INVENTORY OF EMISSIONS FROM NON-AUTOMOTIVE VEHICULAR SOURCES

FINAL REPORT

KVB

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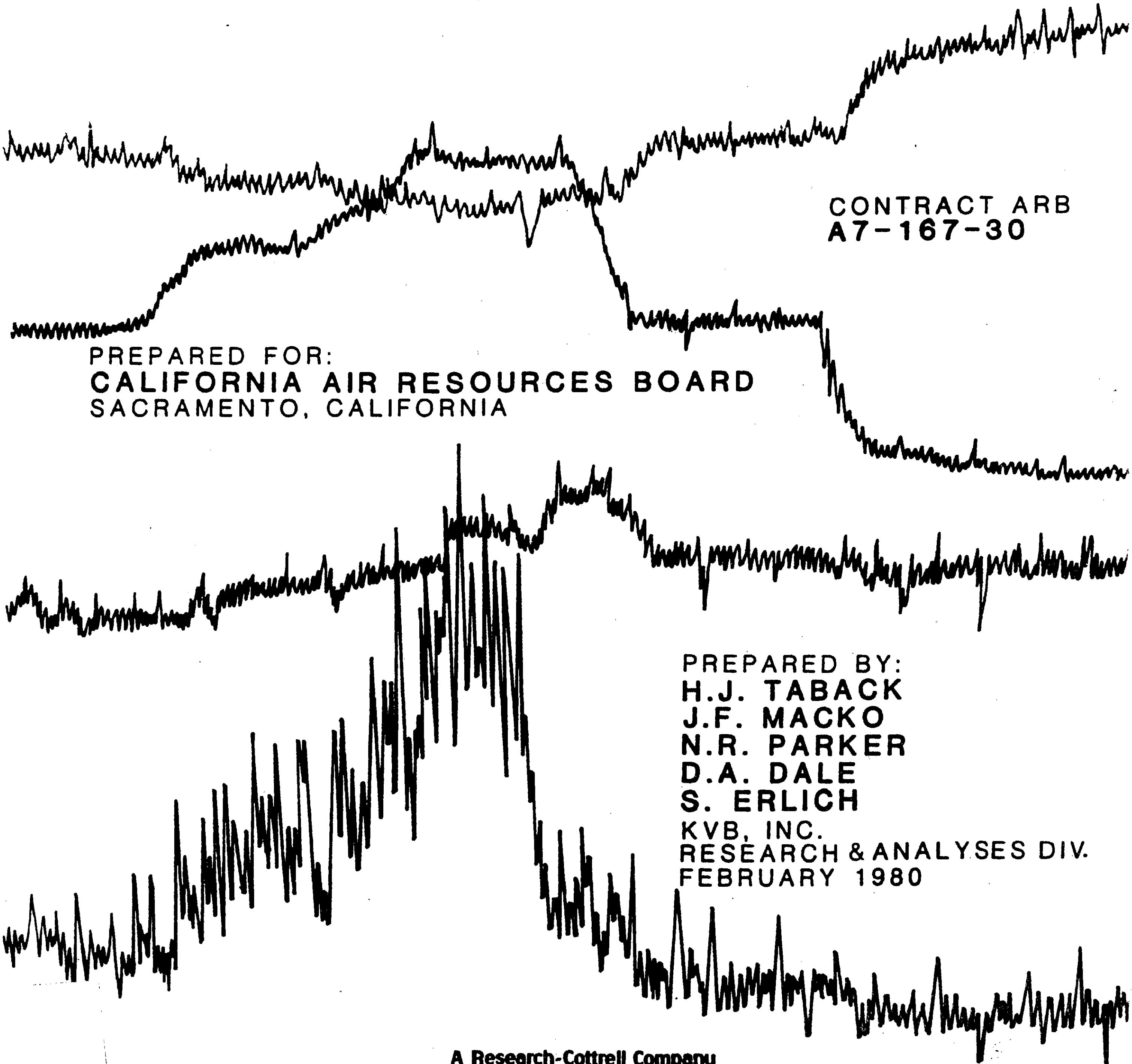

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February 1980

Prepared for

California Air Resources Board
Sacramento, California

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ABSTRACT

To add air pollutant emissions from non-automotive vehicular sources to the California Air Resources Board's (ARB's) area source data base, this program was conducted to inventory emissions from (1) construction equipment, (2) farm machinery, (3) boats, and (4) industrial vehicles. Methodologies were developed for each of the four vehicle categories to inventory the emissions from each county and air basin in the state. Using the developed methods an inventory was performed for the South Coast Air Basin (SCAB). It was found that these emissions are significant when compared with those from stationary point sources in the SCAB.

This final report presents the considerations taken into account in developing the methodologies, presents procedural statements for conducting a statewide inventory, and summarizes the SCAB inventory results. A computer magnetic tape file of the individual area source and a computer printout of these data were also delivered to the ARB as part of this program.

The information presented in this report was compiled specifically for the State of California and may not be applicable to regions outside of this state.

ACKNOWLEDGEMENTS

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Abacus Programming Corp., Santa Monica, CA. Inventory Software Design and Programming.

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California Department of Transportation, Riverside, CA. Voluntary assistance in obtaining highway data.

National Marine Fisheries Service, San Francisco, CA. Voluntary information on diesel fuel sales for commercial boating.

Sea magazine, Newport Beach, CA. General information on pleasure boating in Southern California.

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Los Angeles County Agricultural Commissioner's Office, Los Angeles, CA. Provided information on nursery products production.

The following individuals played key roles:

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SECTION 1.0

EXECUTIVE SUMMARY

The Air Resources Board (ARB) is required to inventory air pollutants emitted from stationary and mobile sources throughout California. Much has been accomplished in this immense task. For area sources more sophisticated methods are replacing those used previously to estimate these emissions. In this connection, the ARB sponsored this study of non-automotive-vehicle emissions sources, specifically (1) construction, (2) farm, and (3) industrial off-road vehicles plus (4) pleasure and commercial boats. The objectives of this study are to:

- Develop methodologies, applicable to all areas of California, for inventorying emissions from each of these non-automotive sources.
- Use these methodologies to compile an inventory for California's South Coast Air Basin (SCAB).

The study is now complete. Methods have been developed for each of the four non-automotive-vehicle emissions sources specified. A computerized area source inventory for the SCAB in the study base year, 1977, has been prepared in the ARB's area-source format. This inventory, delivered to the ARB under separate cover, consisted of a computer printout, a magnetic tape file of the data, and a user's manual for the magnetic tape.

KVB's final program report, this document, traces the evolution of the methodologies, provides a step-by-step procedure for inventorying other areas in the state, and presents the SCAB inventory results. In this executive summary the alternative methods considered are reviewed, a recommended approach for the statewide inventory is outlined, the results of the SCAB inventory are summarized, and a forecast of emissions in the SCAB is presented.

For these four non-automotive-vehicle sources the general approach was to determine total annual fuel consumption by vehicle type, then multiply each total by EPA emission factors. The major effort, then, was to determine fuel consumption. The following pages describe this procedure for the four source categories.

1.1 CONSTRUCTION VEHICLES

1.1.1 Methods Development

For construction vehicles two alternative methods were developed to determine fuel consumption--one based on construction activities and the other on vehicle population.

A. Construction Activities Method--

Construction activities were divided into building construction, freeway construction, and public works. In building construction we related fuel consumption to cubic yards of earth moved, and then related the quantity of earth moved to the dollar cost of construction. We learned that Security Pacific Bank publishes a reliable new-construction-cost summary for each county in California ("California Construction Trends"). Therefore, we could relate fuel consumption to new construction cost as a measure of building construction activity. For freeways the relation of fuel consumption to miles of freeway constructed was the activity measure. For public works we related fuel consumption to human population.

B. Vehicle Population Method--

For the vehicle population method we computed fuel consumption by multiplying the vehicle population (obtained from local equipment sales staffs) by factors of hours of operation per year and gallons of fuel consumed per hour. The problem is in determining how much time the vehicles located in the area under study actually work in that area. This limitation became the primary basis for selecting the construction activity method as the primary method for the statewide inventory.

C. Comparison of the Methods--

For the SCAB in 1977, each of the two methods was used to compute fuel consumption. The construction activity method resulted in an estimate of 68,000,000 gallons; the vehicle population method resulted in an estimate of 80,000,000 gallons--a difference of 16 percent in the average of the two numbers. We believe that this is good agreement in view of the use of completely independent methods.

1.1.2 Statewide Inventory Procedure

The procedure for the statewide inventory is as follows:

1. Obtain construction cost data from Security Pacific's publication, "California Construction Trends."

2. Apply factors to convert those data to cubic yards of earth moved.

3. Multiply the results by the factor for gallons per cubic yards of earth moved to get the total fuel consumed.

4. Obtain freeway miles constructed and the human population for the study areas.

5. Apply the factors of gallons per freeway mile and gallons per capita for freeway construction and public works fuel consumption.

6. Multiply the total fuel consumption for each of the three construction activities by the respective composite emission factors to obtain the specific emissions for each major pollutant.

7. Distribute the emissions uniformly throughout the study area. (i.e. county or air basin)

1.1.3 SCAB Inventory Results

Table 1-1 is a summary of fuel consumption and emissions computed using the above procedure for 1977 in the SCAB. Approximately 97 percent of the fuel is diesel. Of the total fuel and emissions, 68 percent is attributed to building construction, 22 percent to public works, and 10 percent to freeway construction.

1.1.4 Emissions Forecast

Based on projected construction activities through the year 2000 and assuming no major technology changes, we forecast that fuel consumption by

TABLE 1-1. SUMMARY OF CONSTRUCTION VEHICLES' FUEL CONSUMPTION/EMISSIONS IN THE SOUTH COAST AIR BASIN, 1977

	1977 Fuel Consumption § 10^3 Gal/Yr		Pollutant Emissions § Tons/Year					
County*	Diesel	Gasoline	SO_x	CO	HC	NO_x	HCHO†	Particulate
SCAB	66,000	2,300	870	7,000	1,440	12,300	230	700
Los Angeles	32,000	1,100	430	3,400	690	6,200	115	340
Orange	16,000	600	210	1,800	360	3,000	57	180
San Bernardino	10,000	340	130	1,000	220	1,700	35	100
Riverside	8,000	250	100	800	170	1,400	28	80

§ Confidence level is estimated at ± 20%.

* Includes only that portion located in the South Coast Air Basin.

† HCHO - Aldehydes as Formaldehydes.

off-road construction vehicles will increase about 25 to 30 percent. Whether or not this will produce a corresponding increase in emissions depends on action taken to mandate emission controls on these vehicles.

1.2 AGRICULTURAL VEHICLES

1.2.1 Methods Development

For agricultural emissions we investigated methods based on farmer-reported fuel expense, equipment population, and crop production. The first two methods use data from Census of Agriculture, which is published every five years (last edition for 1974). The third method uses county crop reports ~~with~~ with fuel-use factors derived from sample cost-to-produce sheets prepared by farm advisors in various counties. The University of California, Davis, (UCD), developed this third technique in conjunction with a program to assess the total energy consumption in the agricultural industry. After evaluating the three methods, we judged the first two to be deficient because data for the last edition of Census of Agriculture was collected three years before the 1977 base year of the SCAB inventory. Furthermore, these methods were not easily usable to obtain spatial distribution of emissions. So we worked with UCD personnel to develop a statewide methodology that would be more accurate than the original UCD method used in their energy study. We refer to this fourth method as the KVB/ARB method.

To assess the accuracy of the statewide method, a calculation of fuel consumption was made for Orange and Riverside Counties for the year 1974 (to use latest Census of Agriculture data). The spread in the estimated fuel consumption calculated by the four methods (KVB/ARB, UCD, fuel expense, and vehicle population) ran 18 and 30 percent for the two counties, respectively. The KVB/ARB method used for the SCAB inventory resulted in the highest estimate for one county and the lowest for the other. Therefore, we feel that the accuracy of the methodology is approximately ±25 percent because of the greater inherent confidence in crop report data than in Census of Agriculture data.

1.2.2 Statewide Inventory Procedure

The procedure for the statewide inventory is as follows:

1. From the county crop reports obtain the annual number of harvested acres of each crop type.

2. Multiply the annual number of acres of standard and specialty crops by the respective fuel consumption factors in this report (paragraph 3.2*).

3. Summarize diesel and gasoline fuel (gallons/year) for standard crop types.

4. Multiply the gallons per year of diesel by 1.1 and the gallons per year of gasoline by 3.0 to account for off-road trucks and automobiles. (Specialty crop fuel consumption factors account for trucks and autos.)

5. Multiply annual fuel consumption by the EPA's composite emission factors. (Separate factors are provided for standard and specialty crops.)

6. Spatially distribute the emissions by consulting a land use map.

1.2.3 SCAB Inventory Results

Using the above procedure the fuel consumption and emissions were estimated for the SCAB as shown in Table 1-2. The total fuel consumption is 6.3 million gallons of which 60 percent is diesel and 40 percent is gasoline. Unlike the other areas, the county with the largest emissions is Riverside, followed by Orange, San Bernardino, and Los Angeles.

1.2.4 Emissions Forecast

A forecast of agricultural off-road fuel consumption shows that it will decrease by a little over 1 percent per year with emphasis shifting to diesel.

1.3 BOATING

Boating emissions were determined in two categories, pleasure and commercial.

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*Paragraph citations refer to this document.

TABLE 1-2. SUMMARY OF OFF-ROAD AGRICULTURAL VEHICLES' FUEL CONSUMPTION/EMISSIONS IN THE SOUTH COAST AIR BASIN, 1977

	1977 Fuel† Consumption 10^3 Gal/Yr		Pollutant Emissions† Tons/Year					
County*	Diesel	Gasoline	SO_x	CO	HC	NO_x	HCHO	Particulate
SCAB TOTAL	3,700	2,600	66	2,900	370	710	21	89
Los Angeles	520	470	9.4	490	63	101	2.9	13.0
Orange	840	800	15.3	850	104	168	4.8	21.0
San Bernardino	690	470	12.0	540	67	143	3.9	18.3
Riverside	1,690	880	29.0	1,040	138	310	9.4	39.0

* Includes only that portion located within South Coast Air Basin.

† Confidence level estimated at ± 25%.

1.3.1 Methods Development

A. Pleasure Boating--

The pleasure boating methodology was based on procedures developed by Arthur Young & Co. in a program for the California Department of Navigation and Ocean Development. The California Department of Motor Vehicles (DMV) provided state boat registration data covering 99 percent of the diesel and gasoline-powered pleasure boats. A small number of pleasure boats documented by the Coast Guard (and not the DMV) were also included. Boat usage (boat days/ year), fuel consumption (gallons/boat day), and operating location data (percent of boat days in coastal waters, rivers, or lakes) were derived from surveys conducted by Arthur Young & Co. All lake and river boating was found to be gasoline powered. The diesel fuel consumed by pleasure boats in coastal waters (including the Sacramento Delta) was determined by a KVB survey of fuel docks in the marina areas of the SCAB. A factor was developed to relate diesel fuel consumption to the number of berths for extrapolation to the entire state.

From the fuel consumption data thus compiled the emissions were determined by applying emissions factors from AP-42. Spatial distribution was made by determining boat days per year for individual lakes, rivers, and coastal areas. Several publications were found to provide broad data; telephone contacts with managers of the more popular boating lakes provided the most current data for the specific year of the inventory. It happens that 1977, the year selected for the SCAB inventory, was a drought year. Therefore boating activity on lakes and rivers was off approximately 10 percent. Methods for crosschecking and adjusting the fuel consumption figures to reflect the drought are presented.

B. Commercial Boating--

Commercial boating emissions were based on an inventory of the diesel-powered boats along the coast and the fuel sold to them. These include fishing boats, tug boats, work boats, lightering barges, excursion boats, utility craft, and Coast Guard cutters. The oil companies responded well to requests for coastal marine diesel fuel sales. A National Marine Fisheries Service (NMFS) survey also provided an independent estimate of coastal diesel fuel sales to commercial and party fishing boats. It was necessary to adjust the two sets of figures to a common basis. The oil company survey yielded an estimated commercial boat fuel consumption of 70 million gallons/year; the NMFS survey gave 82 million gallons/year, a difference of 16 percent based on the average value of 76 million gallons/year.

Because of the agreement obtained with various crosschecks of the data we feel that our pleasure boat data are accurate to within ±30 percent. The error associated with the commercial boat data is estimated at ±20 percent.

1.3.2 Statewide Inventory Procedure

The methodology developed for inventorying boat emissions is divided into pleasure boats and commercial boats.

A. Pleasure Boat Procedure--

The pleasure boating procedures were designed to be applied to selected large sectors of the state encompassing lake, river, and coastal water boating. (Even in inventorying the SCAB a seven-county area was used from which the SCAB emissions were extracted.) The commercial boating procedure is strictly a coastal water activity including the Sacramento Delta.

The pleasure boat procedure is as follows:

1. Obtain boat population data for the study area from the DMV and use factors provided in paragraph 4.2 to obtain the annual average number of boat days and gallons of gasoline per boat day for lakes, rivers, and coastal waters, respectively.

2. Since 1977 was a drought year, an adjustment must be made for the average figures on lakes and rivers to account for reduced activity (approximately 10 percent) by contacting lake and stream managers to obtain several years' boat count data to determine the 1977 dropoff.

3. Multiply the adjusted boat days by the gallons of gasoline per boat day and by the appropriate emission factors to obtain the emissions for lakes and rivers.

4. Spatial distributions for lakes and rivers are made by boat count data obtained in Step 2.

5. To the coastal boating fuel consumption computed in Step 1 add the fuel consumed by Coast Guard-registered gasoline-powered pleasure boats and diesel-powered pleasure boats. The coastal boating days computed in Step 1 include berthed and trailered boats registered with the DMV. The gasoline used by Coast Guard-registered boats (i.e., documented) is obtained by an Arthur Young & Co. formula presented in paragraph 4.2. This is proportioned to the study area according to the precentage of berths in the study area compared to those in the entire state. Finally, the diesel fuel used in pleasure boats operating in coastal waters is added. A factor of 70 gallons of diesel fuel per marine berth was used in the SCAB but needs to be checked for use elsewhere.

6. Calculate emissions using emission factors presented in paragraph 4.2.

7. Spatial distribution for coastal pleasure boating is made on the basis of the operating areas used by boaters as obtained from marina personnel and the publishers of Sea magazine.

B. Commercial Boat Procedure--

The commercial boating procedure is as follows:

1. Use the data provided in paragraph 4.3 to obtain fuel consumption for various categories of commercial boating by geographical areas.

2. Multiply the fuel consumption for various categories by the emission factors in paragraph 4.2 to obtain emissions.

3. The commercial and party fishing boats' spatial distribution is made using gridded fish block maps provided by the California Department of Fish and Game.

4. Tugs, work boats, excursion boats, etc., are distributed assuming that they operate within the harbor where they are berthed or up to five miles along the shore.

