,900.	268.	31.7	11.	20.9	2,380.
	St. Louis	68.3	803.	114.	13.3	4.8	8.8	1,010.
	St. Louis City	-------	-------	------	-----	-----	-----	-------
Total AQCR 070		1,760.	20,900.	2,970.	353.	120.	233.	26,400.

[a]52.5 percent of gallons are diesel fuel, 47.5 percent gasoline.

unnecessary complication, the results of this calculation are given in Table 31 as totals for all the farm equipment in each county rather than as totals for each type of equipment. In the computations for farm equipment emissions and fuel consumption, it is necessary to assume that the diesel and gasoline population fractions are the same as for the national population. Although this assumption may be somewhat in error for specific counties, no data are available at the county level which would permit a more refined analysis.

Having calculated emissions and fuel consumption for the seven categories of internal combustion engines under study, it is now possible to construct a summary which can be compared to the NEDS (National Emissions Data System) survey data for AQCR 070. This summary is presented in Table 32 with the NEDS data for off-highway gasoline- and diesel-powered vehicles and a total for the AQCR.

Table 32. SUMMARY OF EMISSIONS FROM ENGINE CATEGORIES UNDER STUDY

Category	Emissions, 10^3 kg/yr					
	HC	CO	NO_x	Part.	RCHO	SO_x
Outboard motors	4,370.	13,000.	25.6	-------	-----	25.0
Snowmobiles	132.	205.	2.1	5.8	1.9	0.2
Motorcycles[a]	1,200.	3,700.	9.4	24.	8.9	3.5
Lawn and garden	1,530.	12,200.	124.	32.5	28.	13.0
Construction	1,720.	17,700.	11,500.	875.	240.	849.
Industrial	2,120.	33,700.	4,720.	332.	96.	304.
Farm	1,760.	20,900.	2,970.	353.	120.	233.
Total	12,800.	101,000.	19,400.	1,620.	490.	1,430.
NEDS gasoline[b]	4,050.	22,200.	1,290.	59.	-----	36.
NEDS diesel[b]	337.	2,050.	3,370.	118.	-----	246.
NEDS total[b]	4,390.	24,200.	4,660.	177.	-----	282.

[a]25 percent of this total estimated off-highway.
[b]Off-highway I.C. engine area sources.

VI. METHODOLOGY FOR GRID ELEMENT EMISSIONS ESTIMATES

The intrinsic properties of grid elements which can be helpful in making emissions estimates for them include:

1. area (1, 4, 25, or 100 km^2) - some portion of area <u>may not</u> be in county for a given element
2. highway mileage by type of highway in rural areas (street details not given on maps)
3. presence and amount of surface water suitable for boating
4. area in open land suitable for farming
5. area in towns, cities, and incorporated places
6. number of dwellings (some counties) in rural areas

To indicate typical detail given on a county highway map (scale is 1/2 inch = 1 mile or 1:126, 720), a section of the map for St. Louis County, Missouri is included as Figure 1. Several of the grid elements have been laid out on this map section to document their appearance, the larger ones being 5 km square and the smaller ones 2 km square. The computer program (a copy of which is in Appendix D) prints geographical coordinates to the nearest 0.01 second of angle, which represents the nearest 8×10^{-5} inch for longitude and the nearest 1×10^{-4} inch for latitude on the maps. It is obvious that the grids cannot be plotted with this kind of accuracy, and a reasonable estimate of accuracy is ±0.02 inches on the map or an actual error of ±65 m on the ground.

The distributions of several engine categories under investigation in this methodology development program are probably related more strongly to population than to any other single variable. Population data by grid element, however, are not available from any known source. It seems desirable to have a system for allocating population to grid elements; so this problem will be analyzed here before addressing specific methodologies for engine categories. Neglecting population density variations within incorporated places (incorporated places are outlined on county highway maps), grid element population can be estimated by

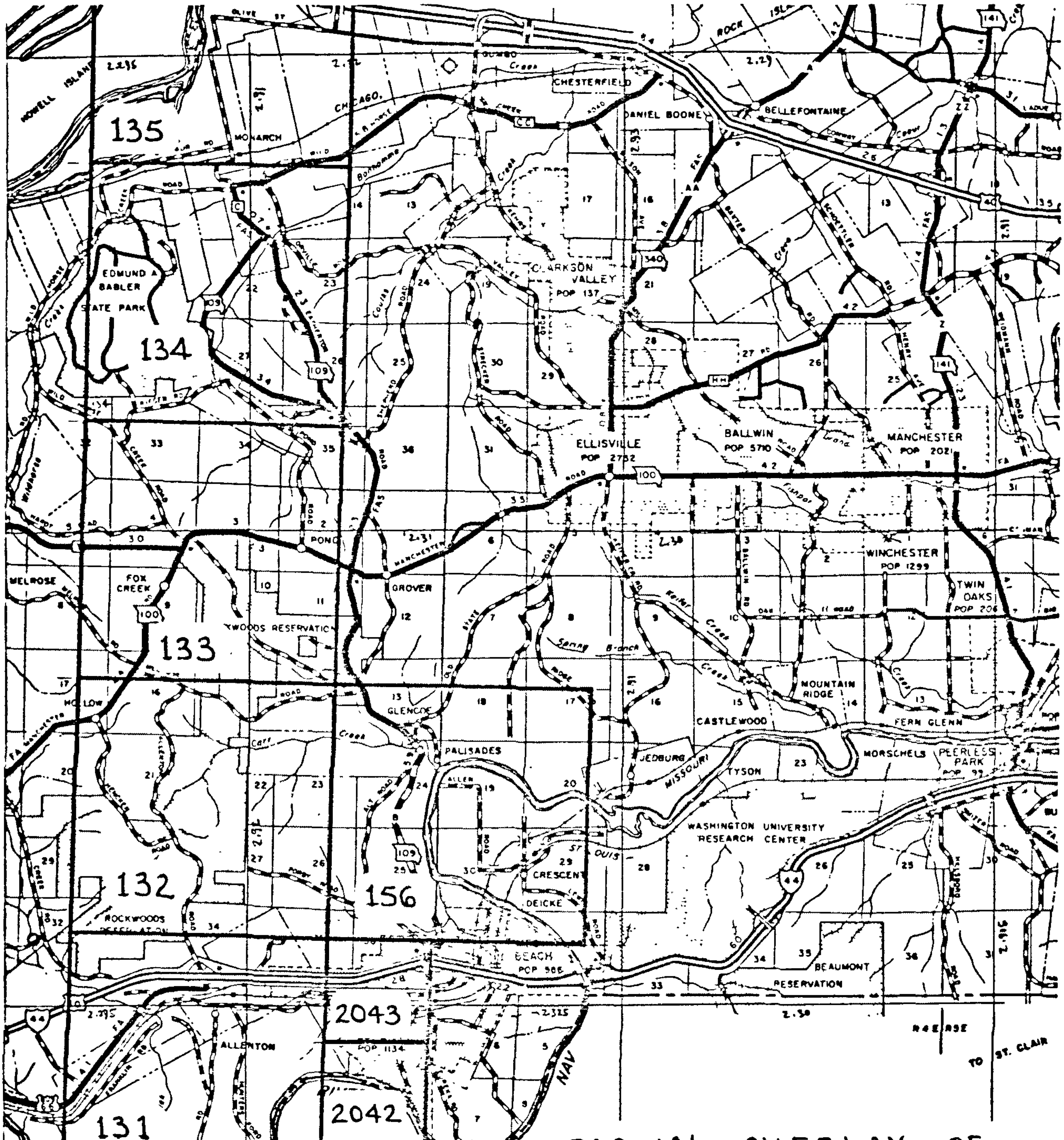

Figure 1. Sample layout of grid elements on a county highway map

$$\text{grid element population} = \left(\frac{\text{privately-owned grid land area}}{\text{area of incorporated place}}\right) \times \text{(population of incorporated place)}.$$

Grid element area is given by definition, and both the other variables can be obtained from Appendix B, Table B-2 of the County and City Data Book[39] for places having a population of 2500 or more. Places having fewer than 2500 people are outlined on county highway maps, and their populations are given; so both variables can still be obtained (area to be measured by geometric sections or polar planimeter). For a serious effort directed at grid element estimates, larger-scale maps than the ones obtained for reference during this project should be available and are highly recommended for use.

Population estimates for grid elements not in incorporated areas are not as simple as those for incorporated areas. In this case, the best which can be done is to allocate (by area) the county's rural population to land remaining after all incorporated areas have been subtracted. This process takes the form

$$\text{grid element population} = \left(\frac{\text{privately-owned grid land area}}{\text{county unincorporated area}}\right) \times \text{(county farm population + county rural nonfarm population)},$$

where "county unincorporated area" can be determined by subtracting areas of incorporated places from total county area. An easier but somewhat less rigorous estimate could be made by assuming that "county unincorporated area" is equal to county area in farms[39], with small probable errors in most parts of the country.

Although not mentioned specifically thus far, grid elements which contain parts of two incorporated places, and/or two counties, and/or both incorporated and unincorporated places will have to be treated in separate parts. After the parts have been analyzed, the grid total population estimate can be summed.

A. OUTBOARDS

The major variable by which boating can be allocated to grids is availability of surface water of a suitable nature. The relationship proposed for outboard emission estimates is

$$\text{grid element emissions (kg/yr)} = \text{(county emissions, kg/yr)} \times \left(\frac{\text{grid surface water area}}{\text{county surface water area}}\right).$$

The equation should be satisfactory where all county surface water is suitable for boating, but the accepted total county figure[41] should probably be revised if some water geometrically OK for boating is heavily polluted, moving very swiftly, or otherwise unfit for use by small boats. The degree of care exercised on this point depends on the desired accuracy of the estimate and the amount of detailed data available for the area under study. Surface water areas for grid elements can be determined by measurement (e.g., by polar planimeter) using maps of the largest practically available scale. On a map such as the segment shown in Figure 1, minimum-size features used as input to tabular data[41] are represented by ponds 0.14 inch in diameter and rivers 0.062 inch wide. This reporting guideline does not necessarily reflect a typical minimum water area for outboard operation, but it would be an involved matter to form a new criterion since re-measurement of all the county's inland water area would be involved. In all cases, county surface water area from Reference 41 should be checked (at least roughly) against the county map, because many reservoirs have been built since 1960.

B. SNOWMOBILES

Emissions from snowmobiles will be allocated on an area basis, since urban and non-urban ownership and usage patterns have already been accounted for in the county methodology. The relationship which follows is

$$\text{grid element emissions (kg/yr)} = \left(\frac{\text{grid element land area}}{\text{county land area}}\right) \times \text{(county emissions, kg/yr)}.$$

This estimate could be modified by adding lakes which might be frozen during the snowmobile season to the area terms, but such a modification could hardly be justified by the accuracy of the overall estimate in most cases. In the same way, uniform subtractions of areas in which snowmobiles do not run can probably not be justified.

C. MOTORCYCLES

Although some other variables may be significant, motorcycles in service and their usage are probably related strongly to distribution of population within the county. It is proposed, therefore, that the grid element estimates for motorcycles be determined by the relationship

$$\text{grid element emissions (kg/yr)} = \text{(county emissions, kg/yr)} \times \left(\frac{\text{grid population estimate}}{\text{county population}}\right);$$

where the grid population estimate is made as described above.

D. LAWN AND GARDEN EQUIPMENT

Following the same general method used in allocating emissions from lawn and garden equipment to counties, it will still be attempted to apportion these emissions to grids according to location of one-unit housing structures. Using the technique developed earlier for estimating grid element population, the relationships which result are

$$\text{grid element emissions (kg/yr)} = \left(\frac{\text{grid one-unit structures}}{\text{county one-unit structures}}\right) \times \text{(county emissions, kg/yr)}$$

and

$$\text{grid one-unit structures} = \text{(grid population)}\left(\frac{\text{area one-unit structures}}{\text{area population}}\right).$$

The last term in the second equation is available for cities of 25,000 or more in tabular form(39). In all other privately-owned areas, the value of that term will be assumed as 0.230, which is the national average(39).