1.3.3 SCAB Boating Inventory Results

Using the above procedures an inventory of the SCAB boating emissions for the year 1977 was made. A summary of these emissions is presented in

Table 1-3. The absence of particulate emissions from pleasure boating is due to a simplifying assumption made in AP-42 that the scrubbing effect of the water on the engine exhaust, which is discharged below the surface from all outboard and most small inboard engines, will reduce the particulate emissions to a negligible amount. The validity of this assumption is discussed further in Section 4.0. Most commercial boats have stacks and therefore discharge particulates to the atmosphere. There are no navigable rivers in the SCAB; therefore, there are no emissions in this category.

1.3.4 Emissions Forecast

Our forecast of boating emissions is very uncertain because of the impact of recent gasoline price increases on boating activity. We predict a 1 percent annual increase, but the activity could actually decline drastically as gasoline prices continue to soar.

TABLE 1-3. SUMMARY OF BOATING FUEL CONSUMPTION AND EMISSIONS IN THE SOUTH COAST AIR BASIN, 1977

Boating Categories	Fuel Consumption † 10^6 Gallons/Year		Pollutant Emissions † Tons/Year				
	Gasoline	Diesel	SOx	CO	HC	NOx	Particulate
Pleasure, Lakes	11	0	36	12,500	3,400	340	0
Pleasure, Rivers	0	0	0	0	0	0	0
Pleasure, Coastal	10	1.7	55	8,800	1,700	810	0
Comm., Fishing	0	9.1	124	500	230	1,230	133
Comm., Other*	0	2.9	40	163	72	400	43
TOTAL	21	13.7	250	22,000	6,100	2,800	176

* Other includes tugs, work boats, excursions, Coast Guard, and miscellaneous small commercial boats.

† Confidence level is estimated at ± 30% for pleasure boating and ± 20% for commercial boating.

1.4 INDUSTRIAL VEHICLES

1.4.1 Methods Development

Industrial vehicles' fuel consumption was the most difficult area on which to obtain data because relatively little is available from public sources, and the number of industrial sites is too great to conduct a cost effective survey. To estimate fuel consumption, therefore, we first estimated vehicle population, then multiplied by a use rate (hours/year) and a fuel consumption rate (gallons/hour).

Two independent estimates were made of California's industrial vehicle population. The first was based on a nationwide vehicle population estimate scaled down to our state level. The other was based on an estimate of vehicle population in Los Angeles County that we made in conjunction with vehicle suppliers. We scaled the Los Angeles estimate to the state level to compare with the nationwide estimate. The first method yielded an estimate of 95,000 vehicles (forklifts and non-forklifts*) in the state; the second method yielded 83,000. The average is 89,000, and the difference is 13 percent.

In scaling the nationwide and local data to the state level an economic indicator termed "value added by manufacture" was used. This parameter reflects the value of shipments less the cost of materials, which we believe is the best measure of manufacturing activity and hence a reasonable means to proportion industrial vehicle population.

1.4.2 Statewide Inventory Procedure

The statewide methodology for estimating industrial vehicle emissions is based on the 89,000 average vehicle population (forklifts and non-forklifts*) and 1140 industrial/construction vehicles** in the state. These vehicles are apportioned to various counties or air basins on the basis of the ratio of the value added by manufacture in the study area to that for the entire state. The value added by manufacture is obtained from the California Bureau of the Census. A table presenting the percent of the statewide value added for each county is presented in paragraph 5.3.1. The recommended procedure is as follows:

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* Non-forklifts include portable generators, mobile fluid handling equipment, mobile cranes, airport tugs, light-duty construction-type vehicles, etc.

**Industrial/construction vehicles are used for mining, logging, quarrying, etc.

1. Multiply the state vehicle populations by the county percentage to obtain the county vehicle population.

2. Multiply the vehicle population by the vehicle use and fuel consumption factors presented in paragraph 5.1.3 to obtain total fuel consumption.

3. Multiply the total fuel consumption by the composite emission factors presented in paragraph 5.1.4.

4. Land use maps and work schedule information for the specific study area should be consulted to obtain spatial and temporal variation.

1.4.3 SCAB Inventory

Using this statewide methodology for the SCAB resulted in fuel consumption and emissions for industrial off-road vehicles as shown in Table 1-4. A total of 58 million gallons of fuel were used for industrial off-road vehicles in 1977. Nearly 80 percent of that total was consumed in Los Angeles County, 17 percent in Orange and 3 percent divided between San Bernardino and Riverside Counties.

1.4.4 Emissions Forecast

We forecast that emissions from industrial vehicles will not change significantly in the SCAB over the next 20 years (through the year 2000) unless some controls are placed on this equipment. While the projected national growth in industrial capacity is increasing, Southern California's growth appears to be less than average. This, combined with a trend toward the use of electric forklifts, should keep emissions at current levels.

1.5 COMPOSITE FUEL CONSUMPTION AND EMISSION DATA

A comparison of the fuel consumption and emissions data from the four non-automotive-vehicle categories is given in Table 1-5. The largest fuel consumers are construction vehicles, accounting for 43 percent of the fuel used; industrial vehicles are next at 31 percent, followed by boats at 22 percent and agricultural vehicles at 4 percent. No aldehyde emissions are included for boating because EPA document AP-42 does not contain emission factors for aldehyde emissions from boats. The high CO and HC emissions from boating and

TABLE 1-4. SUMMARY OF INDUSTRIAL OFF-ROAD VEHICLE FUEL CONSUMPTION AND EMISSIONS IN THE SOUTH COAST AIR BASIN, 1977

	Fuel Consumption† 10^3 Gallon/Year			Pollutant Emissions† Tons/Year					
County*	Diesel	Gasoline	LPG	SOx	CO	HC	NOx	HCHO	Particulate
SCAB	9,700	19,300	29,000	280	30,000	3,500	7,900	79	290
Los Angeles	7,600	15,100	23,000	179	24,000	2,700	5,700	53	192
Orange	1,600	3,300	4,800	42	4,900	580	1,200	12	44
San Bernardino	300	620	900	49	1,070	152	820	12	47
Riverside	140	290	420	11	430	56	200	3	9

* Includes only that portion of each county within SCAB.

† Confidence level is estimated at ± 25%.

TABLE 1-5. SUMMARY OF FUEL CONSUMPTION AND EMISSIONS FROM SELECTED OFF-ROAD VEHICLES IN THE SOUTH COAST AIR BASIN, 1977

Non-Automotive-Vehicle Category	Fuel Consumption 10^6 Gallons/Year			Emissions Tons/Year					
	Gasoline	Diesel	Total	SOx	CO	HC	NOx	HCHO*	Part.
Construction	2.3	66	68	870	7,000	1,400	12,300	230	700
Agricultural	2.6	3.7	6.3	66	2,900	370	710	21	89
Boats	21	13.7	35	250	22,000	6,100	2,800	-	176
Industrial	48†	9.7	58	280	30,000	3,500	7,900	79	290
Total	74	93	167	1,470	62,000	11,200	24,000	330	1,250

* HCHO = Aldehydes

† Industrial gasoline consumption total includes LPG consumption.

industrial vehicles are due to their high gasoline consumption.

Table 1-6 is a comparison of the non-automotive-vehicle emissions with total emissions for SCAB in 1976. The total emission data are from the document, Emission Inventory - 1976, published by the ARB Technical Services Division in September, 1979. The data show that the non-automotive emissions in the SCAB are low but not insignificant. The composite non-automotive emissions are 2% of the composite total emissions in the Basin.

1.6 COMPUTERIZED DATA BASE

The non-automotive-vehicle emissions developed for the SCAB on this study were computerized using the ARB area source format. A magnetic tape containing the entire data base was delivered to the ARB along with a user's manual for the file. A printed report of these emissions was delivered to ARB in the form of a computer printout in two sections.

The first section contains a summary of emissions by pollutant (HC, particulate, CO, SOx, NOx) and by vehicle category (boating, construction, industrial, farming). The data include emissions in tons per year and pounds per day. Daily emissions are provided for a typical weekday, week-end day, an average July (summer-season) day, and an average January (winter-season) day. Table 1-7 shows total emissions (from Table 1-5) broken down by day of the week and season as extracted from the computer printout.

The second section of the printout is a list of all emissions source entries. The entries are listed by county (Los Angeles, Orange, Riverside, San Bernardino) and vehicle category (construction, industrial, farming, pleasure boat, commercial boat). Files contain information on the source identification, classification, location, emissions, emission factors, maximum emissions, temporal changes, confidence rating, etc.

TABLE 1-6. COMPARISON OF NON-AUTOMOTIVE-VEHICLE# EMISSIONS TO TOTAL EMISSIONS FOR THE SCAB, 1977

Pollutant Source	Pollutant, Tons/Year				
	SOx	CO	HC	NOx	Part.
Non-Automotive Vehicles, Tons/Year	1,470	62,000	11,700*	24,000	1,250
Total Basin† Tons/Year	142,000	3,300,000	690,000	460,000	540,000
Non-Automotive/ Total Basin, Percent	1	2	2	5	0.2

Non-automotive vehicles include construction, agricultrual and industrial vehicles plus pleasure and commercial boats.

* Includes 330 tons/year aldehydes.

† ARB, Emission Inventory - 1976, Technical Services Division, September 1979.

TABLE 1-7. NON-AUTOMOTIVE-VEHICLE* EMISSIONS AT VARIOUS TEMPORAL CONDITIONS IN SCAB, 1977

Pollutant	Tons/Year	January (lb/day)			July (lb/day)		
		Weekday	Weekend	Average	Weekday	Weekend	Average
HC	11,500	2,000	410	1,560	5,800	3,400	5,100
Part.	1,250	320	68	240	650	86	480
CO	62,000	14,300	1,990	10,600	28,000	12,700	24,000
SOx	1,470	350	63	270	800	122	600
NOx	24,000	6,100	720	4,600	12,400	1,410	9,200

* Non-automotive vehicles include construction, agriculture and industrial vehicles plus pleasure and commercial boats.

1.7 CONCLUSIONS

The air-pollutant emissions from non-automotive vehicles in the SCAB are low but significant ranging from a high of 5% of the total NO_x emissions to less than 0.2% of the total particulate emission. As a composite they account for 2% of the total emissions in the SCAB.

Our emissions forecast indicates that there will be a relatively slow increase.

The statewide methodologies for calculating emissions from farming, construction, and industrial vehicles are routine. Data sources are specified, and the analysis follows a prescribed routine. Even the spatial distribution of the emissions is relatively routine.

Boating emissions, on the other hand, are more difficult to determine and require further data acquisition regarding local recreational activities, fuel sales, operating areas, etc.

The information in this report was developed specifically for the State of California and may not be applicable for regions outside of this state.

SECTION 2.0

CONSTRUCTION VEHICLES

The basic program plan calls for development of a methodology applicable to the entire state of California, limiting the use of that methodology to an inventory of emissions only in the South Coast Air Basin (SCAB). In the case of construction vehicle emissions a combined approach was taken. That is, we developed two different methods for inventorying construction vehicle emissions in the SCAB, and then selected the better of the two for inventorying the other counties in the state. Because of the extensive sales and use of construction equipment in the SCAB, we were able to obtain a great deal of information from the industry, such as vehicle population, quantity of fuel used, cubic yards of earth moved, gallons of fuel used per freeway mile constructed, and percent utilization of various types of construction equipment on a typical construction job. All of the ratios developed can be applied statewide. A major California banking institution publishes a document containing unit numbers and building costs of construction in every California county. With the help of industry we developed ratios which would convert these numbers and costs into vehicle use rates. Once the vehicle use rate (i.e., the total hours per year for each vehicle type) is determined, it is a routine process to compute emissions by using emission factors provided in EPA publication AP-42 (Ref. 1). These factors were adjusted slightly to take into account average horsepower ratings and loads for California construction vehicles.

The construction vehicle fuel consumption for the SCAB was computed using the primary methodology based on construction activities. As an accuracy check, fuel consumption was also computed in a completely independent manner using an equipment inventory provided by major equipment sellers in the

* References for Section 2.0 are listed on page 2-44.

SCAB. The two methods agreed within 16 percent. Since emissions are directly related to fuel consumed, this comparison can be used as a measure of accuracy.*

While it is comforting that the two values agree reasonably well, we feel that the construction activity method is more reliable and more readily adaptable to the statewide inventory. The equipment inventory provided by major equipment suppliers was assumed to be reasonably accurate for the four-county area comprising the SCAB, but it was difficult to determine how much of the time that equipment was used inside the SCAB. The final computations were therefore based on the assumption that the activities of imported construction equipment would be balanced by the activities of exported construction equipment. Construction activities, on the other hand, were based on fairly well established data such as published figures on construction costs, miles of freeway construction, and extent of public works activities.

In the sections following, we describe the overall approach taken in developing the two different methods; then we provide a step-by-step methodology for conducting a statewide inventory of construction vehicle emissions; finally we present the results of the construction vehicle emission inventory for the SCAB.

2.1 APPROACH

In approaching the construction vehicle emission problem the primary objective was to determine fuel consumption by individual vehicle type. This could be done either by identifying each construction task and its associated fuel use or by determining the vehicle population, use rate (hours per year), and fuel consumption rate. The construction activity method required an activity measure, a fuel consumption factor by that activity, and a vehicle profile. A major benefit of using the construction activity approach is that

*Using the construction activity method, a total of 68 million gallons of fuel per year was consumed. Using the vehicle population method, this figure was 80 million gallons. The difference of 12 million gallons per year divided by the average of 73 million gallons per year gives the 16 percent difference mentioned above. Figures are from 1977.

the data published for the activity measure are usually provided by municipalities so that spatial distribution of emissions can be computed. At the outset, the equipment inventory method seemed easier since AP-42 provides an equipment use rate (hours per year), and the vehicle fuel consumption rate (gallons per hour) is available from various equipment manufacturers' handbooks. However, in addition to the mentioned problem of vehicle migration, we also learned that the equipment usage rate provided in AP-42 may not be accurate for California.

In the remainder of this section we describe the two different inventory methods, construction activities and equipment inventory; compare the results of the two methods at the fuel consumption level; and describe the methods used for computing emissions.

2.1.1 Construction Activities Method

Three areas of construction activities were identified: buildings, highways, and public works. For building construction, the best activity indicator was cubic yards of earth moved. Unfortunately, not all counties maintain an estimate of cubic yards moved as a part of their building permit files. Security Pacific Bank (Ref. 2), on the other hand, publishes the number of residential units built and the dollar value of all other types of construction throughout California. There is good correlation between the Security Pacific information and the cubic yards of earth moved for those areas where that parameter was available. Therefore, cubic yards of earth moved could be computed from the Security Pacific data. For freeway construction, the activity indicator was miles of freeway constructed. Public works activities can be correlated to local population; thus population became the activity indicator for public works.

A. Buildings--

As in the entire study, our objective was to develop a methodology that would be applicable statewide and that could be calibrated using data from the SCAB. Building permits in Los Angeles and Orange Counties contain estimates of the cubic yards of earth moved for each project; cubic yards was selected as the construction indicator, and we began to collect information from construction firms relating gallons of fuel used to cubic yards of earth moved.

The building permits in Los Angeles and Orange Counties only cover their unincorporated areas. In the incorporated cities in those counties, the records were not complete. Many communities do not maintain a cumulative yearly cubic yard estimate, and neither do Riverside nor San Bernardino Counties. As an alternative method for computing cubic yards, the Security Pacific Bank publication, "California Construction Trends," gives information on all counties' residential, commercial, industrial, and other buildings; these data are broken down into major cities and unincorporated areas. For single and multiple dwellings, numbers of units and dollar valuations are provided. For commercial, industrial, and other (churches, schools, hospitals, etc.), only the dollar valuation is provided. From a joint study by Toups Engineering Corporation and PBR, Inc. (Ref. 3), we determined that a single-family house on a hillside requires that 1500 cubic yards of earth be moved; in a flat area, the same house would require that 500 cubic yards of earth be moved. In the unincorporated areas, 1500 cubic yards per unit was used; in the incorporated areas, 500 cubic yards per unit was used.

In the study these cubic yards per building numbers included numbers for single-family dwellings which were used to compute the cubic yards per building for the other building types on the basis of the number of acres per unit; see Table 2-1. Single-family dwellings average five to the acre while multiple dwellings, which include duplexes, triplexes, fourplexes, etc., as well as apartment houses, average 12 units per acre*. Commercial units such as motels and hotels plus individual shops in shopping centers average slightly less than two acres per unit. Industrial sites average one acre per unit; churches and schools average three and one-half acres per unit. The cubic yards for building pads shown in Table 2-1 were computed as a direct function of the acres per unit also shown in that table. Starting with 1500 and 500 cubic yards per building pad for the unincorporated and incorporated areas, respectively, the other numbers are proportional to the acres per unit. The acres per unit listed in Table 2-1 were derived from estimates provided by various sources including builders, realtors, and architects.

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*While a typical apartment density is 20 units/acre; in 1977 the base year of this study, Security Pacific (Reference 2) indicates a large proportion of duplexes, fourplexes and low density (condominium type) apartments built which lowers the density to 12 units/acre.

TABLE 2-1. PARAMETERS USED IN THE COMPUTATION OF CUBIC YARDS OF EARTH MOVED PER BUILDING PAD FOR VARIOUS BUILDING TYPES*

Building Type	Acres/Unit	Yd^3/Building Pad		Value/Unit, $
		Unincorporated	Incorporated	
Single Dwelling	0.20	1,500	500	50,000
Multiple Dwelling	0.08	600	200	25,000
Commercial	1.83	13,700	4,600	500,000
Industrial	1.13	8,500	2,800	280,000
Other (churches, schools, hospitals, etc.)	3.5	26,000	8,800	800,000

* Building pad refers to the area immediately beneath the building. To obtain the total excavated area per building, double this number.

Multiple dwellings include duplexes, quadraplexes and apartment houses; commercial building include hotels, amusements, parking, service stations, office buildings, and stores. The numbers are weighted composites of estimates for each of these types of buildings. The value per unit is derived from data in Security Pacific's "California Construction Trends." We computed this value per unit for the entire state, for the four Southern California counties, and for the Los Angeles area and found that the average numbers were fairly consistent throughout the state. As noted in Table 2-1, the value of cubic yards per building pad takes into account only the amount of excavation immediately adjacent to and under the building. It does not include excavation for access roads, interior streets, parking areas, driveways, open space areas, swimming pools, etc. To determine this additional excavation, tract maps from county planning departments were consulted to determine the density of buildings to total site development. Of approximately 25 maps for the housing development consulted, the average total-site-to-building-area ratio was just over 2.0. On the basis of 15 non-residential development maps, an average total site-to building-area ratio of 1.7 was determined. On this basis it seemed reasonable to conclude that approximately 50 percent of the total cubic yards of earth were moved for the building pad preparation and 50 percent for additional site development. Therefore, to obtain the total cubic yards per building, the cubic yards per building pad listed in Table 2-1 were multiplied by 2.