E. CONSTRUCTION AND INDUSTRIAL EQUIPMENT

It is doubtful that any of the intrinsic properties of grid elements correlate directly with construction equipment usage. While major construction projects such as highways, sewer systems, and large buildings are built to serve people's needs, they are often built on the periphery of the densely-populated areas. Industrial areas are also often located near, but not in, the most heavily-populated areas. These industrial areas can be pinpointed, however, by examining zoning maps for the area of interest if extreme accuracy is desired.

Having noted the shortcomings of the method, it is still necessary (due to lack of other data) to allocate construction and industrial engine emissions by population. The method derived earlier for grid population estimates can be used in the relationship

$$\text{grid element emissions (kg/yr)} = \left(\frac{\text{estimated grid element population}}{\text{county population}}\right) \times \text{(county emissions, kg/yr)}.$$

A more refined technique, using zoning laws, can be applied to industrial engine emissions in areas of industrial zoning. This technique results in the equation

$$\text{grid element emissions (kg/yr)} = \left(\frac{\text{grid element area in industrial/ commercial zones}}{\text{county area zoned industrial/ commercial}} \right) \times$$

$$\text{(county emissions, kg/yr),}$$

and this second technique is considered highly preferable to the population-based method where the necessary information is available.

F. FARM EQUIPMENT

It will be assumed that emissions from farm equipment correlate well with area (acreage) in farms, leading to the relation

$$\text{grid element emissions (kg/yr)} = \left(\frac{\text{privately-owned unincorporated grid area}}{\text{county area in farms}} \right) \times$$

$$\text{(county emissions, kg/yr).}$$

Depending on the desired level of accuracy, the term in the denominator could be checked against the county sum of privately-owned unincorporated area, which it is assumed to equal. If the two are not equal, then "county area in farms" could be replaced by "county privately-owned unincorporated area" to make the sum of the grid/county ratios equal 1.0.

VII. SUMMARY

All the phases of this study have been completed, but it should not be assumed that the results are a completely authoritative and correct analysis of emissions and fuel consumption on a county basis. Throughout the narrative, it has been stressed that achieving the project's objectives has often required usage of data which are really insufficient for the task. The results must be used only with full knowledge of their limitations, most of which were known even before the study began.

Most of the basic emissions data on which county methodologies (and hence grid methodologies) were derived are probably quite accurate; but even from the points at which modal data were combined to yield composite data or individual vehicle/engine data were combined to produce category data, errors have certainly occurred. In all cases, however, so many variables are missing that the errors cannot be estimated statistically. Proper use of the study's results, then, requires the knowledge that they are limited to estimates of an accuracy commensurate with the time and effort which went into the project. In other words, the estimates are reasonably good but in no way rigorous.

A number of good sources of emissions, population, and usage data were found; and these sources are essentially the composition of the List of References. A few References (e.g., 7-10, 39, 41, and perhaps others) are primarily sources of county data relatable to vehicle or engine population or usage, and a more complete list of these documents is found in Table 19. Secondary sources of county/small area data are listed in Appendix B, but they were not used much in preparation of this report.

The county and grid element methodologies themselves have been structured as much as possible to permit "plugging in" values with little or no prior computation involved. In some cases, values will have to be processed before use, such as those for percentages of state population in a given county. It is simply not practical here to convert all data to be used in the methodologies to compatible terms, especially since the methodologies may not be used for all areas at any foreseeable time.

Due to the length of equations and explanations used in the methodologies, it is not considered practical to reiterate them all in this section. It is in order, however, to give an assessment of the estimated relative accuracy of the methodologies. A rank-ordering from most accurate to least accurate is as follows:

1. farm equipment
2. motorcycles
3. construction equipment
4. lawn and garden, and outboards (tie)
5. industrial equipment and snowmobiles (tie)

This assessment is based first on availability of county population data, then on accuracy of emissions data, and finally on availability of usage information.

As shown in Table 32, total emissions from sources under study in this project exceed by considerable margins those estimated for off-highway internal combustion engine sources by the NEDS system. The basis for the NEDS estimates is not known at this time. To further compare emissions estimated by the methodologies developed herein to NEDS figures, Table 33 is presented to illustrate the impact of off-highway source emissions on totals for AQCR 070. This comparison shows estimated emissions of HC, CO, and NO_x from uncontrolled engines to be small but significant contributors to air pollution around St. Louis. It likewise shows that these engines do not contribute significantly to total particulate or SO_x emissions in that area.

Table 33. IMPACT OF OFF-HIGHWAY SOURCES ON EMISSIONS IN AQCR 070

Source categories	Emissions, 10^3 kg/yr				
	HC	CO	NO_x	Part.	SO_x
NEDS area sources	196,541	922,148	111,181	34,043	42,730
NEDS point sources	71,194	2,573,063	282,132	287,709	1,077,113
NEDS all sources	295,123	3,495,211	393,314	321,752	1,119,843
NEDS gasoline off-highway	4,050	22,200	1,290	59	36
NEDS diesel off-highway	337	2,050	3,370	118	246
NEDS all off-highway	4,390	24,200	4,660	177	282
Off-highway (this report)	12,800	101,000	19,400	1,620	1,430
- as % NEDS total	4.34	2.89	4.93	0.504	0.128

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APPENDIX A

TABULAR DATA ON POPULATION, USAGE, AND EMISSIONS OF SELECTED MOBILE SOURCE CATEGORIES

Table A-1. 1973 BOAT REGISTRATIONS AS COMPILED BY THE U. S. COAST GUARD[1]