To check this procedure, data from Los Angeles and Orange Counties were used. For both counties, the cubic yards of earth moved were calculated using the above procedures, and the result was compared to the total cubic yards recorded on building permits for these counties. The results are shown in Tables 2-2 and 2-3. For Los Angeles County, the calculated volume of earth moved was 25.6 million cubic yards, though the grading permits indicated only 22 million cubic yards. The calculated value was higher than the permit value by 3.6 million cubic yards. In Orange County, the result was exactly reversed. The calculated value was four million cubic yards less than the recorded permits. These results demonstrate a satisfactory agreement between the method of calculating cubic yards of earth from Security Pacific's data and the data recorded on the building permits.

TABLE 2-2. COMPARISON OF CALCULATED YD^3 OF EARTH MOVED TO YD^3 RECORDED ON BUILDING PERMITS FOR UNINCORPORATED LOS ANGELES COUNTY

Unit Type	Total Value, $*	Value/Units, $	Number of Units*	Yds^3/Unit	Total Yds^3
Single Dwelling			5,200	1,500	7,800,000
Multiple Dwelling			1,800	600	1,080,000
Commercial	37,000,000	500,000	74	13,700	1,010,000
Industrial	27,000,000	280,000	96	8,500	820,000
Others	66,000,000	800,000	82	26,000	2,100,000
		Grand Total (Building Pad Only)			12,800,000
		Total Site (2 x Building Pad)			25,600,000
		County Grading Permits†			22,000,000
		Difference			+ 3,600,000

*"California Construction Trends," 1977, Ref. 2.

†Ref. 4.

TABLE 2-3. COMPARISON OF CALCULATED YD^3 OF EARTH MOVED TO YD^3 RECORDED ON BUILDING PERMITS FOR UNINCORPORATED ORANGE COUNTY

Unit Type	Total Value, $*	Value/Units, $	Number of Units*	Yds^3/Unit	Total Yds^3
Single Dwelling			5,100	1,500	7,650,000
Multiple Dwelling			2,100	600	1,260,000
Commercial	21,000,000	510,000	41	13,700	560,000
Industrial	13,500,000	280,000	48	8,500	410,000
Other	16,100,000	800,000	20	26,000	520,000
		Grand Total (Building Pad Only)			10,400,000
		Total Site (2 x Building Pad)			21,000,000
		County Grading Permits†			26,000,000
		Difference			- 4,000,000

*"California Construction Trends," 1977, Ref. 2.

†Ref. 5.

With a satisfactory means to compute cubic yards of earth moved, the next step was to determine a relationship between cubic yards moved and gallons of fuel consumed. We contacted 35 construction estimators to determine if they used a factor of this sort for estimating the cost of construction. Of the 35 contacted, 15 gave us values ranging from 0.20 to 0.35 gallon per cubic yard. We selected 0.27 gallon per yard, which is the midpoint of this range and includes diesel and gasoline fuels. The equipment manufacturers reported that nearly all of the construction equipment used in California is diesel-powered. The exceptions are skiploaders and backhoes of which 25 percent are gasoline-powered; rollers of which half are gasoline-powered; and miscellaneous vehicles which are 30 percent gasoline-powered.

In order to determine fuel consumption as a function of individual equipment types, an equipment profile and fuel usage pattern was developed for building construction as shown in Table 2-4. Column 1 of the table shows the relative use of the various types of equipment on a given building construction job. For example, tracked tractors use 11 percent of all of the equipment hours on a typical building construction job, and scrapers use 30 percent of the hours . These factors, obtained from the Construction Industry Research Board in Los Angeles and confirmed by various construction contractors, take into account not only the primary construction pad development but also secondary construction: streets, sidewalks, parks, etc. Note that in this breakdown the skiploaders, rollers, and miscellaneous vehicles are divided into diesel and gasoline equipment. Column 2 in the table lists the individual equipment type fuel consumption rate in gallons per hour. These fuel consumption rates came from Caterpillar Performance Handbook. Column 3 is a weighted fuel consumption rate and is equal to the product of column 1 X column 2. Column 4 is the fraction of the fuel consumed by the various equipment types. For example, on any given job tracked tractors will use 8.6 percent of the total amount of gasoline for that job and scrapers will use over 58 percent. Column 4 also indicates that 3.7 percent of the total fuel consumed is gasoline, and the balance is diesel. Multiplying the fractions in Column 4 by the annual fuel

TABLE 2-4. EQUIPMENT PROFILE AND USAGE PATTERN FOR BUILDING CONSTRUCTION

Category	(1) Equipment Relative Use Factor, Fraction of Total Construction Time*	(2) Equipment Fuel Consumption Rate Gal/Hr†	(3) Fuel Consumption Rate Gal/Hr (1) x (2)	(4) Equipment Fuel Consumption Rate, Fraction of Total Fuel Consumed (3) ÷ Σ (3)
Tracked Tractor	0.11	7.5	0.855	0.086
Wheeled Tractor	0.02	12.3	0.283	0.028
Skiploader/Backhoe				
Diesel	0.09	2.0 ℓ	0.186	0.019
Gasoline	0.03	4.3 ℓ	0.133	0.013
Wheeled Dozer	0.06	12.3	0.750	0.076
Scraper	0.30	18.4	5.57	0.563
Motor Grader	0.05	4.4	0.198	0.020
Wheeled Loader	0.04	7.4	0.281	0.028
Tracked Loader	0.04	4.2	0.189	0.019
Off-Highway Truck	0.06	14.8	0.858	0.087
Roller				
Diesel	0.03	1.1	0.0275	0.001
Gasoline	0.03	3.5	0.0875	0.009
Miscellaneous				
Diesel	0.10	3.5	0.340	0.014
Gasoline	0.04	3.5	0.147	0.015
	1.00		Σ = 9.91	1.000

*Use factor obtained from Ben Bartolotto, Director Construction Industry Research Board, Los Angeles, and construction contractors.

†Equipment fuel consumption rates calculated from Caterpillar Performance Handbook, Caterpillar Tractor Company, except as noted.

ℓFor equipment indicated, fuel consumption rates provided were by Keith Barnes, Case Equipment Co.

consumption determined above for building construction, the annual fuel consumption by equipment type can be determined.

Before leaving the subject of building construction, it may be interesting to compare annual use rates for various equipment types, as determined by the KVB study, with those published in the EPA document AP-42 (Ref. 1). This comparison is shown in Table 2-5. The calculated annual use rate was determined as follows: the fraction of total fuel consumed by equipment type (from Table 2-4) was multiplied by the total fuel consumed, 68 million gallons per year. This provided the annual quantity of fuel used by each equipment type. Dividing this by the equipment fuel consumption rate in gallons per hour provided the annual use rate for each piece of equipment in hours per year. Dividing this number by the estimated number of machines of each type (as listed in Table 2-5) gives the calculated annual use rate in hours per year per unit in the SCAB. The agreement between the two rates is fairly good. The California calculations indicate that the larger items of equipment such as scrapers, wheeled dozers, and off-highway trucks are used at a higher rate than indicated by AP-42. Several construction firms were consulted about these results, and they indicated that this was reasonable since these major items of equipment are often run more than eight hours a day and occasionally more than five or six days a week. Smaller, less expensive equipment like tracked tractors and skiploaders is comparatively low in initial cost; therefore, contractors frequently have a surplus of this equipment to be used when and where needed on a job.

B. Freeways--

To estimate freeway construction emissions we contacted the major contractors working on two projects in the SCAB: Freeway 210 in Los Angeles County and the Lake Elsinore Freeway in Riverside County. The 210 Freeway contractor (Ref. 6) indicated that this six-mile job would require 24 months to complete with an average of 72,000 gallons per month of fuel expended. The Elsinore freeway contractor (Ref. 7) reported that these four miles of construction would require 16 months and average monthly fuel consumption of 94,000 gallons. The total fuel consumed by both freeway projects divided by

TABLE 2-5. ANNUAL USE RATES FOR EQUIPMENT TYPE FROM AP-42 AND FROM KVB's STUDY

Equipment Category	Estimated No. of Machines In SCAB*	Calculated Annual Use Rate, Hr/Yr In SCAB‡	Annual Use Rate, Hr/Yr AP-42†
Tracked Tractor	1370	480	1050
Wheeled Tractor	180	850	740
Skip Loader/Backhoe	5000	720	1000
Wheeled Dozer	150	2400	2000
Scraper	730	2400	2000
Motor Grader	690	750	830
Wheeled Loader	500	600	1140
Tracked Loader	530	710	1100
Off-highway Truck	300	2400	2000
Roller	1100	300	740
Miscellaneous	5300	800	500

* Ninety-one percent of four-county area is located inside the SCAB. Estimated number of machines was adjusted to this percent.

† Reference 2-1.

‡ Calculated annual usage by equipment type (fraction of fuel consumed by equipment type · total fuel consumed) ÷ (estimated gallons per hour) ÷ (estimated number of units, Caterpillar) = hours of annual usage per machine. By using AP-42's annual hours of operation, and the project-developed estimated gallons per hour, these are the hours per equipment type necessary to consume the fuel by our activity analysis.

the total number of miles constructed results in an average of 320,000 gallons of fuel per freeway mile, which was the value used for this study.

Table 2-5a presents the fuel use by equipment category for freeway construction and is similar in format and derivation to Table 2-4 for building construction.

C. Public Works--

Off-road construction equipment is used by counties' and cities' public works department for street maintenance, flood control, and parklands conservation. To estimate fuel consumption by public works, fleet inventories were obtained from major cities and four counties servicing the unincorporated areas. Contacts were made with the public works departments of the cities of Los Angeles, Santa Ana, Costa Mesa, Riverside, and San Bernardino as well as counties of Los Angeles, Orange, Riverside, and San Bernardino. This information gives a representative picture of equipment types used in public works as shown in Table 2-6.

For each city and county shown in the table the number for each equipment type was multiplied by the corresponding operating hours per year given in AP-42 and the corresponding fuel consumption rate in Table 2-4. The summation of these products for each city and county resulted in the total estimated fuel consumption for each of these cities and counties. Since we did not have equipment information from each city in the SCAB, and since we were looking for a factor to apply statewide, we reasoned that population should be a good basis on which to distribute public works fuel consumption. Table 2-7 shows the total fuel consumed for each city or county divided by the respective population. Studying Table 2-7, it can be seen that average gallons per capita of 1.5 is fairly representative for each of the communities listed. San Bernardino County is high and Santa Ana City is low, but generally the individual ratios are fairly consistent with the average. Therefore, by contacting the various planning departments and population resource divisions for the cities and counties throughout the SCAB, a total SCAB population was obtained for the base year of 1977, and the total gallons consumed were determined by multiplying that population by 1.5.

TABLE 2-5a. EQUIPMENT PROFILE AND USAGE PATTERN FOR FREEWAY CONSTRUCTION

Equipment Category	① Equipment Fuel Consumption Rate Gal/Hr *	② Equipment Relative Use Factor, Fraction of Total Construction Time †	③ Fuel Consumption Rate Gal/Hr ① x ②	④ Equipment Fuel Consumption Rate, Fraction of Total Fuel ③ ÷ Σ ③
Tracked Tractor	7.5	0.15	1.125	0.094
Wheeled Tractor	12.3	0.03	0.369	0.031
Skiploader/Backhoe				
Diesel	2.0ℓ	0.015	0.03	0.003
Gasoline	4.3ℓ	0.005	0.02	0.002
Wheeled Dozer	12.3	0.08	0.984	0.083
Scraper	18.4	0.40	7.36	0.618
Motor Grader	4.4	0.06	0.264	0.022
Wheeled Loader	7.4	0.05	0.37	0.031
Tracked Loader	4.2	0.06	0.252	0.021
Off-highway Truck	14.8	0.06	0.888	0.074
Roller				
Diesel	1.1	0.025	0.0275	0.002
Gasoline	3.5	0.025	0.0875	0.007
Miscellanous				
Diesel	3.5	0.028	0.098	0.008
Gasoline	3.5	0.012	0.042	0.004
		1.000	$\Sigma = 11.92$	1.000

* Equipment fuel consumption rates calculated from Caterpillar Performance Handbook, Caterpillar Tractor Co., except as noted.

† Use factor obtained from Ben Bartolotto, Director, Construction Industry Research Board, Los Angeles and Construction Contractors.

ℓ For equipment indicated, fuel consumption rates were provided by Keith Barnes, Case Equipment Co.

TABLE 2-6. FLEET INVENTORIES USED IN PUBLIC WORKS

Equipment Type	Cities					Counties			
	Los Angeles	Santa Ana	Costa Mesa	San Bernardino	Riverside	Los Angeles	Orange	San Bernardino	Riverside
Tracked Tractor	57	-	-	-	-	-	-	-	3
Wheeled Tractor	50	1	10	-	-	-	-	-	-
Skiploading Backhoe	7	-	-	-	-	15	1	-	-
Wheeled Dozer	49	-	-	1	3	13	5	10	5
Scraper	7	-	-	-	2	3	-	8	3
Motor Grader	69	1	-	2	1	50	6	40	7
Wheeled Loader	72	-	4	1	7	90	1	20	10
Tracked Loader	5	5	-	-	2	35	5	1	7
Off-highway Truck	6	1	-	2	4	-	-	-	10
Roller	61	-	1	-	-	70	-	-	5
Miscellaneous	-	3	75	3	25	40	-	75	-

TABLE 2-7. FUEL CONSUMED PER CAPITA IN PUBLIC WORKS CONSTRUCTION OPERATIONS IN SELECTED CITIES AND UNINCORPORATED AREAS

	Fuel Consumed Gallons*	Population*	Average Gallon/Capita
City			
Los Angeles	3,595,000	2,760,400	1.3
Santa Ana	71,000	192,500	0.4
Costa Mesa	258,000	242,148	1.1
San Bernardino	104,000	107,000	1.0
Riverside	382,000	160,000	2.4
County			
Los Angeles	1,792,000	971,250	1.8
Orange	181,000	239,400	0.8
San Bernardino	991,000	280,604	3.5
Riverside	604,000	233,920	2.6
TOTALS	8,000,000	5,200,000	

Average Gallons/Capita = 8.0/5.2 = 1.5†

* Fuel consumed and population reflect only unincorporated area of county.

† Because of the variable numbers, the weighted average due to relative importance on each sample was used to achieve a more balanced average.

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Table 2-7a presents fuel use by equipment category for public works. The table format and derivation are the same as those of Table 2-4 for building construction.

2.1.2 Construction Equipment Population Method

The equipment inventory method of computing emissions involves determining the equipment population and multiplying that population by the use rate in hours per year and, in turn, by the fuel consumption rate in gallons per hour. The fundamental problem of this technique is obtaining an accurate inventory of equipment since equipment is continually moving in and out of the study area. Therefore, this method was used only for the SCAB to calibrate and assess the accuracy of the construction activities method.

A. Equipment Inventory--

From the sales department of a leading equipment supplier, who keeps a running status of equipment (of all manufacturers) in the field, we obtained an inventory of equipment by type in the four counties of Los Angeles, Orange, Riverside and San Bernardino (Ref. 8). We also contacted another equipment supplier who specializes in smaller vehicles such as backhoes and skiploaders (Ref. 9). The composite four-county equipment list is given in Table 2-8. To obtain an inventory for the SCAB we multiplied the numbers shown by 0.91, which is the ratio of the land area in the SCAB to the land area in the four counties.

B. Annual Use--

As discussed above (see Table 2-5), different values for annual equipment use rates were used in this study, one listed in AP-42 and the other calculated specifically for the SCAB. Since the calculated annual use rates are related to the construction activities method, which was to be independent of the other method, the AP-42 use rates were used in computing the fuel consumption for the equipment inventory method. These use rates are also tabulated in Table 2-8.

C. Fuel Consumption Rate--

Throughout this study the fuel consumption rates were obtained from the Caterpillar Performance Handbook (Ref. 10) and the Case Equipment Co. for skiploaders and backhoes (Ref. 2-9). The values are tabulated in Table 2-8.

TABLE 2-7a. WORKSHEET 3
EQUIPMENT PROFILE AND USAGE PATTERN
FOR PUBLIC WORKS ACTIVITY

Equipment Category	① Equipment Fuel Consumption Rate Gal/Hr*	② Equipment Relative Use Factor, Fraction of Total Construction Time†	③ Fuel Consumption Rate Gal/Hr ① x ②	④ Equipment Fuel Consumption Rate, Fraction of Total Fuel ③ ÷ Σ③
Tracked Tractor	7.5	0.02	0.15	0.017
Wheeled Tractor	12.3	0.02	0.246	0.037
Skiploader/Backhoe				
Diesel	2.0ℓ	0.03	0.06	0.007
Gasoline	4.3ℓ	0.01	0.043	0.005
Wheeled Dozer	12.3	0.02	0.246	0.027
Scraper	18.4	0.06	1.104	0.122
Motor Grader	4.4	0.16	0.704	0.078
Wheeled Loader	7.4	0.07	0.518	0.057
Tracked Loader	4.2	0.08	0.336	0.037
Off-highway Truck	14.8	0.34	5.03	0.554
Roller				
Diesel	1.1	0.02	0.022	0.002
Gasoline	3.5	0.02	0.07	0.009
Miscellaneous				
Diesel	3.5	0.105	0.3675	0.041
Gasoline	3.5	0.045	0.1575	0.017
		1.000	Σ = 9.1	1.000

* Equipment consumption rates calculated from Caterpillar Performance Handbook, Caterpillar Tractor Co., except as noted.

† Use factor from Ben Bartolotto, Director, Construction Industry Research Board, Los Angeles, and Construction Contractors.

ℓ For equipment indicated, fuel consumption rates provided by Keith Barnes, Case Equipment Co.

TABLE 2-8. ESTIMATED EQUIPMENT POPULATION AND ANNUAL FUEL CONSUMPTION FOR THE COMBINED COUNTIES OF LOS ANGELES, ORANGE, SAN BERNARDINO, AND RIVERSIDE

Equipment	Estimated No. of Units *	Annual Use Rate, Hr/Yr AP-42	Avg. Fuel Rate Gal/Hr †	Annual Fuel Consumption 10^6 Gal.
Tracked Tractor	1,500	1,050	7.5	12
Wheeled Tractor	200	740	12.3	2
Skiploader/Backhoe				
Diesel	5,390	1,000	2.0	11
Gasoline	110	1,000	4.3	0.5
Wheeled Dozer	160	2,000	12.3	4
Scraper	800	2,000	18.4	29
Motor Grader	750	830	4.4	3
Wheeled Loader	550	1,140	7.4	4
Tracked Loader	580	1,100	4.2	3
Off-highway Truck	330	2,000	14.8	10
Roller				
Diesel	600	740	1.1	0.5
Gasoline	600	740	3.5	2
Miscellaneous				
Diesel	4,060	500	3.5	7
Gasoline	1,740	500	3.5	3
				91

* Based on private communication with Robert Bradshaw, representative of Caterpillar Tractor Co., and Keith Barnes, representative of Case Power and Equipment Company, Los Angeles.

† Average gallons/hour calculated from Caterpillar Performance Handbook, Caterpillar Tractor Company.

D. Fuel Consumption--

As shown in Table 2-8, annual fuel consumption is determined by multiplying the estimated number of units times the annual use rate times the average consumption rate.

2.1.3 Comparison, Two Construction Methods

To compare the annual fuel consumption calculated by the equipment population method and the construction activity method, begin with the 91 million gallons per year shown in Table 2-8. Multiply 91 by the factor 0.91 to convert this from the four-county area to the SCAB. Next, deduct four percent from the resulting 83 million gallons per year to account for construction-type vehicles used in industrial applications such as quarries, sand and gravel works, steel mills, etc. Emissions for these vehicles were included in the section covering industrial vehicles. The resulting estimate of annual fuel consumption for nonindustrial construction-type vehicles for the SCAB is 80 million gallons per year. The construction activity method annual fuel consumption total to compare with the above number is 68 million gallons per year. The difference in annual fuel consumption rate between the two methods is 12 million gallons or 16 percent of the average of the two numbers. Considering the basis for these estimates and the fact that they are completely independent of each other, the agreement is remarkably good.

Although it is difficult to decide which of the two numbers is more reliable, KVB has greater confidence in the construction activity method. The construction activity method is comprised of more individual elements than the equipment inventory method. It involves activity indicators such as construction dollars, cubic yards of earth moved, miles of freeways constructed, per capita public works, and factors relating fuel consumption to the activity indicator. All of these were developed uniquely for California or for the particular counties under study.

The equipment inventory method, on the other hand, is based on a census of construction vehicle population compiled for marketing purposes by Caterpillar and Case Equipment Companies who are, respectively, major suppliers in the large and small equipment areas. Because these companies both sell and service construction equipment, they have an excellent knowledge of the available operating equipment, which they use for their own marketing purposes. This current-equipment inventory, combined with a forecast of construction activities in a given area, helps these companies forecast potential sales by area. In spite of the fact that these companies make a significant effort to maintain what they feel is an accurate equipment inventory, there are too many small equipment owners with whom there are no regular contacts. While the inventory may be excellent in predicting broad trends, it could easily be off by ±25 percent. There is also a problem of equipment migration; although equipment is owned by a company in the SCAB, that equipment may be used in other counties or even outside the state. The construction firms contacted indicated that their equipment is always moving in and out of the various counties and even is transported as far as Hawaii and Alaska for jobs.

Therefore, because of our greater confidence in the accuracy of the construction activity method and because that method can be applied more readily statewide, we adopted it as a standard for inventorying construction emissions in the state.

2.1.4 Emissions

Knowing annual fuel consumption by equipment type, annual emissions can be calculated by multiplying fuel consumption by an emission factor. By contract we were directed to use the AP-42 emission factors, which are very comprehensive, applying to equipment throughout the United States. AP-42 provides emission factors in various units, the most universally applicable of which is in grams per horsepower hour. To be useful on this study, this emission factor was converted to pounds per thousand gallons of fuel. AP-42 provides a list for pounds per thousand gallons. However, in computing the emission factor in these units, some assumptions had to be made regarding average horsepower rating and load factors as well as the number of gallons per hour used by the various types of equipment. We checked the AP-42 assumptions and found that they were not the best parameters for use in California. Therefore, beginning with the emission factor in grams per horsepower hour, as listed in AP-42, we computed an emission factor in terms of pounds per thousand gallons by using the specific horsepower rating load factor and hourly fuel consumption most appropriate for California. Tables 2-9 and 2-10 list these emission factors for diesel- and gasoline-powered equipment. At the top of each table are the average horsepower load factor and gallons per hour assumed for each vehicle type. For diesel equipment, the average horsepower was obtained from the Southern California Caterpillar representative; load factors and gallons per hour were obtained from Caterpillar Performance Handbook. For gasoline-powered equipment we used the average horsepower and load factor from AP-42 and the gallons per hour from the Southern California representative of Case Power and Equipment Company. In both tables, two emission factors are listed: one in grams per horsepower hour, which is taken directly from the AP-42 tables; and the other in pounds per thousand gallons, which was computed using horsepower load factors and hourly fuel consumption as listed above.

To simplify the calculation of emissions for the other counties in the state, KVB computed a composite emission factor which could be applied directly to the total fuel consumed for each category of construction. In Tables 2-4, 2-5a and 2-7a, we presented a fraction of the total fuel consumed by each category of construction equipment for each of the three types of construction activities. Using these fractions as a weighting factor, we computed composite emission factors for diesel and gasoline-powered construction equipment in California as shown in Tables 2-11 and 2-12, respectively. Examples for the use of these emission factors are provided in paragraph 4.2 where the detailed methodology for inventorying the emissions in the state is presented.

2.2 STATEWIDE METHODOLOGY

The basic approach taken in the statewide methodology is to:

1. Obtain Security Pacific's construction cost data from Reference 2-2.
2. Apply factors to convert those data to cubic yards of earth moved.
3. Multiply the results by the factor for gallons per cubic yard of earth moved to get the total fuel consumed.

TABLE 2-9. EMISSION FACTORS FOR HEAVY-DUTY DIESEL-POWERED CONSTRUCTION EQUIPMENT

	Tracked Tractor	Wheeled Tractor	Skiploader Backhoe#	Wheeled Dozer	Scraper	Motor Grader	Wheeled Loader	Tracked Loader	Off-highway Truck	Roller	Miscellaneous
Avg. HP*	120	170	50	300	450	125	130	65	415	75	-
Load factor†	0.61	0.64	0.65	0.61	0.50	0.50	0.74	0.62	0.58	0.31	-
Gal/Hr†	7.5	12.3	2.0	12.3	18.4	4.4	7.4	4.2	14.8	1.1	3.5
SOx gm/hphr§	0.851	0.851	0.851	0.867	0.901	0.874	0.857	0.853	0.887	1.00	0.932
lb/10^3 gal	18.3	16.6	30.5	28.4	24.3	27.3	24.6	18.1	31.8	46.4	40.9
CO gm/hphr§	2.39	4.40	4.40	1.83	2.84	2.19	2.62	1.80	2.62	3.65	2.82
lb/10^3 gal	51.3	85.4	157.5	60.0	76.6	68.4	75.0	38.1	93.9	170.00	118.3
HC gm/hphr§	0.685	1.39	1.39	0.576	1.22	0.489	0.888	0.362	0.853	0.781	1.04
lb/10^3 gal	14.7	27.1	50.0	18.9	32.9	15.2	25.4	7.6	30.5	36.4	44.9
NOx gm/hphr§	9.08	9.35	9.35	12.5	12.1	10.5	11.2	6.56	14.9	15.7	14.8
lb/10^3 gal	194.7	182.1	334.5	409.8	326.1	329.5	320.3	138.6	540.5	730.9	648.6
HCHO gm/hphr§	0.170	0.282	0.282	0.160	0.280	0.121	0.197	0.100	0.220	0.196	0.203
lb/10^3 gal	3.6	5.5	10.0	5.2	7.6	3.9	5.7	2.1	7.9	9.1	8.9
Part. gm/hphr§	0.692	1.27	1.27	0.411	0.789	0.625	0.805	0.655	0.502	0.778	0.902
lb/10^3 gal	14.9	24.7	45.5	13.5	21.3	19.5	23.1	13.8	18.0	36.4	39.7

* Private communications with Robert Bradshaw, representative of Caterpillar Company, Los Angeles.
† Calculated from data in Caterpillar Performance Handbook, Caterpillar Tractor Company.
§ Based on AP-42 gm/hphr.
\# Calculated using AP-42's wheel tractor gm/hphr emission factor. Emission factors for skiploader and backhoe not available in AP-42.

TABLE 2-10. EMISSION FACTORS FOR HEAVY-DUTY GASOLINE-POWERED CONSTRUCTION EQUIPMENT IN CALIFORNIA

	Wheeled Tractor	Skiploader Backhoe*	Motor Grader	Wheeled Loader	Roller	Miscellaneous
Avg. HP§	48	48	60	50	97	-
Load factor§	0.64	0.64	0.50	0.74	0.31	-
Gal/Hr†	3.0	4.3	3.1	4.3	3.5	3.5
SOx gm/hphr§	0.227	0.227	0.254	0.238	0.278	0.264
lb/10^3 gal	5.2	3.5	5.3	5.3	5.2	5.3
CO gm/hphr§	142	142	187	163	202	198
lb/10^3 gal	3250	2232.6	3910	3630	3840	3960
Exhaust HC gm/hphr§	5.34	5.34	6.32	5.56	9.25	6.49
lb/10^3 gal	122	84	132	124	176	130
Evaporative HC# lb/10^3 gal	22.7	15.8	21.3	15.2	17.8	16
Crankcase HC# Lb/10^3 gal	24	16.7	26.4	24.7	34.9	32
NOx gm/hphr§	6.37	6.37	4.90	5.42	5.28	4.79
lb/10^3 gal	146	100.2	102	121	100	95.8
HCHO gm/hphr§	0.254	0.254	.288	0.222	0.256	0.222
lb/10^3 gal	5.8	4	6	4.9	4.9	4.4
Part. gm/hphr§	0.361	0.361	0.328	0.314	0.393	0.303
lb/10^3 gal	8.2	5.6	6.8	7	7.4	6.06

* Calculated from AP-42's wheeled tractors gm/hphr emission factor. Emission factors for skiploaders and backhoes not available in AP-42.
† Private communication with Keith Barnes, representative of Case Power and Equipment Company, Los Angeles.
§ Based on AP-42.
\# Evaporative and crankcase based only on operating time.

TABLE 2-11. COMPOSITE EMISSION FACTORS FOR DIESEL-POWERED EQUIPMENT IN CALIFORNIA
lb/10^3 GALLON CONSTRUCTION

	Construction Activity		
Pollutant	Building Construction	Freeway Construction	Public Works
SO_x	15	25	29
CO	91	74	86
HC	50	36	36
NO_x	340	330	450
Particulates	21	20	20

TABLE 2-12. COMPOSITE EMISSION FACTORS FOR GASOLINE-POWERED EQUIPMENT IN CALIFORNIA
$lb/10^3$ GALLON CONSTRUCTION

Pollutant	Construction Activity		
	Building Construction	Freeway Construction	Public Works
SO_x	5	5	5
CO	3300	3600	3700
HC	143	168	156
NO_x	98	99	98
Particulates	6	7	9

4. Obtain freeway miles constructed and the human population for the study areas.
5. Apply the factors of gallons per freeway mile and gallons per capita for freeway construction and public works fuel consumption.
6. Multiply the total fuel consumption for each of the three construction activities by the respective composite emission factors to obtain the specific emissions for each major pollutant.

2.2.1 Building Construction

A. Security Pacific Data--

The first step in preparing the construction inventory for any county in the State of California is to consult Security Pacific's publication entitled "California Construction Trends" (Ref. 2), which is available from Security Pacific Bank, Research Department, H8-3, Post Office Box 2097, Terminal Annex, Los Angeles, CA 90051. From this publication, obtain the following information:

1. Number of residential units, both single and multiple
2. Building costs (dollar valuation) for nonresidential (i.e., commercial, industrial, schools, churches, hospitals)

These data are presented by each major metropolitan area in the county plus the unincorporated areas. The decision to segregate this information by areas should be based on the need to provide spatial distribution for construction emissions. If a simple approach is taken in which the total emissions for the county are to be calculated and distributed uniformly by area across the county, then there is no need to collect building information by individual communities. However, if the objective is to identify emission concentrations around certain cities, then this information should be collected by individual locations.

B. Computation of Cubic Yards of Earth Moved--

To compute the total cubic yards of earth moved for each type of building, the following procedure was used:

1. For single-family dwellings, multiply the number of units by 3000 cubic yards per unit for the unincorporated areas and by 1000 cubic yards per unit for the incorporated areas.

2. For multiple dwellings, multiply the number of units by 1200 cubic yards per unit for unincorporated areas and 400 cubic yards per unit for the incorporated areas.

3. For commercial buildings, first divide the total commercial building valuation, obtained from Security Pacific Bank, by the factor $513,000 per unit to compute the number of units. Then multiply by 13,700 cubic yards per unit for unincorporated areas and by 4,600 cubic yards per unit for the incorporated areas.

4. For industrial buildings, first compute the number of units by dividing Security Pacific Bank's valuation by $276,000 per unit, then multiply this number by 8400 cubic yards per unit for the unincorporated areas and by 2800 cubic yards per unit for the incorporated areas.

5. For other buildings such as churches, schools and hospitals, compute the number of units by dividing Security Pacific Bank's valuation by $800,000 per unit, then multiply by 26,000 cubic yards per unit for the unincorporated areas and by 8700 cubic yards per unit for the incorporated areas.

Note that in all five computations above, total cubic yards includes both pad preparation and secondary earth movement to prepare for streets, sidewalks, parks, swimming pools, etc.

C. Fuel Consumption--

To obtain fuel consumption, multiply the cubic yards determined above by the factor 0.27 gallon per cubic yard. The result will be the total fuel consumed; 96 percent of this fuel is diesel, and four percent is gasoline.

D. Emissions--

For each air basin, county or subsection, multiply the total fuel consumed by the following emission factors proportioned according to the 96/4 diesel-to-gasoline ratio:

	Emissions in lbs per 1000 Gallons	
Pollutant	Diesel	Gasoline
SOx	15	5
CO	91	3300
HC	50	143
NOx	350	100
TSP	21	6

2.2.2 Freeway Construction

A. Freeway Miles--

To obtain the freeway miles constructed in the study area during the inventory year, contact the California Department of Transportation (Ref. 11).

B. Fuel Consumption--

To obtain total fuel consumption for construction of freeways, multiply the number of freeway miles by 320,000 gallons per mile. Ninety-nine percent of this fuel is diesel and one percent is gasoline.

C. Emissions--

To obtain emissions, multiply the fuel consumption proportioned according to diesel and gasoline by the following emission factors:

	Emissions in lbs per 1000 Gallons	
Pollutant	Diesel	Gasoline
SOx	25	5
CO	74	3600
HC	36	170
NOx	330	100
TSP	20	7

2.2.3 Public Works

A. Population--

To determine the population of any county or city, consult the local planning department, the Chamber of Commerce, or the California State Department of Finance.

B. Fuel Consumption--

To obtain the fuel consumption for public works construction, multiply the population for a given area by 1.5 gallons per person; apportion this as 97 percent diesel and three percent gasoline.

C. Emissions--

To obtain the emissions from public works vehicles, multiply the fuel consumption proportioned according to diesel and gasoline by the following emission factors:

Pollutant	Emissions in lbs per 1000 Gallons	
	Diesel	Gasoline
SOx	29	5
CO	86	3700
HC	36	157
NOx	450	98
TSP	20	9

2.3 EMISSIONS FROM CONSTRUCTION IN THE SOUTH COAST AIR BASIN

Using the approach discussed in paragraph 2.1, the emissions from construction vehicles were computed for California's SCAB. The results were included using the ARB area source format and inserted into a computerized data base. The emissions were aggregated by three construction types (buildings, freeway, and public works), four counties (Los Angeles, Orange, Riverside, and San Bernardino), and two fuels (diesel and gasoline). A computer report of these data has been transmitted to the ARB along with a computer tape containing the data base and a user's manual describing the technique for accessing data from the base. In the remainder of this section the results of this inventory are summarized.

2.3.1 Building Construction

A. Cubic Yards of Earth Moved--

The computation of cubic yards of earth moved for building construction in the SCAB is summarized in Tables 2-13 through 2-16 which show the computations for Los Angeles, Orange, Riverside, and San Bernardino Counties, respectively. The number of units for single-family and multi-family dwellings were obtained directly from Security Pacific's "Construction Trends" publication. The number of units for commercial, industrial, and other structures were

TABLE 2-13. CUBIC YARDS OF EARTH MOVED FOR BUILDING CONSTRUCTION IN LOS ANGELES COUNTY, 1977

Unincorporated				Incorporated			
Type	No. of Units Constructed	Yd^3/unit	Total Yd^3	Type	No. of Units Constructed	Yd^3/unit	Total Yd^3
Single Family	5,200	3,000	15,700,000	Single Family	12,600	1,000	12,600,000
Multi-Dwelling	1,800	1,200	2,100,000	Multi-Dwelling	20,000	400	7,900,000
Commercial	72	27,000	1,960,000	Commercial	710	9,100	6,400,000
Industrial	99	17,000	1,680,000	Industrial	3,500	5,200	19,500,000
Other§	83	53,000	4,400,000	Other§	330	17,600	5,800,000
Known yd^3: 22,000,000*			26,000,000		Total yd^3		53,000,000
Less 4% outside SCAB†			1,000,000				
Total Yards			25,000,000				
Total for SCAB = 78×10^6 yd^3							

* County records.

† Based on population.

§ Churches, hospitals, schools, non-buildings.

TABLE 2-14. CUBIC YARDS OF EARTH MOVED FOR BUILDING CONSTRUCTION IN ORANGE COUNTY, 1977

Unincorporated				Incorporated			
Type	No. of Units Constructed	Yd^3/unit	Total Yd^3	Type	No. of Units Constructed	Yd^3/unit	Total Yd^3
Single Family	5,105	3,000	15,000,000	Single Family	10,507	1,000	10,500,000
Multi-Dwelling	2,118	1,200	2,500,000	Multi-Dwelling	9,774	400	3,900,000
Commercial	41	27,000	1,120,000	Commercial	427	9,100	3,900,000
Industrial	49	17,000	830,000	Industrial	691	5,700	3,900,000
Other†	20	53,000	106,000	Other†	100	17,600	1,760,000
		Total yd^3	21,000,000			Total yd^3	24,000,000

Known yd^3: 26,000,000*

Total for SCAB = 45×10^6 yd^3

(100% Inside SCAB)

* County records.

† Churches, hospitals, schools, non-buildings.

TABLE 2-15. CUBIC YARDS OF EARTH MOVED FOR BUILDING CONSTRUCTION IN SAN BERNARDINO COUNTY, 1977

Unincorporated				Incorporated			
Type	No. of Units Constructed	Yd^3/unit	Total Yd^3	Type	No. of Units Constructed	Yd^3/unit	Total Yd^3
Single Family	9,184	3,000	27,000,000	Single Family	6,379	1,000	6,400,000
Multi-Dwelling	576	1,200	690,000	Multi-Dwelling	1,635	400	750,000
Commercial	19	27,000	530,000	Commercial	73	9,100	670,000
Industrial	44	17,000	750,000	Industrial	49	5,700	280,000
Other†	31	53,000	161,000	Other†	36	17,600	620,000
			31,000,000			Total yds^3	8,800,000
	Less 35% outside of SCAB*		11,000,000				
	Total Yd^3		20,000,000				
	Total for SCAB = 29×10^6 yd^3						

* Based on population.