State	Outboard boats	State	Outboard boats
Alabama	131,933	Nebraska	31,266
Alaska	11,642	Nevada	14,170
Arizona	41,706	New Hampshire	6,844
Arkansas	67,201	New Jersey	93,746
California	264,085	New Mexico	22,141
Colorado	29,027	New York	295,171
Connecticut	54,159	North Carolina	87,716
Delaware	17,027	North Dakota	12,085
Dist. of Columbia	2,349	Ohio	127,509
Florida	219,433	Oklahoma	125,686
Georgia	53,414	Oregon	85,337
Hawaii	8,185	Pennsylvania	119,872
Idaho	36,541	Rhode Island	10,483
Illinois	182,120	South Carolina	119,206
Indiana	91,264	South Dakota	18,049
Iowa	100,009	Tennessee	161,136
Kansas	61,100	Texas	385,196
Kentucky	82,586	Utah	19,264
Louisiana	102,868	Vermont	21,369
Maine	29,441	Virginia	96,407
Maryland	57,579	Washington	78,110
Massachusetts	103,823	West Virginia	11,971
Michigan	512,302	Wisconsin	331,980
Minnesota	306,165	Wyoming	7,362
Mississippi	37,545	Guam	437
Missouri	105,013	Puerto Rico	7,200
Montana	13,299	Virgin Islands	2,802
		Total including 48 states and D. C.	4,984,065

Table A-2. ESTIMATED STATE DISTRIBUTION OF OUTBOARD MOTORS, DECEMBER 31, 1973[2]

State	Motors	State	Motors
Alabama	150,000	Nebraska	38,000
Arizona	44,000	Nevada	16,000
Arkansas	121,000	New Hampshire	43,000
California	385,000	New Jersey	185,000
Colorado	38,000	New Mexico	19,000
Connecticut	92,000	New York	534,000
Delaware	23,000	North Carolina	134,000
Dist. of Columbia	26,000	North Dakota	24,000
Florida	527,000	Ohio	293,000
Georgia	152,000	Oklahoma	114,000
Idaho	43,000	Oregon	114,000
Illinois	312,000	Pennsylvania	195,000
Indiana	201,000	Rhode Island	28,000
Iowa	103,000	South Carolina	129,000
Kansas	71,000	South Dakota	20,000
Kentucky	99,000	Tennessee	167,000
Louisiana	292,000	Texas	470,000
Maine	86,000	Utah	35,000
Maryland	131,000	Vermont	23,000
Massachusetts	177,000	Virginia	120,000
Michigan	482,000	Washington	185,000
Minnesota	380,000	West Virginia	27,000
Mississippi	68,000	Wisconsin	370,000
Missouri	196,000	Wyoming	8,000
Montana	20,000		
		Total	7,510,000

Table A-3. U. S. SNOWMOBILE REGISTRATIONS AS OF MARCH 1, 1974[11]

State	Snowmobiles
Alaska	20,100
Arizona	1,000
California	15,000
Colorado	23,000
Connecticut	15,300
Idaho	32,000
Illinois	34,500
Iowa	26,000
Maine	75,260
Massachusetts	71,900
Michigan	400,000
Minnesota	290,400
Montana	30,000
Nebraska	400
Nevada	3,000
New Hampshire	49,000
New Jersey	12,000
New Mexico	2,100
New York	172,776
North Dakota	37,751
Ohio	12,500
Oregon	10,600
Pennsylvania	60,000
Rhode Island	1,050
South Dakota	25,077
Utah	13,500
Vermont	13,013
Washington	10,500
Wisconsin	233,569
Wyoming	12,000
Total U. S.	1,714,796

Table A-4. 1973 MOTORCYCLE REGISTRATIONS BY STATE[18]

State	Motorcycles	State	Motorcycles
Alabama	65,560	Montana	37,133
Alaska	15,143	Nebraska	45,000
Arizona	62,768	Nevada	15,434
Arkansas	34,036	New Hampshire	20,544
California	631,961	New Jersey	69,208
Colorado	81,871	New Mexico	30,799
Connecticut	51,440	New York	91,575
Delaware	6,050	North Carolina	95,435
Dist. of Columbia	4,045	North Dakota	18,738
Florida	142,478	Ohio	179,359
Georgia	90,454	Oklahoma	94,156
Hawaii	12,000	Oregon	100,203
Idaho	45,936	Pennsylvania	231,475
Illinois	177,487	Rhode Island	15,190
Indiana	99,000	South Carolina	33,232
Iowa	118,545	South Dakota	19,785
Kansas	99,399	Tennessee	74,000
Kentucky	49,112	Texas	257,400
Louisiana	40,000	Utah	51,375
Maine	20,713	Vermont	8,981
Maryland	44,000	Virginia	69,000
Massachusetts	67,000	Washington	91,184
Michigan	269,185	West Virginia	48,703
Minnesota	119,277	Wisconsin	77,080
Mississippi	130,000	Wyoming	14,893
Missouri	95,263		
		Total	4,362,605

Table A-5. MOTORCYCLE BREAKDOWNS BY SIZE FOR REGIONS OF THE UNITED STATES[19]

"Region" of the U. S.	Motorcycle size distribution		States included in "region"
	Displacement, cc	% of population	
New England	90 and less	9	Connecticut
	91-190	20	Maine
	191-290	9	Massachusetts
	291 and over	59	New Hampshire
	Unclassified	3	Rhode Island
			Vermont
Middle Atlantic	90 and less	20	New Jersey
	91-190	22	New York
	191-290	12	Pennsylvania
	291 and over	46	
	Unclassified	0	
East North Central	90 and less	23	Illinois
	91-190	22	Indiana
	191-290	11	Michigan
	291 and over	42	Ohio
	Unclassified	2	Wisconsin
West North Central	90 and less	18	Iowa
	91-190	26	Kansas
	191-290	11	Minnesota
	291 and over	45	Missouri
	Unclassified	0	Nebraska
			North Dakota
			South Dakota
South Atlantic	90 and less	22	Delaware
	91-190	25	Dist. of Columbia
	191-290	10	Florida
	291 and over	40	Georgia
	Unclassified	3	Maryland
			North Carolina
			South Carolina
			Virginia
			West Virginia

table continued next page

Table A-5 (continued). MOTORCYCLE BREAKDOWNS BY SIZE FOR REGIONS OF THE UNITED STATES(19)