† Churches, hospitals, schools, non-buildings.

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TABLE 2-16. CUBIC YARDS OF EARTH MOVED FOR BUILDING CONSTRUCTION IN RIVERSIDE COUNTY, 1977

Unincorporated				Incorporated			
Type	No. of Units Constructed	Yd^3/unit	Total Yd^3	Type	No. of Units Constructed	Yd^3/unit	Total Yd^3
Single Family	5,388	3,000	16,100,000	Single Family	4,625	1,000	4,600,000
Multi-Dwelling	391	1,200	470,000	Multi-Dwelling	1,789	400	720,000
Commercial	15	27,000	400,000	Commercial	41	9,100	380,000
Industrial	16	17,000	370,000	Industrial	46	5,700	260,000
Other†	26	53,000	1,390,000	Other†	29	17,600	510,000
			18,700,000			Total yd^3	6,600,000
	Less 25% outside SCAB*		4,700,000				
	Total yd^3		14,000,000				
Total for SCAB = 21×10^6 yd^3							

* Based on population.

† Churches, hospitals, schools, non-buildings.

obtained by dividing the valuation by the conversion factors shown in Table 2-1. Note that the basic data in the four tables are for the entire counties, although only portions of Los Angeles, Riverside, and San Bernardino counties lie in the SCAB; Orange County is entirely in the SCAB. Therefore, the cubic yards for the unincorporated portion of each county have been adjusted for that portion of the county which is within the SCAB. In the case of Los Angeles County, four percent of the cubic yards were deducted, for San Bernardino County 35 percent, and for Riverside County, 24 percent. At the bottom of each table is the total cubic yards of earth moved in the respective counties for the area within the SCAB. A total of 173 million cubic yards of earth were moved for building construction in the SCAB in 1977.

B. Fuel Consumption and Emissions--

Multiplying the cubic yards presented above by the factor of 0.27 gallon of fuel per cubic yard yields an estimate of 47 million gallons of fuel for building construction vehicles in the SCAB in 1977. Total emissions are discussed in paragraph 2.3.4.

2.3.2 Freeway Construction

Freeway construction figures in the South Coast Air Basin were provided by the California Department of Transportation (Caltrans), Districts 7 and 8 (Refs. 12 and 13). For the four counties, 20 miles of freeway, expressway and conventional roads were constructed in 1977. A breakdown of these miles by counties along with total fuel consumption is shown in Table 2-17. Construction vehicles used 6,500,000 gallons of fuel in freeway construction in 1977.

2.3.3 Public Works Construction

Annual fuel consumption for public works construction is based on the total population in a given area at the ratio of 1.5 gallons of fuel per person. Table 2-18 presents a tabulation of the populations of the four SCAB counties, both total and within the basin.

TABLE 2-17. FREEWAY CONSTRUCTION ACTIVITY
AND FUEL CONSUMPTION IN SCAB, 1977

County	Miles Constructed	Average Fuel Use/ Miles, 10^3 Gal	Total Fuel Consumed (Gallons)
Los Angeles	8.5	323	270,000
Orange	1.5	323	490,000
San Bernardino	4	323	1,290,000
Riverside	6	323	1,940,000
		TOTAL	6,500,000

TABLE 2-18. POPULATION TABULATIONS BY COUNTY

County	Population	Population Within SCAB	Percent Population Within SCAB
L.A.	7,200,000	7,100,000	98.7
Orange	1,770,000	1,780,000	100
S.B.	770,000	630,000	82.4
Riverside	560,000	400,000	70.6
		9,900,000	

Multiplying the total SCAB population by 1.5 produces total estimated fuel consumption of 14,800,000 gallons for public works in the SCAB in 1977.

2.3.4 Emission Summary

With the annual fuel consumption for buildings, freeways, and public works determined, emissions were computed with the usage profiles shown in Tables 2-4, 2-5a, and 2-7a, respectively. Using the emissions factors shown in Table 2-9, emissions were computed by equipment type, activity, and county. Table 2-19 shows fuel consumption and emissions by county and construction activity in the SCAB in 1977. Building construction represents the most significant area of construction activity, producing over 70 percent of the pollutant emissions; public works is next with 20 percent; and freeway construction causes ten percent of the emissions. It is interesting to note that while Los Angeles has over 70 percent of the population of the SCAB, it accounts for only 50 percent of the construction emissions. Orange County has 25 percent and San Bernardino and Riverside share the remainder almost evenly.

The spatial distribution of construction emissions represents a significant problem since these emission sources vary in location from year to year. While it may be possible to forecast the emissions in total for a county, it is difficult to forecast the geographical location for these emissions. Therefore, it was decided with the ARB staff that construction emissions would be distributed uniformly, county by county.

TABLE 2-19. CONSTRUCTION'S FUEL CONSUMPTION/EMISSIONS BY COUNTY AND ACTIVITY WITHIN THE SOUTH COAST AIR BASIN FOR 1977

County	Activity	1977 Fuel Consumption 10^3 Gal/Year		Pollutant Emission Tons/Year					
		Diesel	Gasoline	SO_x	CO	HC	NO_x	HCHO	Part
SCAB	Building Construction	45,000	1,700	580	5000	1100	8,000	160	490
	Freeway Construction	6,500	80	80	400	100	1,000	20	60
	Public Works	14,000	500	210	1600	240	3,300	50	150
	Total	65,500	2,300	870	7000	1440	12,300	230	700
Los Angeles	Building Construction	19,300	740	250	2100	475	3,400	68	210
	Freeway Construction	2,700	35	30	200	40	450	9	30
	Public Works	10,000	330	150	1100	170	2,400	38	100
	Subtotal	32,000	1,100	430	3400	685	6,300	115	340
Orange	Building Construction	13,000	500	170	1500	315	2,300	46	140
	Freeway Construction	500	6	5	30	8	80	2	5
	Public Works	2,600	80	35	280	40	600	9	30
	Subtotal	16,000	590	210	1800	363	2,900	57	180
San Bernardino	Building Construction	7,600	290	100	830	180	1,300	28	80
	Freeway Construction	1,300	17	16	80	20	200	4	13
	Public Works	920	30	13	100	20	210	3	9
	Subtotal	9,800	340	130	1000	220	1,700	35	100
Riverside	Building Construction	5,400	210	70	600	130	1,000	19	55
	Freeway Construction	2,000	26	24	120	30	300	7	19
	Public Works	600	18	8	60	8	130	2	6
	Subtotal	8,000	250	100	780	168	1,400	28	80

2.4 FORECAST OF CONSTRUCTION EMISSIONS IN THE SOUTH COAST AIR BASIN

With the fuel consumption results presented in paragraph 2.3 as a baseline, a 20-year emissions forecast was made for off-road construction equipment.

The initial step involved separation of construction activities by fuel consumption in the baseline year. The separation was required for derivation of a percentage factor for total fuel consumed by each activity; then to estimate emissions through a function of the projected increase.

In the baseline year, a total of 68 million gallons of fuel were consumed; the breakdown follows:

	Fuel Consumed 10^6/Gal	Percent Fuel Consumed
Building Construction	47	68
Public Works	15	22
Freeway Construction	7	10
	68	100

The percentage factors of fuel consumption from each activity were then used as the basis for projection of emissions for distribution by activity.

In building construction, projection of emissions was based on increased construction costs. Estimates of projected building dollar valuations were obtained (Ref.14). Figure 2-1 presents the construction costs increase. By taking baseline year construction cost and dividing this into each construction cost relative to each increment of time, an increase factor was estimated. This factor times the percentage of fuel consumed from the baseline year yielded an emissions increase percentage rate for building construction. This method was also used for forecasting emissions in public works operations by estimated population increase (Fig. 2-2).

New freeway construction is projected over a period of 20 years, declining to no activity after the year 2000 (Ref. 12). Therefore, as shown in Figure 2-3, freeway construction is presented as a linear regression.

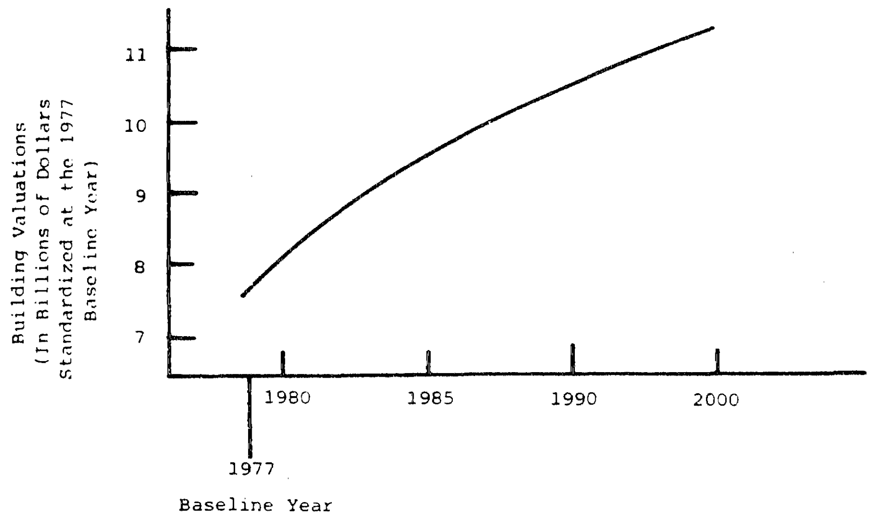

Figure 2-1. Projected Building Construction Costs in the California South Coast Air Basin.

Source: Ben Bartolotto, Director, Construction Industry Research Board.

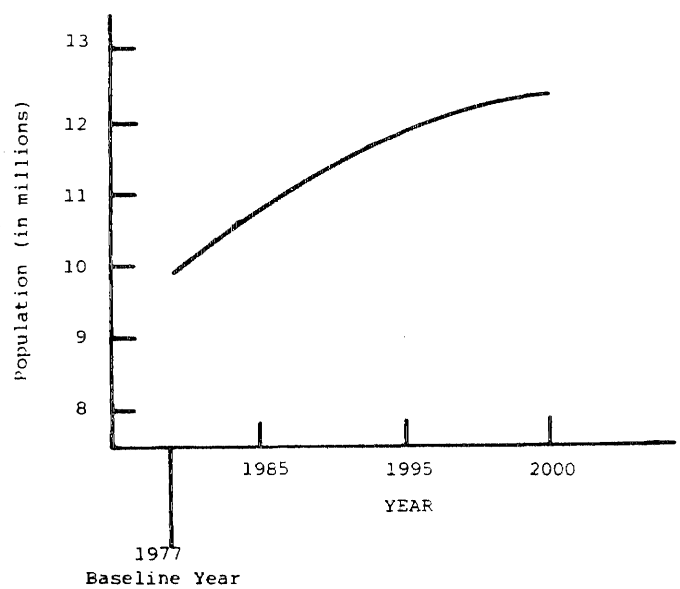

Figure 2-2. Projected Population.

Source: Dennis Masyczek, Southern California Association of Governments.

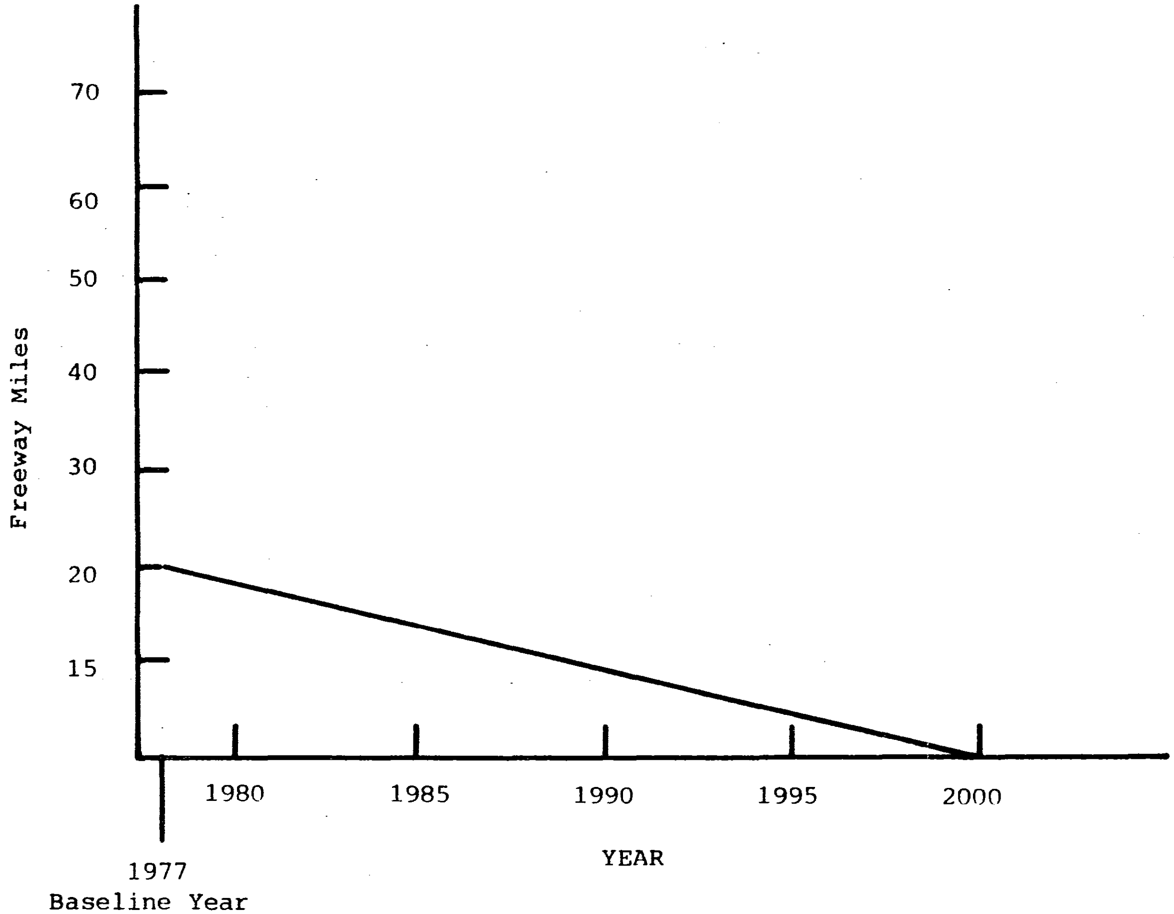

Figure 2-3. Projected Freeway Construction.

Source: Tom Smith, Information Office, California Transportation (CALTRANS).

Combining the factors from the three areas of construction activity, without any control techniques, the results of increased emissions for off-road equipment are presented in Table 2-20.

TABLE 2-20. FACTORS OF INCREASED CONSTRUCTION EMISSIONS

Year	Construction Activities						
	Building Construction	+	Public Works	+	Freeway Construction	=	Total Emission Increase
Baseline 1977	0.68		0.22		0.1		1.00
1980	0.73		0.23		0.1		1.06
1985	0.84		0.24		0.06		1.14
1990	0.98		0.25		0.04		1.27
2000	1.00		0.28		0.0		1.28

SECTION 2.0

REFERENCES

2-1 "Compilation of Air Pollutant Emission Factors," Part A, Publication A-42, EPA, August, 1977.

2-2 "California Construction Trends," December 1977, Security Pacific Bank, P. O. Box 2097, Terminal Annex, Los Angeles, CA 90051.

2-3 Personal communication with Lawrence Buxton, Phillips, Brandt, Reddick & Associates, Irvine, CA.

2-4 Personal communication with Cal McIntee, Los Angeles County Building and Safety Division, Statistical Section.

2-5 Personal communication with Jack Pigeon, Orange County Environmental Management Agency, Building and Safety Division.

2-6 Personal communication with Mr. Kasler, Kasler Construction Company, Los Angeles, CA.

2-7 Personal communication with Mr. Shoop, Estimator, Yeager Construction Company, Riverside, CA.

2-8 Personal communication with Robert Bradshaw, Caterpillar Tractor Co., Los Angeles.

2-9 Personal communication with Keith Barnes, Case Power and Equipment Co., Los Angeles.

2-10 Caterpillar Performance Handbook, Ed. 5, Caterpillar Tractor Co., January, 1975.

2-11 California Department of Transportation (Caltrans).

2-12 Mr. Ketling, Information Officer, Caltrans, District 7.

2-13 Tom Smith, Information Officer, Caltrans, District 8.

2-14 Ben Bartolotto, Director, Construction Industry Research Board.

SECTION 3.0

AGRICULTURAL VEHICLES

The methodology adopted to inventory statewide agricultural vehicle emissions, and also used for the South Coast Air Basin (SCAB) inventory, is based on a detailed breakdown of individual farming operations by crop type. Each county's annual crop report contains an enumeration of total acreage for each crop type based on data collected from farmers by the County Agricultural Commissioner's office. Information on farm equipment type and use to produce each crop type forms the basis for fuel consumption and emission calculations. These farm operational data are available from county farm advisors* in the form of sample cost-to-produce sheets.

While developing the methodology adopted, four approaches were considered. One was based on fuel expenses as presented in a federal document entitled Census of Agriculture. The second used the vehicle population data given in Census of Agriculture. The third, University of California at Davis's (UCD's) method based on county crop reports, appeared to be the best. With advice from UCD's agricultural staff and county farm advisors, KVB upgraded UCD's method to give a more accurate estimate of off-highway fuel consumption. The fourth approach was called the KVB/ARB (California Air Resources Board) method.

In the paragraphs that follow, all four approaches are described; and an explanation is given of the process by which KVB arrived at a method for the California statewide inventory. A comparison is made of the results obtained by using all four methods for Orange and Riverside counties. Then a step-by-step methodology is provided for conducting the statewide inventory of agricultural vehicle emissions. Finally, the results of the inventory performed for the SCAB, as well as a forecast of these emissions through the year 2000, is presented.

*Farm advisors are members of the University of California Cooperative Agricultural Extension Service (UCCAES).

3.1 APPROACH

To determine the emissions from agricultural vehicles it is essential to know their annual fuel consumption and associated emission factors. From the outset it was agreed that the EPA's emission factors as listed in AP-42 (Ref. 1)* would be used in this study. Therefore the primary requirement was to establish fuel consumption by vehicle type. We felt that this information could be developed by obtaining fuel consumption directly; by obtaining vehicle populations and applying fuel-use factors; or by identifying agricultural tasks and applying fuel-use factors to each. While Census of Agriculture provides comprehensive data on fuel use and vehicle population, the most recent edition was published for 1974; the next edition will cover 1979 but will not be published until 1982. There is some question as to the reliability of the information in Census of Agriculture. Crop reports, on the other hand, are current and reliable. Sample costs-to-produce sheets presented below define each operation required to grow various crops, and the UCCAES publication, Farm Machinery Costs (Ref. 2), provides fuel consumption data for each of these operations. In 1973, UCD performed a similar study aimed at identifying total energy requirements for agriculture in California. UCD's study went beyond farm vehicle energy consumption, also including the energy required to produce farm chemicals and to process and distribute crops. We studied UCD's methodology and found ways to make our study more accurate for specific county locations. In developing this modified technique we worked closely with UCD and farm advisors, all of whom concurred with our methods.