"Region" of the U. S.	Motorcycle size distribution Displacement, cc	% of population	States included in "region"
East South Central	90 and less	24	Alabama
	91-190	27	Kentucky
	191-290	3	Mississippi
	291 and over	40	Tennessee
	Unclassified	6	
West South Central	90 and less	21	Arkansas
	91-190	33	Louisiana
	191-290	7	Oklahoma
	291 and over	36	Texas
	Unclassified	3	
Mountain	90 and less	28	Arizona
	91-190	32	Colorado
	191-290	10	Idaho
	291 and over	22	Montana
	Unclassified	8	Nevada
			New Mexico
			Utah
			Wyoming
Pacific	90 and less	20	Alaska
	91-190	27	California
	191-290	16	Hawaii
	291 and over	35	Oregon
	Unclassified	2	Washington

Table A-6. SALES, PRODUCTION, AND POPULATION ESTIMATES FOR LAWN AND GARDEN EQUIPMENT

Previous Population Estimate for Small Utility Engines (1968-All)[14]

Engine type	Average rated hp	Engines in service
Lawn and garden 4-stroke	3.43	36,200,000
Lawn and garden 2-stroke	3.43	2,500,000
Miscellaneous 4-stroke	3.86	5,550,000
	Total	44,250,000

Outdoor Equipment Sales and Population Estimates[30]

Type of equipment	Sales or population for sales year, millions						
	[a]1973	1972	1971	1970	1969	1968	1967
Walking mowers	5.45	5.2	4.7	4.7	4.7	4.56	4.9
Lawn tractors and riding mowers	0.74	0.68	0.88	0.95	1.0	0.93	0.25
Garden tractors	0.26	0.25	b	b	b	b	b
Total lawn and garden	6.45	6.13	5.58	5.65	5.7	5.49	5.15
Estimated total in use	--	43.	38.	37.	36.	--	--
Motor tillers	0.43	0.43	0.36	0.36	0.38	0.38	0.35
Snow throwers	0.33	0.32	0.26	0.24	0.26	0.26	0.18

[a]Prediction
[b]Included with lawn tractors and riding mowers.

Breakdown of 1966-1970 Small Engine Production by Application[31]

Application	Production (millions)	% of total
Riding mower	2.84	7.1
Walking mower	23.67	59.4
Garden tractor	1.19	3.0
Motor tiller	1.70	4.3
Snow thrower	1.18	3.0
Other lawn and garden	1.31	3.3
Total lawn and garden	31.89	80.0
Recreation	1.10	2.8
Industrial	2.65	6.6
Agriculture	0.97	2.4
Miscellaneous	3.27	8.2
Total	39.88	100.0

Table A-7. EMISSION FACTORS AND FUEL CONSUMPTION FOR CONSTRUCTION EQUIPMENT BY CATEGORY AND REFERENCE

Equipment category	Diesel or gasoline	Ref.	Brake specific emissions, g/hp hr						BSFC g/hp hr
			HC	CO	NO_x	Part.	RCHO	SO_x	
Tracklaying tractors	Diesel	38[a]	0.69	2.39	9.08	0.69	-	0.85	-
		34	0.685	2.39	9.08	0.692	0.17	0.851	193.
Tracklaying loaders	Diesel	38[a]	0.36	1.80	6.56	0.66	-	0.85	-
		34	0.362	1.80	6.56	0.655	0.10	0.853	194.
Motor graders	Diesel	38[a]	1.68	4.08	9.03	1.51	-	0.92	-
		34	0.532	2.15	10.6	0.613	0.12	0.874	199.
	Gasoline	38[a]	7.18[b]	218.	5.24	0.37	-	0.22	-
		34	8.62[c]	187.	4.92	0.320	0.30	0.26	295.
	Both	34	0.936	11.4	10.3	0.598	0.13	0.844	-
Scrapers	Diesel	38[a]	1.22	2.84	12.1	0.79	-	0.90	-
		34	1.22	2.84	12.1	0.789	0.28	0.901	205.
Off-highway	Diesel	38[a]	0.85	2.62	14.9	0.50	-	0.89	-
		34	0.853	2.62	14.9	0.502	0.22	0.887	201.
Wheel loaders	Diesel	38[a]	1.70	3.34	9.39	1.28	-	0.87	-
		34	0.948	2.63	11.2	0.810	0.20	0.857	195.
	Gasoline	38[a]	6.86[b]	143.	6.62	0.37	-	0.23	-
		34	7.35[c]	163.	5.41	0.312	0.22	0.244	276.
	Both	34	1.97	28.3	10.3	0.730	0.20	0.759	-
Wheel tractors	Diesel	38[a]	1.70	3.34	9.39	1.28	-	0.87	-
		34	1.39	4.40	9.34	1.27	0.28	0.851	193.
	Gasoline	38[a]	6.86[b]	143.	6.62	0.35	-	0.23	-
		34	7.41[c]	142.	6.37	0.360	0.26	0.230	269.
	Both	34	1.99	18.1	9.05	1.18	0.28	0.789	-
Rollers	Diesel	38[a]	1.68	4.08	9.03	1.51	-	0.92	-
		34	0.777	3.64	15.8	0.777	0.20	1.00	228.
	Gasoline	38[a]	7.18[b]	218.	5.24	0.37	-	0.23	-
		34	12.0[c]	202.	5.47	0.394	0.25	0.279	325.
	Both	34	6.71	193.	8.57	0.506	0.24	0.495	-

table continued next page

Table A-7 (continued). EMISSION FACTORS AND FUEL CONSUMPTION FOR CONSTRUCTION EQUIPMENT BY CATEGORY AND REFERENCE

Equipment category	Diesel or gasoline	Ref.	Brake specific emissions, g/hp hr						BSFC
			HC	CO	NO_x	Part.	RCHO	SO_x	g/hp hr
Wheel dozers	Diesel	38[a]	0.58	1.83	12.5	0.41	-	0.87	-
		34	0.576	1.83	12.5	0.411	0.16	0.867	197.
General purpose	Diesel	38[a]	1.68	4.08	9.03	1.51	-	0.92	-
		34	1.03	2.82	14.8	0.907	0.20	0.933	212.
	Gasoline	38[a]	7.18[b]	218.	5.24	0.37	-	0.23	-
		34	8.31[c]	198.	4.79	0.300	0.23	0.273	308.
	Both	34	1.85	32.1	13.3	0.816	0.21	0.834	-
All equip't.	Both	34	1.45	14.9	9.61	0.731	0.20	0.752	-
Earth-movers only	Diesel	35[d]	0.958	2.84	6.53	-	-	-	-
		36[e]	0.630	3.19	8.94	0.29	-	1.53	-
		34	1.04	2.90	9.62	0.633		0.769	-

[a]All Reference 38 values based on Reference 34.
[b]25 percent allowance included for evaporative and crankcase emissions.
[c]Allowance included for evaporative and crankcase emissions (variable).
[d]Estimate for 1969 made in 1970.
[e]Estimate for 1969 made in 1972.

APPENDIX B

LIST OF COUNTY DATA SOURCES

PRIMARY SOURCES

1. County and City Data Book, A Statistical Abstract Supplement. U. S. Department of Commerce. 1972.

2. 1969 Census of Agriculture, Volume I - Area Reports. U. S. Department of Commerce, Bureau of the Census.

3. Area Measurement Reports. U. S. Department of Commerce/ Bureau of the Census. Publication GE-20, No. 1. May 1970.

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5. Statistical Abstract of Ohio - 1969. Economic Research Division Development Department.

6. South Carolina Statistical Abstract - 1973. South Carolina Budget and Control Board, South Carolina Division of Research and Statistical Services. July 1973.

7. Wisconsin Statistical Abstract - Third Edition. Department of Administration, State Bureau of Planning and Budget, Information Systems Unit. June 1974.

8. Motor Vehicle Units Registered for the Year 1973. State of Illinois. Accounting Revenue Division.

9. 1973 County Audit Report. Missouri Department of Motor Vehicles.

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11. Arizona Statistical Review. Phoenix, Arizona, Economic Research Department, September 1973.

12. The Arkansas Almanac 1972. Little Rock, Arkansas, Arkansas Alamanca, Incorporated.

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16. Norman Nybroten. Idaho/1971 Statistical Abstract, Moscow, Idaho, University of Idaho, August 1971.

17. 1972 Edition Illinois State and Regional Economic Data Book. State of Illinois Department of Business and Economic Development.

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21. 1973 Maryland Statistical Abstract. Department of Economic and Community Development, State of Maryland, Annapolis, Maryland.

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24. Mississippi Statistical Abstract 1973. Mississippi State, Mississippi, Division of Research, College of Business and Industry, Mississippi State University, May 1973.

25. Data for Missouri Counties. Columbia, Missouri, University of Missouri.

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27. Nebraska Statistical Handbook, 1974-1975. Lincoln, Nebraska, The Nebraska Department of Economic Development.

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30. Statistical Abstract of Oklahoma 1972. Norman, Oklahoma, Bureau for Business and Economic Research, University of Oklahoma, May 1973.

31. Pennsylvania Abstract 1973. Harrisburg, Pennsylvania, Department of Commerce.

32. Tennessee Statistical Abstract 1971. Knoxville, Tennessee, Center for Business and Economic Reasearch, The University of Tennessee.

33. Texas Almanac and State Industrial Guide 1972-1973. A. H. Belo Corporation.

34. Statistical Abstract of Utah 1973. Bureau of Economic and Business Research, Center for Economic and Community Development, University of Utah.

35. Vermont Facts and Figures 1973. Montpelier, Vermont, Vermont Department of Budget and Management, March 1973.

36. Statistical Abstract of Virginia 1966, Vol. I and 1970, Vol. II. Charlottsville, Virginia, University of Virginia.

37. The Research Council's Handbook, Fourth Edition. Olympia, Washinton, Washington State Research Council.

38. The 1973 Statistical Handbook. Charleston, West Virginia, West Virginia Research League, Inc.

39. Wyoming Data Book 1972. Laramie, Wyoming, Division of Business and Economic Research, University of Wyoming.

APPENDIX C

DOCUMENTATION OF COUNTY METHODOLOGY DEVELOPMENT

DOCUMENTATION OF COUNTY METHODOLOGY DEVELOPMENT

The purpose of this Appendix is to present procedures utilized in arriving at two of the county methodologies described in Section IV, including several methods which proved unsuccessful. The categories for which this presentation will be made are outboard motors and snowmobiles. Methodologies for the other categories were developed in a more straightforward way because either (1) ample information was available on which to base a logical method or (2) insufficient information was available to check on the method developed. In the first case, the methodologies will yield emissions data having good accuracy. In the second case, the accuracy of calculated values simply cannot be assessed; so they must be accepted as gross estimates. The categories for which good data are available are motorcycles and farm equipment. Those for which few data are available are lawn and garden equipment, construction equipment, and farm equipment.

1. Outboard Motors

A number of general regression analyses were attempted; and to show the results concisely, the following terms are defined:

f1 = percent of state boat registrations in county
f2 = percent of state boat usage in county
f3 = percent of state population in county
f5 = percent of state inland water area in county.

Data were obtained on f1, f3, and f5 for New York[7], Ohio[8], South Carolina[9], and Wisconsin[10]. Data on f2 were obtained only for New York. Regressions were calculated for all the data together, and also for individual states, urban and rural areas, and coastal and inland areas. The results of these regression analyses are shown in Table C-1, and none of the general ones is very promising.

Another approach tried was to characterize the outboard population in terms of generalities and then to fit a mathematical model to these generalities once complete. The observations and calculated data were the following:

(a) Boat registrations are basically proportional to population in each state.
(b) Except for inland counties having no surface water usable for boating ("dry" counties), boats used correlate strongly with boat registrations (r^2 over 0.9). To be recorded, ponds must have areas of 40 acres (0.16 km^2) or more and streams must be at least 1/8 mile (0.20 km) wide.