To compare the KVB/ARB method with the UCD, fuel use, and vehicle population methods, we calculated fuel consumption for two counties for the last census year, 1974.

3.1.1 Fuel Expense Method

The fuel expense method, developed by Peat, Marwick, Mitchell, & Co. (Ref. 3) in 1971 and updated biennially (last in 1977), consists of extracting fuel expense in dollars from Census of Agriculture and dividing by the per-gallon cost of fuel to obtain the total number of gallons of fuel. The

*References for Section 3.0 are listed on page 3-32.

problems are that (1) fuel cost is only presented for larger farms and (2) farmers typically report all of their fuel costs rather than only off-road fuel in spite of specific instructions on the Census of Agriculture questionnaire. Although fuel expenses are listed only for large farms, the vehicle population in Census of Agriculture is listed for both large farms and all farms. The 1974 ratio of primary equipment (tractors, harvesters, etc.) for all farms to that for larger farms is 1.2. Total fuel expense can be derived by multiplying the fuel expense for large farms by 1.2. Selecting a factor to obtain the off-road portion of the fuel expense is more difficult. UCD felt that the application of an average off-road fraction to all areas of the state would not yield an accurate result due to regional variations in crops grown, climate, farm size, and proximity to urban areas. Peat, Marwick, Mitchell & Co. derived a factor of 0.55 for off-highway gasoline usage. We assumed a factor of 1.0 for diesel fuel.

To illustrate this method in detail, the following calculation is presented of fuel consumption for Riverside County in the year 1974:

1. From the 1974 edition of Census of Agriculture, pages IV-194 and -195, gasoline expense is given as $2,596,000 and diesel expense as $1,281,000 for farms with sales greater than $2,500.

2. The adjustment for smaller farms is made by multiplying the gasoline and diesel expense in Item 1 by the factor 1.2.

3. From the Public Utilities Commission we obtained the following weighted average fuel prices:

   Diesel (without tax) $0.36/gallon
   Gasoline (including tax) $0.46/gallon

4. The off-highway usage factor for gasoline is 0.55 and for diesel 1.0.

5. To obtain the total fuel consumption in gallons per year, the product of Items 1, 2 and 4 is divided by Item 3:

   Gasoline consumed = 2,596,000 x 1.2 x 0.55 ÷ 46¢ = 3,700,000 gallons/year
   Diesel consumed = 1,281,000 x 1.2 x 1.0 ÷ 36¢ = 4,300,000 gallons/year

3.1.2 Vehicle Population Method

Calculating farm vehicle fuel consumption by using vehicle population involves multiplying the number of vehicles in each vehicle category by the following factors: a fraction to divide the number of vehicles between those that are gasoline-powered and those that are diesel-powered, an average horsepower rating for that category, a fuel consumption rate in gallons per horsepower hour, and a use factor in hours per year. Unfortunately, many of these factors are subject to large variations due to farm size, the type of crops, the type of soil, etc. For example, in a recent study by Implement and Tractor magazine (Ref. 4) the annual usage rate (hours per year) for new high-horsepower (200+) farm tractors was found to range from 250 to 2,100 hours per year. Because of problems in estimating appropriate factors for the SCAB and the other counties in the state, this method was discarded. However, in certain counties if the proper factors are known, then this method can be used to check the accuracy of the primary method of estimating using county crop reports. To illustrate the use of this method, a calculation is performed for Riverside County.

The 1974 edition of Census of Agriculture (page IV-195) lists the following farm machinery for Riverside County:

Wheeled Tractors (Less Than Five Years Old)	940
Wheeled Tractors (More Than Five Years Old)	2,400
Crawler Tractors (Less Than Five Years Old)	56
Crawler Tractors (More than Five Years Old)	390
Trucks (Including Pickups)	3,700
Automobiles	1,830

To obtain the diesel/gasoline split in this population, KVB analyzed the production figures in Implement and Tractor magazine (Refs. 5 and 6) over the past 20 years. We arrived at the following split:

	Diesel	Gasoline
Wheeled Tractors (Less Than Five Years Old)	0.78	0.22
Wheeled Tractors (More Than Five Years Old)	0.43	0.57
Crawler Tractors (Less Than Five Years Old)	1.00	0
Crawler Tractors (More Than Five Years Old)	1.00	0
Trucks (Including Pickups)	0.05	0.95
Automobiles	0.02	0.98

The average horsepower of California's farm vehicle population was obtained from Balance Sheet of the Farming Sector (Ref. 7), farm equipment dealer's guide (Ref. 8) Implement and Tractor magazine (Refs. 6, 7, and 8) and previous studies on the subject (Refs. 9, 10, and 11). The fuel consumption rate in gallons per horsepower hour was obtained from an average of Farm Machinery Costs (Ref. 2) and an Automotive Environmental Systems, Inc. (AESi) study (Ref. 11). The use rate used in KVB's analysis was obtained from an average of the ASEi study (Ref. 11) and the Society of Automotive Engineers studies (Refs. 9 and 10). These factors are as follows:

	HP Avg.	Gal/HP Hr	Hrs/Yr
Wheeled Tractors (Less Than Five Years Old)	80	0.054	570
Wheeled Tractors (More Than Five Years Old)	45	0.054	450
Crawler Tractors (Less Than Five Years Old)	99	0.056	570
Crawler Tractors (More Than Five Years Old)	56	0.056	400

For trucks and automobiles, we used factors developed by UCD (Ref. 12). They found that diesel-fueled trucks burned 700 gallons/year while gasoline-powered trucks burned 350 gallons/year. Both gasoline-fueled and diesel-fueled automobiles burned 42 gallons/year in off-road farm activities. Combining all these factors, the following fuel consumption for Riverside County was calculated:

	Diesel Gal/Yr	Gasoline Gal/Yr
Wheeled Tractors (Less Than Five Years Old)	1,800,000	350,000
Wheeled Tractors (More Than Five Years Old)	1,100,000	1,300,000
Crawler Tractors (Less Than Five Years Old)	120,000	0
Crawler Tractors (More Than Five Years Old)	490,000	0
Trucks (Including Pickups)	130,000	1,200,000
Automobiles	1,800	75,000
Total	3,800,000	3,000,000

Note that in the factors developed for equipment greater than five years old, an average was taken for that equipment between 5 and 20 years of age.

3.1.3 UCD Agricultural Production Method

The methodology for calculating fuel consumption based on agricultural production was developed by UCD for the study "Energy Requirements for Agriculture in California" (Ref. 12). The purpose of this study was to estimate the amount of energy required by the entire agricultural sector. In addition to the energy used by field equipment, they also determined the energy used in the production of agricultural chemicals, distribution of the produce, and food processing. It was therefore necessary to extract the data pertinent to farm vehicle use.

Tables 41 through 76 of the UCD study contain the diesel and gasoline fuels consumed for crop establishment, culture, and harvest. The units are in gallons per ton. Also presented is the five-year average yield in tons per acre.

Thus for any specific crop the total annual fuel consumption can be obtained by summing the gallons per ton for the three different operations, multiplying by the number of tons per acre, and multiplying again by the number of acres from the county crop reports. For tree crops, county crop reports differentiate between bearing and non-bearing acres. Examination of various sample cost-to-produce sheets for tree crops indicates that harvesting accounts for approximately 50 percent of the total fuel consumption. Therefore, a factor of 0.5 is applied for acres that are non-bearing.

To account for off-highway fuel consumption by trucks and automobiles, UCD applied fuel-use factors to the vehicle population data in Census of Agriculture (Ref. 13). (These are the same factors we used in the vehicle population technique discussed previously.) UCD assumed that the truck population was broken down as 95 percent gasoline-powered and 5 percent diesel-powered; and automobiles were broken down as 98 percent gasoline-powered and 2 percent diesel-powered. They determined that gasoline-powered trucks would use 350 gallons/year off-highway, and diesel-powered trucks would use 700 gallons/year off-highway, while both diesel-powered and gasoline-powered automobiles would use 42 gallons/year off-highway.

As an example, the following calculation of fuel consumption for grapefruit growing is presented. The UCD report (Table 68) lists the following data:

Crop Activity	Diesel Gal/Ton	Gasoline Gal/Ton
Establishment	0.06	0.04
Cultural practices	0.25	0.13
Harvest	0.18	0.45
TOTAL	0.49	0.62

This same table indicates that the average yield is 10 tons/acre; therefore, total fuel consumption per acre will be 4.9 gallons diesel and 6.2 gallons gasoline. Riverside County's 1974 Crop Report lists 12,143 acres of bearing grapefruit trees and 3,129 acres of non-bearing grapefruit trees. Multiplying the respective numbers gives the following results: for the grapefruit bearing acres, fuel consumption was 59,500 gallons diesel and 75,900 gallons gasoline. The non-bearing acres used 7,700 gallons diesel and 9,800 gallons gasoline. Repeating this procedure for each of the crops listed in the Riverside County 1974 Crop Report, a total of 4,400,000 gallons of diesel and 1,700,000 of gasoline were calculated. The 1974 Census of Agriculture lists 3,700 trucks and 1,822 automobiles as located on farms in Riverside County. Multiplying 3,711 times 0.95 (gasoline-powered fraction) times 350 gallons/year per truck yields 1,230,000 gallons/year for gasoline-powered trucks. Similarly, diesel-powered trucks account for 130,000 gallons/year, gasoline-powered automobiles for 75,000 gallons/year and diesel-powered automobiles for 1,800 gallons/year.

Total fuel consumption for Riverside County in 1974 was computed at 4,500,000 gallons of diesel and 3,200,000 gallons of gasoline .

3.1.4 KVB/ARB Method

The KVB/ARB method is patterned on the UCD method. Four significant changes were made to upgrade accuracy for specific county determinations particularly: (1) a change was made in the computation of fuel consumption of trucks and automobiles; (2) the method of computing fuel usage from the sample cost-to-produce sheets was revised; (3) the diesel/gas ratio was changed; and (4) 16 additional specific crop analyses were added.

A. Trucks and Automobiles--

The method used by UCD to determine fuel consumption by trucks and automobiles presented two problems for the KVB/ARB study. The first was that while using a flat gallons-per-year-per-vehicle might produce an average number for the entire state which was reasonably accurate, it did not appear to us nor to the farm advisors to be a suitable means for a county by county determination. Farm trucks and automobiles near large urban centers probably have a low percentage of off-road use; conversely, vehicles on large agricultural spreads away from urban centers spend nearly all of their time in off-highway use. The other problem was that the UCD method required a vehicle population from Census of Agriculture which was available only for 1974. Therefore, KVB developed a ratio between the primary equipment (tractors, harvesters, etc.) fuel consumption and the truck and auto fuel consumption.

KVB did this for two locations, the Irvine Ranch in Orange County and all of Riverside County. The management of Irvine Ranch gave us their entire fuel consumption record for 1977, both diesel and gasoline. We used our developed method to calculate the fuel consumption by primary equipment and subtracted this from the total fuel consumption. We attributed the difference to trucks and autos. Since the fuel they reported to us was for off-road use, this truck and auto fuel was for off-road only. The calculated results for the Irvine Ranch are shown in Table 3-1, which indicates that their diesel-powered trucks and autos used 0.19 times the fuel that the diesel-powered primary equipment used; but their gasoline-powered trucks and autos used 2.5 times the gasoline used by the primary equipment.

The other area we investigated was Riverside County because its crop production statistics are representative of statewide crop production. We did an analysis for 1974 using the UCD method. As shown in Table 3-1, we found a somewhat lower set of ratios than for the Irvine Company. We realized that the UCD method incorporates a diesel/gasoline split which is not up to date. The UCD method indicates a 72 diesel to 28 gasoline split, but KVB's analysis indicates the ratio should be 86 to 14, as discussed below. Therefore, we adjusted the UDC/Riverside County results for the new diesel/gasoline split (as shown in the calculation at the bottom of Table 3-1). The adjusted factors were then 0.026 gallon of diesel for trucks and automobiles for each gallon of diesel used by primary equipment, and 1.66 gallons of gasoline for trucks and automobiles for each gallon of gasoline used by primary equipment.

To arrive at factors to be used for the statewide methodology and for the SCAB, we averaged the results of the Irvine Ranch and the adjusted UCD results for Riversity County. These results are also shown at the bottom of Table 3-1.

TABLE 3-1. CALCULATION OF FUEL CONSUMED ON-SITE BY AUTOS AND TRUCKS RELATED TO AGRICULTURAL ACTIVITY

	① Calculated Fuel Consumed by Tractors and Harvesting Equipment				② Calculated Fuel Consumed On-Site by Trucks and Autos				③ Ratio of Fuel Consumed by Trucks and Autos to Fuel Consumed by Tractors & Harvesting Equipment	
	Diesel		Gasoline		Diesel		Gasoline		Diesel	Gasoline
	1a	1b	1c	1d	2a	2b	2c	2d	3a	3b
Data Base/Method of Calculation	10^3 Gal/Yr	Fraction of Primary Fuel 1a ÷ 1a + 1c	10^3 Gal/Yr	Fraction of Primary Fuel 1c ÷ 1a + 1c	10^3 Gal/Yr	Fraction of T&A Fuel 2a ÷ 2a + 2c	10^3 Gal/Yr	Fraction of T&A Fuel 2c ÷ 2a + 2c	2a ÷ 1a	2c ÷ 1c
1977 Irvine Company Crop Report and Reported Fuel Usage, KVB/CARB Method*	145	0.73	54	0.27	28	0.17	134	0.83	0.193	2.48
1974 Riverside County Crop Report, U.C. Davis Method	4400	0.72	1720	0.28	135	0.09	1430	0.91	0.031	.83
1974 Riverside County Crop Report, KVB/CARB Method	5080	0.86	851	0.14	-	-	-	-	Below	Below

Computation of KVB/CARB Ratio Trucks and Autos to Tractors and Harvesting Equipment

a. Adjust UCD ratios for new diesel/gasoline split

$$\text{Diesel} - \text{UCD 3a} \times \frac{\text{UCD 1b}}{\text{KVB 1b}} = 0.031 \times \frac{0.72}{0.86} = 0.026$$

$$\text{Gasoline} - \text{UCD 3b} \times \frac{\text{UCD 1d}}{\text{KVB 1d}} = 0.83 \times \frac{0.28}{0.14} = 1.66$$

b. Average Irvine and Adjusted UCD Ratios

Diesel, 3a - 0.193 + 0.026 = 0.219 ÷ 2 = 0.109 use 0.1

Gasoline, 3b - 2.48 + 1.66 = 4.14 ÷ 2 = 2.07 use 2.0

The final factors are 0.1 gallon of diesel by trucks and automobiles for each gallon of diesel used by primary equipment, and 2.0 gallons of gasoline for trucks and automobiles for each gallon of gasoline used by the primary equipment.

B. Subcontracted Operations--

The sample cost-to-produce sheets, an example of which is shown in Table 3-2, identify each operation required to produce a certain crop. For certain operations the equipment used, the number of hours, the amount of labor, and a fuel and repairs cost is indicated, as shown in Table 3-2. For other operations (see herbicide, fertilizer, and insecticide applications in Table 3-2), only the total cost is indicated, and there is no fuel and repair entry. We learned from UCD that their gallons per acre or gallons per ton, listed in the tables in Ref. 12, did not include the cost of these subcontracted operations. They were accounted for elsewhere in their report in that the energy consumption for fertilizer included both the manufacturing and the application of the chemicals. Therefore, in developing the KVB/ARB factors for this study, we recomputed the gallons-per-acre factors from the sample cost-to-produce sheets. Where the sample cost-to-produce sheets did not indicate equipment type and hours, we referred to the publication Farm Machinery Costs (Ref. 2). In the preparation of these crop-type factors, we worked closely with UCD personnel who concurred with our methods (Ref. 13).

C. Diesel/Gasoline Split--

In the last 15 years there has been a strong shift in the diesel/gasoline split for farm machinery. Implement and Tractor magazine (Refs. 5, 6, and 8) publishes production data which reflect this split. Fifteen years ago the split was approximately 50-50. Today, gasoline-powered equipment accounts for less than 2 percent of total farm equipment production. Considering a weighted average over the past 15 years, the approximate split in California is 85 percent diesel and 15 percent gasoline. For the KVB/ARB method the diesel/gasoline split was calculated crop by crop based on information from the sample cost-to-produce sheets. For example, if the equipment specified on the

TABLE 3-2. SAMPLE COSTS TO PRODUCE CELERY IN MONTEREY COUNTY 1976
by J. W. Huffman and E. A. Yeary, Farm Advisors

Yield: 1,000 crates (60 lbs) per acre
Harvest: June through December
Plant-Transplant: February through mid-August

Total Labor Costs/Hour[1/]		Hourly Tractor Costs	Cash Costs	Depreciation	Interest
Cl. I Equipment Operator	4.85	80 H.P. Crawler Diesel	7.06	3.13	2.34
Cl. II Equipment Operator	4.73	80 H.P. Wheel Diesel	3.44	1.63	.82
Other Labor	3.90	55 H.P. Wheel Diesel	2.26	1.12	.56

Operation	Tractor Used	Hours Acre	Labor	Fuel & Repairs	Contract and Materials	Total Acre
Cultural:						
Cover crop					Proportion of cost to celery	$ 30.00
Manure, 5 tons @ $13/ton spread						65.00
Disc & roll 3x	C-80	0.69	3.26	4.87		8.13
Chisel 2x	C-80	1.0	4.73	7.06		11.79
Land plane 2x	C-80	0.52	2.46	3.67		6.13
List & preplant fertilizer					Contract @ $4.50/acre, 600 lbs. 5-17-17 @ $54.90	[illegible]
Shape beds & roll	WD-80	0.25	1.18	0.57		1.75
Plant - 4 bed - 2 men[2/]	WD-80	0.5	7.25	1.13	Seed 1.5 lbs. coated seed @ $17.00	25.30
Herbicide					Contract @ $6.05/acre Materials @ $17.03	23.08
Irrigation 12x (5x sprinkler, 7x furrow)		38.75	151.00		4.5 ac. ft. @ $7.50/ac. ft. $2.00 booster pump	186.75
Thin		16.5	64.35			64.35
Fertilizer - Sidedress 2x					Contract @ $3.75/ac./applic 315 lbs. @ 0.27/lb.	92.55
Fertilizer - Irrigation					Application @ $1.00/acre 60 lbs. @ 0.27/lb.	17.20
Insecticide applications 4x					Contract @ $4.55/ac./applic Materials $70.00 (includes fungicides)	88.20
Cultivations 7x	WD-55	3.0	14.19	6.78		20.97
Hoe & weed		6.0	23.40			23.40
Miscellaneous (includes setup & moving)		4.0	15.60	5.50		21.10
TOTAL CULTURAL AND MATERIAL COSTS						$ 745.18
Overhead:						
Business Costs: Office and business expense @ 7% of cultural costs						$ 52.00
Taxes: Equipment						10.00
Rent: $400.00 per acre, 2/3 to celery						267.00
TOTAL OVERHEAD COSTS						$ 329.00
Harvest: $2.70 per crate - includes cutting, packing, crate, hauling and selling charge.						$2,700.00
TOTAL CULTURAL, OVERHEAD AND HARVESTING COSTS						$3,774.18

Annual Costs:

	Investment	Per Acre	Depreciation	Interest - 8%	
2/3 charged to celery. Tractors are on an hourly basis.	Buildings	$ 50.00	$ 2.50	$ 2.64	
	Irrigation system	90.00	9.00	4.75	
	Port. Irrig. system	25.00	2.50	1.32	
	Tractors	150.00	11.51	7.48	
	Equipment	100.00	10.00	5.28	
		$415.00	$35.51	$21.47	
	9 Months (except tractors and equipment) to celery				48.67
TOTAL COST PER ACRE					$3,823.[illegible]
TOTAL COST PER CRATE					$ 3.[illegible]

sample cost-to-produce sheet was a crawler tractor, it was considered to be 100 percent diesel. If the operation specified specialty equipment, it was considered to be 100 percent gasoline. Because gasoline engines are available in many more sizes than diesel engines, there is a tendency to use them in special applications. Diesel engines, on the other hand, have been developed generally for large production-quantity application. The diesel/gasoline split ranges from 95/5 to 65/35, with field crops using more diesel and fruit and nut crops using a higher proportion of gasoline. Table 3-3 tabulates the diesel and gasoline consumption factors for various crop types computed by KVB for this study. The information in this table is discussed more extensively below, but it is presented at this time to exemplify the diesel/gasoline split for the various crop types.