Table C-1. REGRESSION ANALYSES ATTEMPTED ON OUTBOARD MOTOR DATA

Dependent variable	Independent variable(s)	Data utilized	Coefficient(s) a	b	c	r^2
f2	f1	All NY	0.0431	0.905		0.892
f1	f3	All coastal	1.103	0.672		0.694
f1	f3	All inland	0.255	0.885		0.809
f1	f3	NY coastal	0.616	1.195		0.686
f1	f3	Ohio coastal	0.781	0.591		0.958
f1	f3	SC coastal	0.503	1.075		0.985
f1	f3	Wisc. coastal	0.545	0.532		0.991
f1	f3	NY inland	0.150	1.42		0.752
f1	f3	Ohio inland	0.172	0.880		0.836
f1	f3	SC inland	0.0874	0.910		0.813
f1	f3	Wisc. inland	0.340	0.873		0.766
f1	f3, f5	All NY	0.0627	1.257	0.146	0.795
f1	f3	All urban	3.97	0.420		0.372
f1	f3	All non-urban	0.222	0.927		0.806

(c) As an average, 9 percent more boats are used in coastal counties than are registered in those counties[7]. This generalization includes counties bordering the great lakes as well as the oceans.

(d) Congested urban areas generally show fewer outboards registered than would be projected solely on a population basis.

The following terms were also defined:

ρ = county population density (inhabitants/mi^2), $\rho \geq 1000$ is criterion for urban county;

', '', ''' as superscripts indicate values after first, second, and third corrections (coastal-inland correction, dry-wet correction, and urban—non-urban correction, respectively);

c, i, d, w, u, and n as second subscripts mean "coastal", "inland", "dry", "wet", "urban", and "non-urban", respectively.

The estimation procedure was as follows:

(a) Assume f2 = f3 (f3, f5, and ρ, and an indicator of coastal or inland status should be tabulated by county for the state)

(b) Make the "coastal-inland" correction by calculating:

$$f2c' = 1.09 f2c; \quad f2i' = f2i\left(1 - 0.09\,\frac{\sum f2c}{\sum f2i}\right);$$ and tabulating by county.

(c) Make the "dry-wet" correction by calculating:

$$f2d'' = 0; \quad f2w'' = f2w'\left(1 + \frac{\sum f2d'}{\sum f2w'}\right);$$ and tabulating by county.

(d) Make the "urban-rural" correction by calculating:

$$f2u''' = \left(\frac{f2u''}{0.026\,\rho^{0.53}}\right); \quad f2n'' = f2n''\left(\frac{\sum f2'' - \sum f2u'''}{\sum f2'' - \sum f2u'''}\right);$$ and tabulating by county.

The values $f2'''$ were the final results for all the counties on a percentage basis and could be multiplied by the state boat population to yield the actual number of boats used in each county. While the method guarantees that the sum of the $f2'''$ equals 100 percent, the individual f''' did not agree very well with the individual f2 for New York ($r^2 = 0.35$).

2. Snowmobiles

The only county snowmobile registration data located were for New York[7], and a number of approaches were attempted before a usable relationship was found. The following terms are defined for convenience:

g1 = percent of state snowmobile registrations in county
g2 = percent of state snowmobile usage in county
g3 = percent of state population in county
g4 = snowfall, in/yr
g5 = development index = (number of snowmobile developments in county)$^{0.5}$.

The regression analyses attempted are described in Table C-2, verifying that snowmobile usage correlates well with registration. Table C-2 also shows that separating urban and rural areas enhances the accuracy of the estimate for rural areas and that the "development index" is only a marginal contributor to variability in usage. The expression second from the bottom of Table C-2 was the one modified for use in the methodology, along with an empirical correction to reflect low registrations and usage in congested urban areas. The modification consisted of normalizing the snowfall term to a percentage of snowfall at the state's geographical center, making the coefficient c take on the new value 0.0321.

Table C-2. REGRESSION ANALYSES ATTEMPTED ON NEW YORK SNOWMOBILE DATA

Dependent variable	Independent variable(s)	Data utilized	Coefficient(s)					r^2
			a	b	c	d	e	
g2	g1	All	0.0392	0.977				0.994
g2	g1, g5, g3, g4	All	-2.224	-0.00294	0.234	0.272	0.0478	0.425
g2	g1, g5, g3, g4	Non-urban	-2.418	-0.00175	0.143	1.576	0.0433	0.665
g2	g1, g3, g5, g4	Urban	0.119	0.981	-0.00272	0.0945	-0.00660	0.999
g2	g3	All	1.702	-0.0092				0.00016
g2	g4	All	-1.020	0.0400				0.317
g2	$(g5)^2$	All	1.306	0.111				0.0633
g2	g3, g4	All	-2.125	0.250	0.0521			0.408
g2	g3, g5, g4	All	-2.229	0.273	0.236	0.0476		0.424
g2	g3, g4	Non-urban	-2.345	1.560	0.0458			0.657
g2	g3, g4, g5	Non-urban	-2.424	1.579	0.0432	0.145		0.665

APPENDIX D

UTM TO GEOGRAPHIC COORDINATE CONVERSION PROGRAM

```
                 PROGRAM UTMGEO(INPUT,OUTPUT)
000003           DIMENSION YNORTH(4 ),XEAST(4),ILD(4),ILM(4),SLA(4)
000003           DIMENSION                  IGD(4),IGM(4),SNG(4)
         C       (DEGREES)   PROGRAM TRANSFORMS  UTM  TO GEOGRAPHIC
         C                   COORDINATES      (TBM-16-JAN-73)
000003           SCALE = .9996
000004           ESQ = .006768658
000006           SECRD = 4.848136811E-06
000007           SEPQ = .0408887094
000011           FE = 500000.
000012           EPSQ = ESQ/(1.-ESQ)
000015           IDIR = 0
000016           IZONE=15
000017           IPAGE=1
000020           LCT=58
000021        32 READ 101,ID,XEAST,YNORTH
000033           IF(ID   .EQ.0) GO TO 99
000034           XZONE = IZONE
000036           DO 200 I=1,4
000037           YY=YNORTH(I)
000040           XX=XEAST(I)
000042           CM = (6. * XZONE - 183.) * 3600.
000045           PPRD = (YY * .1570499810 * 10.0E-7) / SCALE
000050           SNLT = SIN(PPRD)
000052           CSLT = COS(PPRD)
000054           CSSQ = CSLT * CSLT
000055           PHRD = ((CSSQ*.24682+30.02335)*CSSQ+5078.64977)*(SNLT*CSLT)
                1*10.E-7 + PPRD
000067           PHIS = PHRD/SECRD
000070           Q = (XX-FE)*10.E-7
000073           IF(Q.NE.0) GO TO 720
000075           DLAM = 0.
000075           XLAT = PHIS
000077           GO TO 740
000100       720 CONTINUE
000100           SNLAT = SIN(PHRD)
000102           CSLAT = COS(PHRD)
000104           SNSQ = SNLAT * SNLAT
000106           CCSQ = CSLAT * CSLAT
000107           TNLAT = SNLAT/CSLAT
000110           TNSQ = TNLAT * TNLAT
000111           ENU = 6378206.4 / SQRT(1.-ESQ*SNSQ)
000117           ENSNS = ENU * SECRD
000121           EPCS = EPSQ * CCSQ
000123           EPCSQ = 1. + EPCS
000124           QSQ = Q*Q
000126           QCU = QSQ * Q
000127           QFR = QCU * Q
000130           QFV = QFR * Q
000131           QSX = QFV * Q
000132           SCLAT = 1./CSLAT
000133           ENSNS = ENU**4 * ENSNS
000136           SVN = (((TNLAT/(2.*ENU*ENSNS))*EPCSQ)/(SCALE*SCALE))*10.E11
000145           EG=5.+3.*TNSQ+SEPQ*(CCSQ-SNSQ)-(3.*EPSQ**2*CCSQ)*(CCSQ+3.
                1*SNSQ)
000162           EGH = TNLAT/(24.*ENU**3*ENSNS)
000166           EGHT = (EGH*EG/SCALE**4)*10.E+23
```

```
000172         D61=61.+(45.*TNSQ)*(2.+TNSQ-EPSQ*SNSQ)+EPSQ*(107.*CCSQ
              1-162.*SNSQ)
000206         D62=TNLAT/(720.*ENU**5*ENSNS)
000213         D6 = (QSX*D62*D61/SCALE**6)*10E+35
000220         ANINE = (SCLAT/ENSNS)/SCALE*10.E5
000223         TEN = (SCLAT/(6.*ENU**2*ENSNS))*(1.+2.*TNSQ+EPCS)
              1/SCALE**3*10.E17
000236         E5 = QFV*(SCLAT/(120.*ENSN5))*(5.+(4.*TNSQ)*(7.+6.*TNSQ)
              1+(2.*EPSQ)*(3.*CCSQ+4.*SNSQ))/SCALE**5*10.E29
000264         XLAT = PHIS-SVN*QSQ + EGHT*QFR - D6
000272         DLAM = ANINE*Q - TEN*QCU +E5
000300     740 CONTINUE
000300         XLONG = CM + DLAM
000302         YLONG = -XLONG/3600.
000304         YLAT = XLAT/3600.
000306         ID1 = YLAT
000310         REM = (YLAT-ID1) * 3600.
000313         IM1 = REM/60.
000315         S1 = REM - (IM1*60.)
000320         ID2 = YLONG
000322         REM = (YLONG - ID2) * 3600.
000325         IM2 = REM/60.
000327         S2 = REM-(IM2*60.)
000332         ILD(I)=ID1
000335         ILM(I)=IM1
000336         SLA(I)=S1
000340         IGD(I)=ID2
000341         IGM(I)=IM2
000343         SNG(I)=S2
000344     200 CONTINUE
000346         IF(LCT .LT. 58) GO TO 40
000350         PRINT 104,IPAGE
000356     104 FORMAT(*1*,15X,*ST LOUIS AQCR GRID SQUARE COORDINATES*/* PAGE*,I3/
             1         *   ID          1              2              3            4*
             2   /10X,      *DEG MIN SEC    DEG MIN SEC    DEG MIN SEC    DEG MIN SE
             3C*)
000356         LCT=4
000357         IPAGE =IPAGE+1
000361      40 PRINT 102,ID,(ILD(I),ILM(I),SLA(I),I=1,4),
              1             (IGD(I),IGM(I),SNG(I),I=1,4)
000413         LCT=LCT+3
000415     101 FORMAT(I4,1X,-3P8F5.1)
000415     102 FORMAT(*0*,I4,*  LAT*,4(I4,I3,F6.2)/5X,* LONG*,4(I4,I3,F6.2))
000415         GO TO 32
000415      99 STOP
000417         END
```

TECHNICAL REPORT DATA *(Please read Instructions on the reverse before completing)*		
1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Methodology for Estimating Emissions from Off-Highway Mobile Sources for the RAPS		5. REPORT DATE 10-30-74 6. PERFORMING ORGANIZATION CODE
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15. SUPPLEMENTARY NOTES		

16. ABSTRACT

Emissions, population, and usage data existing in the technical literature have been collected and organized for the following unregulated sources: outboard motors, snowmobiles, motorcycles, lawn and garden equipment, construction equipment, industrial equipment, and farm equipment.

Methodologies for estimating emissions and fuel consumption on a county basis have been developed for the sources noted above. They have been demonstrated for counties in the St. Louis Metropolitan Air Quality Control Region (AQCR 070), and their strengths and weaknesses have been discussed. Methods have also been developed to apportion county emissions estimates to grid elements, but they have not been demonstrated. The exhaust constituents assessed include hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NO_x), particulate, aldehydes (RCHO), and oxides of sulfur (SO_x). For outboard motors, neither particulate nor aldehyde data were available; but carbon dioxide (CO_2) emissions were included.

17. KEY WORDS AND DOCUMENT ANALYSIS		
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Mobile Source Emissions Apportion Emissions		
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