D. Additional Crops--

UCD analyzed 36 different crops in preparing fuel consumption tables for their study. KVB analyzed 53 different crops (as shown in Table 3-3). A separate analysis was run for each one beginning with the sample cost-to-produce sheets and including consultations with farm advisors and UCD (Ref. 13 and 14). Note in Table 3-3 that the fuel consumption for standard crops does not include the fuel expended by support trucks and automobiles. To obtain that, the factors presented above must be applied. For specialty crops, however, we found that it was unsatisfactory to try to separate primary and secondary equipment. Therefore, for mushroom and nursery crop production, we include truck and automobile fuel consumption with primary equipment fuel consumption. Since Table 3-3 was developed using sample cost-to-produce sheets from California, and since sample cost-to-produce sheets for various counties were consulted, we feel that these data should be applicable statewide. However, discretion should be used in applying California fuel-use factors to agricultural areas outside California. While these factors were developed for the year 1977, we feel that cultural practices remain relatively constant over time (Ref. 15),

TABLE 3-3. SUMMARY OF KVB/CARB-DEVELOPED CROP-SPECIFIC ANNUAL FUEL CONSUMPTION FACTORS FOR CALIFORNIA IN 1977 IN GALLONS/HARVESTED ACRE

STANDARD CROPS (INCLUDES PRIMARY EQUIPMENT ONLY; i.e., TRACTORS AND HARVESTERS)

Fruits and Nuts†			Vegetables			Field Crops		
Crop	Diesel Gal/Acre	Gasoline Gal/Acre	Crop	Diesel Gal/Acre	Gasoline Gal/Acre	Crop	Diesel Gal/Acre	Gasoline Gal/Acre
Avocados	7.1	4.7	Bell Peppers	20	3.6	Improved Range§	6.3	0.2
Grapefruit	8.4	4.2	Green Beans	23	4.1	Irrigated Pasture#	5.9	1.0
Lemons	8.4	4.2	Sweet Corn	25	3.6	Hay and Straw	4.8	0.5
Oranges	8.4	4.2	Lettuce and Cabbage	27	6.6	Barley	7.4	0.2
Grapes	22	5.6	Garlic	30	5.2	Oats	7.4	0.2
Walnuts	20	5.3	Chili Peppers	30	5.2	Wheat	7.4	0.2
Almonds	25	6.5	Asparagus	26	11.0	Alfalfa‡		
Prunes	26	6.6	Potatoes	32	4.7	Harvesting	7.2	0.8
Apples	28	7.2	Cucumbers	34	6.0	Reestablishment	12.3	0.4
Olives	29	7.2	Canning Tomatoes	38	16.2	Safflower	11.8	0.3
Peaches	31	7.4	Carrots	39	5.5	Sorghum	11.8	0.3
Apricots	32	8.1	Fresh Tomatoes	37	9.2	Silage Corn	15.8	0.4
Pears	36	9.1	Onions	43	6.2	Sudan Grass	15.8	0.4
Plums	37	9.2	Cauliflower	41	10.3	Dry Beans	17.9	3.2
Cherries	38	9.4	Strawberries	39	16.6	Rice	12	8.5*
Dates	53	12.8	Squash and Melons	40	17.1	Cotton	20	4.0*
			Broccoli	41	10.1	Sugar Beets	27	1.7
			Celery	45	11.4	Flower Seeds	47	11.8

SPECIALTY CROPS (INCLUDES PRIMARY EQUIPMENT AND TRUCKS AND AUTOS).

	Diesel Gal/Ton	Gasoline Gal/Ton		Diesel Gal/Acre	Gasoline Gal/Acre
Mushrooms	19.1	10.0	Nursery Products	60.8	82.9

*Includes aviation gasoline for aerial planting and treating of 8 gal/acre for rice and 2-5 gal/acre for cotton.

†Reduce gallons/acre factor by 1/2 for non-bearing acreage.

§Applies only to the acres of rangeland which were improved during the year. Normally an acre of improved rangeland is worked by a tractor once every 17 years (for brush control).

#Typically, irrigated and permanent pasture lands are worked by a tractor once every seven years (reestablishment of grasses).

‡Stand replanted every 3.5 years. Acreage harvested an average of 6.5 times per year.

and the total gallons per acre included in these tables should be fairly constant. However, because of increasing use of diesel-powered equipment, there will be a tendency to increase the gallons of diesel per acre at the expense of gallons of gasoline per acre. No quantitative generalization can be made, however.

A sample calculation of the fuel consumption taken from a sample cost-to-produce sheet is shown in Table 3-4. The operations are extracted from the sample cost-to-produce sheets or from Farm Machinery Costs as referenced on the table. The hours per acre were obtained from the sample cost-to-produce sheet or from Farm Machinery Costs. The gallons-per-hour figure comes from Farm Machinery Costs, and the gallons per acre are the product of hours per acre times gallons per hour. Note that in obtaining fuel consumption figures for celery (shown in Table 3-3), cost-to-produce sheets for celery from three different counties were analyzed and the results averaged.

3.1.5 Comparison of Four Methodologies

To compare the four methods described above, calculations of total fuel consumption were made for both Riverside and Orange Counties for the year 1974, the year the last edition of Census of Agriculture was compiled. Riverside County was selected because, according to the farm advisors, it is the SCAB county that is most typical of the entire State of California with respect to crop variety. It is also the SCAB county with the largest fuel consumption. Orange County was selected because it has the second largest fuel consumption and also produces specialty crops. Further, Orange County is perhaps most representative of SCAB in terms of crop variety. Table 3-5 summarizes the fuel consumption for the four methods in the two counties. The overall agreement for the total fuel is generally good. The KVB/ARB method indicates a larger diesel fraction than the others because that method has been updated to show the shift in emphasis towards diesel-powered equipment. As would be expected, the UCD and the KVB/ARB methods are in very close agreement. For Riverside County, average total fuel consumption for the four methods is 7,700,000 gallons per year. The KVB/ARB method estimates the highest fuel consumption 6 percent above the average; the equipment population method produces an estimate 12 percent below the average. In Orange County the opposite is true. The KVB/ARB method is 27 percent lower than the county average of 1,960,000 gallons per year; the equipment population method is 27 percent higher than the average for the county.

TABLE 3-4. EXAMPLE CALCULATION OF FUEL CONSUMPTION FROM SAMPLE COST-TO-PRODUCE SHEETS (REFER TO TABLE 3-2)

CELERY IN MONTEREY COUNTY, 1976

Operation	Vehicle Type/HP†	Hr/Acre	Gal/Hr*	Gal/Acre
Spread manure	WD/55	0.29	3.9	1.13
Disc, roll (3X)	C /80	0.69	6.0	4.1
Chisel (2X)	C /80	1.0	6.0	6.0
Land Plane (2X)	C /80	0.52	6.0	3.1
List and Preplant Fertilizer	WD/80	0.32	5.7	1.82
Shape beds and roll	WD/80	0.25	5.7	1.4
Plant	WD/80	0.5	5.7	2.9
Herbicide	WD/55	0.19	3.9	0.74
Fertilizer Sidedress (2X)	WD/80	0.59	5.7	3.4
Fertilizer Irrigation	None	-	-	-
Insecticide Application (4X)	WD/55	1.4	3.9	5.5
Cultivation (7X)	WD/55	3.00	3.9	11.7
Hoe and Weed	None	-	-	-
Harvesting and Miscellaneous	WD/55	4.0	3.9	15.6
			Total Fuel	57

* "Farm Machinery Costs," UCCAES Leaflet 2263, July 1978.

† WD = Wheeled Tractor
C = Crawler Tractor
HP = Horsepower

Diesel/Gasoline for celery = 80/20

0.8 x 57 = 46 gal diesel/acre
0.2 x 57 = 11 gal gasoline/acre

Note: The values 46 gal diesel and 11 gal gasoline differ from values for celery in Table 3-3 because the values are an average of data from three counties whereas the value above is just for Monterey County.

TABLE 3-5. SUMMARY OF THE FOUR METHODS CONSIDERED INITIALLY TO CALCULATE ANNUAL OFF-ROAD AGRICULTURAL VEHICLE FUEL CONSUMPTION

Summary of Fuel-Consumption Calculations for Riverside County in 1974*
Calculated Fuel Consumption
(10^3 gal/yr)

Method of Calculation/ Activity Indicator	Tractors and Harvesting Eq. Diesel	Tractors and Harvesting Eq. Gas	Autos and Trucks Diesel	Autos and Trucks Gas	Total Diesel	Total Gas	Total Fuel
Analysis of Reported Fuel Expense/Census of Agriculture§	+	+	+	+	4,300	3,700	8,000
Analysis of Equipment Population/Census of Agriculture#	+	+	-	+	3,800	3,000	6,800
U.C. Davis County Crop Report++	4,400	1,700	140	1,500	4,500	3,200	7,700
KVB/ARP Gallons Per Acre Factors/ County Crop Report**	5,100	850	550	1,750	5,600	2,600	8,200
							(7,700 Avg)

Summary of Fuel-Consumption Calculations for Orange County in 1974*
Calculated Fuel Consumption
(10^3 gal/yr)

Method of Calculation/ Activity Indicator	Tractors and Harvesting Eq. Diesel	Tractors and Harvesting Eq. Gas	Autos and Trucks Diesel	Autos and Trucks Gas	Total Diesel	Total Gas	Total Fuel
Analysis of Reported Fuel Expense/Census of Agriculture§	-	+	+	+	1,130	1,280	2,400
Analysis of Equipment Population/Census of Agriculture#	+	+	+	+	1,300	1,200	2,500
U.C. Davis County Crop Report++	630	360	25	520	660	870	1,530
KVB/ARP Gallons Per Acre Factors/ County Crop Report**	710	220	77	410	780	640	1,420
							(1,960 Avg)

*Data for 1974 was used for comparison as 1974 was the most recent year in which Census of Agriculture was published.

+These methods do not indicate the equipment category consuming the fuel.

§Formula: Fuel consumed (gallons/year)=reported annual fuel expense ÷ average cost per gallon x fraction of fuel used off-highway.

#Formula: Fuel consumed (gallons/year)=reported equipment population x average horsepower x average load factor x gallons per horsepower hour x annual operating hours.

++Formula: Fuel consumed (gallons/year)=annual acres harvested x average yield per acre x U.C. Davis crop establishment, cultural practices and harvest gallons per ton + reported number of autos x fraction gasoline- or diesel-powered x 41.71 gallons per year per auto + reported number of trucks x fraction gasoline-powered x 350 gallons per gas-powered truck per year + reported number of trucks x fraction diesel-powered x 700 gallons per diesel-powered truck per year.

**Formula: Fuel consumed (gallons/year)=annual acres harvested x project-developed gallons per acre + 2.0 crop production gasoline + 0.1 x crop production diesel.

Because the KVB/ARB method is based on county crop reports, which are authenticated by the County Agricultural Commissioner's office, we feel that this is the best method for the statewide inventory. There is consistently good agreement with the UCD method, and on the average it agrees with the equipment population method. The agricultural fuel expense method averages somewhat higher, but we suspect that some of the fuel reported in Census of Agriculture may include on-road applications. Using the KVB/ARB method should provide estimated emissions with an accuracy of ±25 percent.

3.1.6 Emissions

To calculate the emissions from agricultural vehicles, the fuel consumption computed above must be multiplied by an appropriate emission factor. The most accurate way to compute emissions would be to compute fuel consumption for each individual operation for each crop type. This fuel consumption would then be assigned to a specific vehicle, and the appropriate emission factors would be selected from AP-42 for calculating the emissions. Because there are 5 to 20 operations for each crop, over 50 crop types, and six individual pollutants, there would be nearly 5,000 calculations for each area inventoried. For the SCAB this would be approximately 20,000 calculations. Considering the various assumptions involved with emissions estimates and the site-to-site variations expected, it appeared that the most practical approach would be to develop a composite emissions factor which could be applied directly to the total fuel consumption computed for the area under study. The next paragraph presents a discussion of the derivation of the composite emission factors.

The first step in developing composite emission factors is to determine the fuel usage by individual types of agricultural vehicles. Table 3-6 shows how fuel usage factors were derived for California. Column 1 lists the different types of agricultural equipment and shows the breakdown between the fuel type (diesel or gasoline) and equipment age (less than and greater than eight years). The next column gives KVB's estimate of the number of vehicles in California in each category. This estimate was derived from the figures for vehicle population in the 1974 edition of Census of Agriculture; it shows vehicle populations for the preceding 10 years from which we could develop a trend in these numbers. The third column in Table 3-6 shows the total number of vehicles in each major category as listed in Census of Agriculture. (This is presented to compare with KVB's estimate in the preceding column.) The fourth column is the estimated average horsepower for each of the vehicles listed. This estimated average horsepower was obtained from Implement and Tractor magazine data (Refs. 5, 6, and 8), Balance Sheet of the Farming Sector (Ref. 7) plus studies by ASEi (Refs. 9 and 10) and SAE (Ref. 6). The next column, labeled Estimated Annual Use Factor, is included to distinguish between the greater usage of new vehicles as compared to old vehicles. Note that less-than-eight-year-old vehicles are used only half as much. Note also that field harvesters and miscellaneous harvest equipment have half the use rate of tractors and combines. This is to account for the fact that approximately half the harvest equipment is not self-propelled and must be pulled by a tractor. Multiplying the estimated number of units (the column labeled one) times the average horsepower (two), times the annual use factor (three), equals a fuel use weighting factor. The last two columns, Fuel-Use Factor--one for diesel and one for gasoline--were computed by dividing the respective numbers in column 5 by the respective total for diesel and gasoline. These fuel-use factors are the fraction of the total fuel consumed by the individual types of equipment. For convenience, these fuel consumption factors are summarized in Table 3-7. In addition to listing the fuel consumption factors for standard crop production, Table 3-7 includes factors for two specialties, mushrooms and nursery production. Because mushroom and nursery equipment is unusual, it was not possible to derive factors for this type of agriculture in the same way as for standard crops. Instead, we contacted several nursery and mushroom producers who gave us information on actual experience (Refs. 16 and 17).

TABLE 3-6. DERIVATION OF FUEL USAGE FACTORS FOR STANDARD CROPS IN CALIFORNIA, 1977

Type Equipment/Age	① KVB Est'd No. Units 1977	(Census of Agric. 1974 Ref. 5 Total No. Units)	② Est'd. Average Horsepower	③ Est'd. Annual Use Factor	⑤ Fuel Use Weighting Factor ①x②x③	Fuel Use Factor Diesel ⑤/Σ⑤D	Fuel Use Factor Gasoline ⑤/Σ⑤G
• **Crawler Tractor**		(28,000)					
Diesel - <8 yr.	3,300		100	1.0	10	0.16	
>8 yr.	21,000		63	0.5			
• **Wheel Tractor**		(113,000)					
Diesel - <8 yr.	36,000		90	1.0	4000	0.61	
>8 yr.	31,000		51	0.5			
Gasoline - <8 yr.	7,900		52	1.0	1110		0.27
>8 yr.	38,000		36	0.5			
• **Combines**		(5,400)					
Diesel - <8 yr.	2,100		140	1.0	390	0.06	
>8 yr.	1,700		120	0.5			
Gasoline - <8 yr.	290		110	1.0	123		0.032
>8 yr.	1,700		105	0.5			
• **Field Forage Harv.**		(2,000)					
Diesel - <8 yr.	2,100		175	0.5	230	0.03	
>8 yr.	1,100		150	0.25			
Gasoline - <8 yr.	95		117	0.5	12		0.003
>8 yr.	220		110	0.25			
• **Misc. Harvest Eq.**		(14,100)					
Diesel - <8 yr.	5,700		74	0.5	260	0.04	
>8 yr.	3,400		60	0.25			
Gasoline - <8 yr.	1,100		43	0.5	87		0.021
>8 yr.	6,300		40	0.25			
• **Trucks**		(119,000)					
Diesel & <8 yr.	67,000		-	-	650 (D)	0.10	
Gasoline >8 yr.	53,000		-	-	2,600 (G)		0.64
• **Automobiles**		(64,000)					
Gasoline <8 yr.	55,000		-	-	137		0.034
>8 yr.	8,200		-	-			
						1.00	1.00

TABLE 3-7. PROFILE OF FUEL CONSUMPTION FOR CATEGORIES OF AGRICULTURAL EQUIPMENT IN CALIFORNIA, 1977

Fraction of Fuel Consumed By Equipment Category*

Equipment Category	Mushrooms and Nursery Production		Standard Crop Production	
	Diesel	Gasoline	Diesel	Gasoline
Crawler Tractors†			0.16	
Wheeled Tractors	0.36	0.08	0.61	0.27
Harvesting Equipment§	0.37	0.07	0.13	.055
Automobiles#				.034
Trucks‡	0.27	0.85	0.10	.640

*Based on a California vehicle population/usage analysis.

†Gasoline-powered crawler tractors have not been in production for over 30 years.

§Harvesting equipment includes self-propelled combines, cornpickers, mower conditioners, pickup balers, windrowers, field forage harvesters, and other miscellaneous self-propelled harvesting equipment such as forklifts (used in harvest of canning tomatoes).

#Diesel-powered autos' contribution is considered negligible.

‡In mushroom and nursery production, light- and medium-duty gasoline-powered vehicles are included in the gasoline-powered truck category.

Table 3-8 presents emission factors computed for various categories of agricultural equipment from the data in AP-42, except that factors for gasoline-powered trucks were obtained from the ARB in El Monte, California (Ref. 18). To obtain the composite emission factor the fuel-use factors in Table 3-7 were multiplied by the emission factors in Table 3-8 to produce the results shown in Table 3-9. Thus the recommended procedure for calculating emissions is to compute total fuel consumption for a given study area, and then multiply by the emission factors shown in Table 3-9.

3.2 STATEWIDE METHODOLOGY

The method for inventorying emissions from agricultural equipment in off-highway usage is based on the use of county crop reports and factors presented in paragraph 3.1. The method is outlined in the steps listed below:

1. Consult the county crop reports, which are obtainable from the County Agricultural Commissioner's office, and list the number of harvested acres for each crop. In the case of fruit and nut crops, also list the number of planted or non-bearing acres as well as the number of harvested acres. For any questions concerning the crop report contact the County Agricultural Commissioner's office. For information on field operations, we recommend contacting the farm advisor at the University of California Cooperative Agricultural Extension Service who is located in each county and can be found through the Agricultural Commissioner's office.

2. Multiply the number of acres for each crop type by the respective fuel consumption factors shown in Table 3-3. If a crop is not listed in Table 3-3, select a crop similar to the one desired. For example, pistachio nuts are not listed but they should have factors similar to walnuts or almonds. If there is a special crop so different that none of the factors in Table 3-3 would be satisfactory, then consult the farm advisor or a major producer of the crop. Perhaps they could provide a sample cost-to-produce sheet or actual data from which fuel consumption could be computed.

TABLE 3-8. PROFILE OF EMISSION FACTORS FOR CATEGORIES OF AGRICULTURAL EQUIPMENT

Equipment Category	Pollutant Emissions* ($lb/10^3$ gal) SOx	CO	HC	NOx	HCHO†	Particulates
Crawler Tractors						
Diesel	31.1	87	21	332	6.2	25.3
Gasoline§						
Wheeled Tractors						
Diesel	31.2	119	61	335	12.1	45.7
Gasoline	5.3	3260	173	151	6.8	8.0
Harvesting Equipment						
Diesel	31.1	139	57	307	10.2	51.3
Gasoline	5.3	4100	164	98	4.1	6.9
Automobiles#						
Diesel§	3.9	1414	170	119	N/A	10.2
Gasoline++						
Trucks#						
Diesel**	28.4	890	138	220	3.0	13.2
Gasoline††	6.5	1350	206	68	N/A	12.3

*Emission factors from AP-42 unless otherwise noted.

†Aldehydes as formaldehyde.

§Emissions from this equipment are negligible.

#Emissions mode adjusted to 5 MPH average operating speed (per AP-42).

**Based upon AP-42 estimate of 13.6 MPG.

**Based upon AP-42 estimate of 4.6 MPG.

††ARB El Monte in-use vehicle surveillance program data (16.45 MPG), Ref. 13

TABLE 3-9. COMPOSITE EMISSION FACTORS FOR AGRICULTURAL EQUIPMENT IN CALIFORNIA*

Operation and Fuel Type	Pollutant Emission, $lb/10^3$ gallons					
	SOx	CO	HC	NOx	HCHO	Particulate
Standard Crop Production						
Diesel	31	187	61	320	10.1	40
Gasoline	6.0	2010	193	93.5	2.1	10.7
Specialty† Crop Production						
Diesel	31	129	59	320	11.1	49
Gasoline	5.3	3700	169	126	5.5	8.0

*Computed from data in Tables 3-6 and 3-7.

†Nursery, mushroom, etc.

Note that for non-bearing acres the fuel consumption is one-half the value listed in Table 3-3.

3. Sum the diesel and gasoline consumption for standard crops. Multiply the diesel by a factor of 1.1 and the gasoline by 3.0 to account for off-road trucks and automobiles. If the county under study is in a remote part of the state (i.e., some distance from the nearest urban center) then thought must be given to increasing this factor. Note that the fuel consumption factors for the specialty crops already include a factor for trucks and automobiles; therefore, no additional factor need be calculated.

4. Multiply annual diesel and gasoline consumption by the respective emission factors in Table 3-9. Note that separate emission factors are provided for standard and specialty crop production.

5. To spatially distribute the computed total emissions, consult a land-use map. The recommended procedure is to color it with colors representing various crops. When this is completed the agricultural areas should be bounded by a polygon of not more than six sides. The UTM coordinates for each of the intersections of the sides should then be noted.

3.3 SCAB RESULTS

Emissions from off-road agricultural equipment were inventoried for the SCAB using the methodology described in paragraph 3.2. After obtaining crop reports from the Agricultural Commissioner's office in each of the four counties, it was necessary to determine the portion of each county's crop production which took place within the SCAB. For Los Angeles county, the number of acres of crops produced in the Antelope Valley was subtracted from the entire county's crop report. For Riverside County the sub-county crop report for the East and West Alessandro Districts was used and the Beaumont/Banning District was subtracted so that what remains is only the SCAB portion. San Bernardino County is divided into districts. Only the seven districts which make up the SCAB portion of the county were added together. Orange County is entirely within SCAB and no additional work was required.

The inventory results for SCAB in 1977 are shown in Tables 3-10 and 3-11. Table 3-10 presents the fuel consumption by crop production category

TABLE 3-10. SUMMARY OF AGRICULTURAL FUEL CONSUMPTION BY VEHICLE TYPE AND CROP PRODUCTION CATEGORY FOR THE SOUTH COAST AIR BASIN*

	1977 Fuel Consumption, 10^3 Gal/Yr										
	Fruits and Nuts		Vegetables		Field Crops		Mushroom and Nursery		Subtotal		
County Fuel Type†	Tractors & Harvest Equipment	Autos & Trucks	Tractors & Harvest Equipment	Autos & Trucks	Tractors & Harvest Equipment	Autos & Trucks	Tractors & Harvest Equipment	Trucks§	Tractors & Harvest Equipment	Autos & Trucks	Total All Equipment
SCAB											
Diesel	800	87	1200	133	1000	109	290	100	3300	430	3700
Gasoline	310	640	320	650	69	143	80	410	780	1840	2600
Los Angeles											
Diesel	21	2	240	26	47	5	134	46	440	80	520
Gasoline	9	19	60	123	7	15	37	193	117	360	470
Orange											
Diesel	69	8	470	51	74	8	116	40	730	107	840
Gasoline	36	73	155	320	6	13	31	159	230	590	800
San Bernardino											
Diesel	370	40	54	6	169	18	20	7	620	72	690
Gasoline	118	240	12	24	14	29	6	31	149	320	470
Riverside											
Diesel	330	37	460	50	710	77	17	6	1520	170	1690
Gasoline	140	300	92	189	42	87	5	26	280	600	880

*Based on 1977 county crop reports and project-developed fuel consumption factors (Table 3-3).
†Includes only the crops produced in that portion of each county located within the SCAB.
§Includes light-duty gasoline-powered vehicles other than trucks (i.e., sod buggies, plant transports and other equipment).

TABLE 3-11. SUMMARY OF AGRICULTURAL EMISSIONS BY VEHICLE TYPE FOR THE CALIFORNIA SCAB, 1977

County* Vehicle Type	Pollutant Emissions† Tons/Year SOx	CO	HC	NOx	HCHO	Part.
SCAB						
Tractors and Harvesting Equip.	54	1,490	154	600	20	75
Autos and Trucks	12	1,430	218	112	1	14
Total	66	2,900	370	710	21	89
Los Angeles						
Tractors and Harvesting Equip.	7.2	220	22	80	2.8	10.3
Autos and Trucks	2.2	270	41	21	0.1	3.7
Subtotal	9.4	490	63	101	2.9	13.0
Orange						
Tractors and Harvesting Equip.	12.4	430	39	136	4.7	16.9
Autos and Trucks	3.3	430	65	32	0.2	4.1
Subtotal	15.3	850	104	168	4.8	21.0
San Bernardino						
Tractors and Harvesting Equip.	10.0	290	29	112	3.8	13.8
Autos and Trucks	2.1	250	38	31	0.1	4.5
Subtotal	12.0	540	67	143	3.9	18.3
Riverside						
Tractors and Harvesting Equip.	25.0	560	65	270	9.1	34.0
Autos and Trucks	8.3	480	73	40	0.3	4.8
Subtotal	29.0	1,040	138	310	9.4	39.0

*Includes only that portion of a county located within the SCAB.

†Calculated using the method presented in paragraph 3.2.

and vehicle type. Of interest here is the significant contribution made by the specialty crops such as mushrooms and nursery products, especially in Los Angeles County. In the SCAB these specialty products account for 11 percent of the diesel fuel, 19 percent of the gasoline and 14 percent of the total fuel consumption. In Los Angeles County these percentages increased to 35 percent of the diesel fuel, 49 percent of the gasoline and 41 percent of the total fuel, while in Orange County these numbers are respectively 19 percent, 24 percent, and 21 percent. It is also interesting to note that while Los Angeles County usually has the largest amount of emissions in the state for most stationary sources, in this instance Los Angeles County only accounted for 15 percent of the total fuel consumption in the SCAB. Riverside County is the leading fuel consumer at 41 percent of the total fuel; Orange County is next with 26 percent followed by San Bernardino County with 18 percent. Table 3-11 presents the emissions from agricultural vehicles by county, separating those emissions from primary equipment such as tractors and harvesting equipment from the support equipment such as trucks and automobiles. The pollutants included are oxides of sulfur (SOx), carbon monoxide (CO), hydrocarbons (HC), oxides of nitrogen (NOx), aldehydes (HCHO) and particulates.

The distribution of these emissions within the SCAB is illustrated in Figure 3-1. This is a copy of the land-use map which was used by KVB to locate farming activities within the SCAB. The polygons shown on the map define those areas determined by KVB to be the principal sources of agricultural emissions. In inputting the emissions to the computerized area source inventory we distributed the emissions calculated for each county according to the area of the polygons. If a specific polygon enclosed 10 percent of the total crops produced in a given county, then that polygon was assigned 10 percent of the emissions. For Los Angeles County there were 9 polygons, in Orange County 4, San Bernardino 4, and Riverside 7.

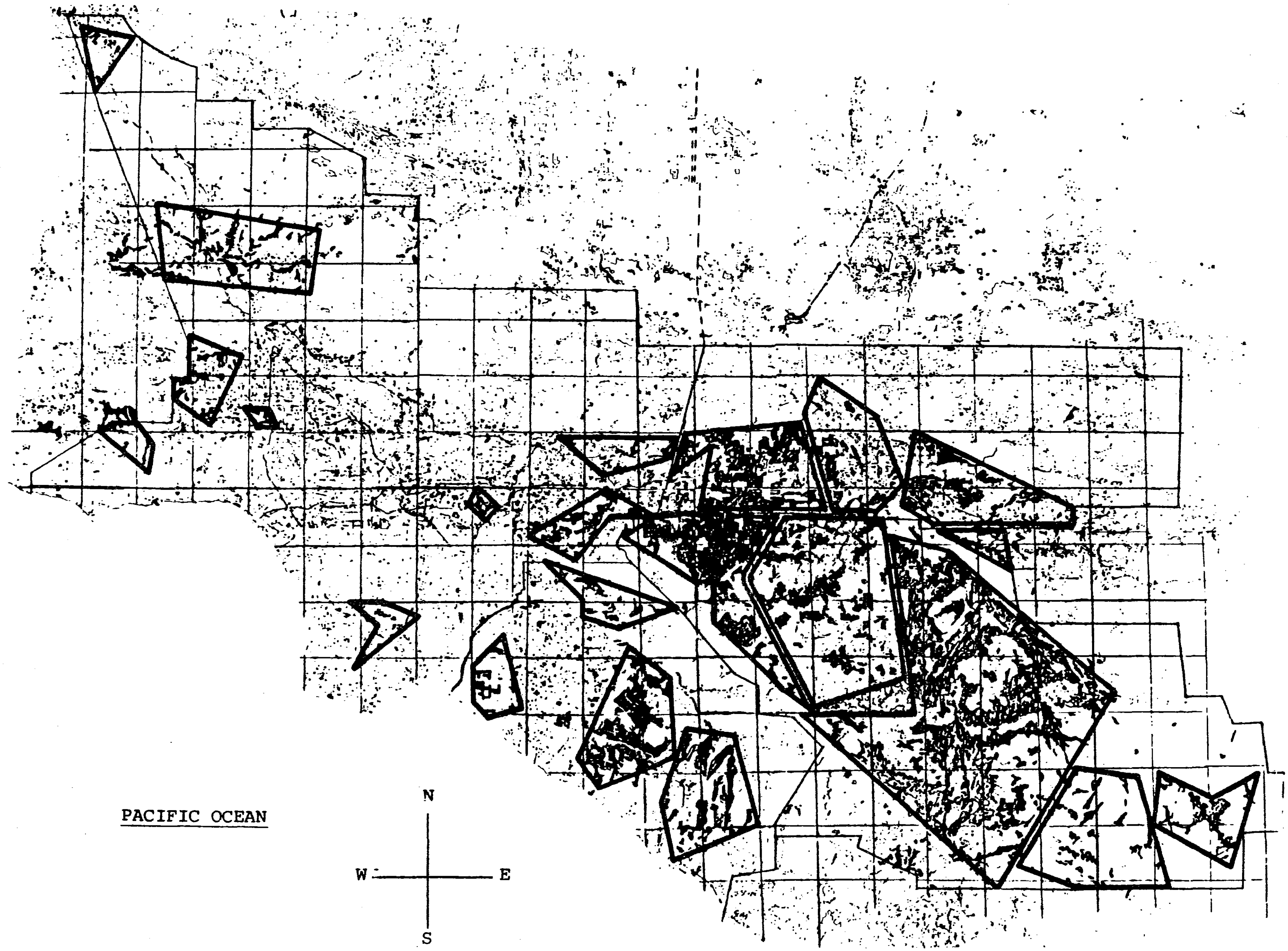

Figure 3-1. Distribution of Emissions within SCAB

3.4 EMISSIONS FORECAST

To forecast the SCAB emissions from off-road agricultural vehicles, we analyzed the annual crop production figures from the county crop reports over the past 15 years and discussed trends with County Agricultural Commissioners and farm advisors. We reached the following conclusions with respect to crop production:

1. Tree crops would decrease at the rate of 1 percent per year.
2. Vegetable crops would decrease at the rate of 2 percent per year.
3. Field crops would decrease at the rate of 6 percent per year.
4. Specialty crops, such as mushrooms and nursery, would increase at 2½ percent per year.
5. Auto and truck fuel would be the same proportion as for 1977.

We also assumed that diesel would become a greater proportion of the total fuel. In 1977 it accounted for 58 percent of the total fuel. We assumed that by 1985 this would increase to 63 percent and would reach 66 percent in the year 2000. The growth in specialty crop production is the limiting factor in relative diesel growth.

Table 3-12 is a forecast of emissions for agricultural off-road vehicles through the year 2000. As a base, the emissions for 1977 are shown. Then for each five-year increment, a factor is presented for each pollutant to reflect the change from the 1977 emissions. For example, for 1995, hydrocarbon emissions will be 71 percent of the 370 tons per year in 1977. The general trend is a reduction in emissions. By the year 2000 we expect a decrease of approximately 15 percent in fuel consumption in agricultural off-road vehicles with a corresponding reduction in emissions unless some emission control measures are instituted.

TABLE 3-12. FORECAST OF EMISSIONS FROM AGRICULTURAL OFF-ROAD VEHICLES

	Pollutant					
	SOx	CO	HC	NOx	HCHO	Part.
1977 Emissions, Tons/Year	66	2900	370	710	21	89
Fraction of Corresponding 1977 Emission for the Following Years						
1980	0.95	0.99	0.93	0.97	0.98	0.96
1985	0.88	0.97	0.81	0.91	0.96	0.89
1990	0.85	0.93	0.76	0.87	0.93	0.86
1995	0.82	0.89	0.71	0.82	0.89	0.82
2000	0.79	0.85	0.66	0.78	0.86	0.79

SECTION 3.0

REFERENCES

3-1 U.S. Environmental Protection Agency, Compilation of Air Pollutant Emission Factors, AP-42. Research Triangle Park, North Carolina, February, 1976.

3-2 University of California Cooperative Extension Service, Farm Machinery Costs, Leaflet No. 2263, July, 1978.

3-3 Peat, Marwick & Mitchell and Co., "Report on Unrefunded Gasoline Tax for Agriculture for the Year 1969," for State of California, Departments of Public Works & Agriculture.

3-4 Implement & Tractor Magazine, "Farmers talk about use of big, late model tractors" Aug. 7, 1979, Vol. 94, No. 16.

3-5 Implement & Tractor Magazine, 40th Annual Statistics Issue, Nov. 7, 1977, Vol 92, No. 22.

3-6 Implement & Tractor Magazine, 41st Annual Statistics Issue, Nov. 7, 1978, Vol. 93, No. 22.

3-7 United States Department of Agriculture, Economics, Statistics and Cooperatives Service, "Balance Sheet of the Farming Sector," Published yearly.

3-8 Implement & Tractor Magazine, 62nd Annual Red Book Issue, Jan. 31, 1978, Vol. 93, No. 3.

3-9 Society of Automotive Engineers, Inc., "Farm and Industrial Tractors - Emission Trends and Their Impact," by G. C. Hardwick and C. R. Hudson, Sept. 10, 1973.

3-10 Society of Automotive Engineers, Inc., "Impact of Emissions from Farm Equipment and Off-Road Heavy Duty Equipment on Air Pollution in California," by M. Van Loan and Larry Resnick, Sept. 10, 1973.

3-11 Automotive Environmental Systems, Inc., "Uncontrolled Vehicle Emission Study" for C.A.R.B.; submitted October 30, 1973.

3-12 Joint Study, California Department of Food and Agriculture and University of California, Davis, "Energy Requirements for Agriculture in California," January, 1974.

3-13 Personal communications with A.D. Reed, Extension Economist, R.G. Curley, Agricultrual Engineering Department, U.C. Davis, W.J. Chancellor, Agricultural Engineering Department, U.C. Davis, and V. Cervinka, California Department of Food and Agriculture, all of Davis, California.

3-14 Personal communication with farm advisors in the counties of Los Angeles, Orange, Riverside, San Bernardino, and San Diego.

3-15 Implement & Tractor Magazine, "Conservation vs. Conventional Tillage: How do they compare," Vol. 94, No. 17, August 21, 1979.

3-16 Personal communication with the General Manager of Ocean View Mushroom Growers, Inc., Huntington Beach, CA.

3-17 Person communication with Mr. Gordon McKelvey of Monrovia Nursery, Inc., Monrovia, CA.

3-18 Personal communication with Mr. M. Luczynski "In-use Vehicle Study," California Air Resources Board, El Monte, CA.