

# **AN IMPLEMENTATION PLAN FOR SUSPENDED PARTICULATE MATTER IN THE LOS ANGELES REGION**

## **TECHNICAL SUPPORT DOCUMENTS**

- 1. ANALYSIS OF AIR MONITORING DATA**
- 2. EMISSION INVENTORIES AND PROJECTIONS**
- 3. AIR QUALITY - EMISSION LEVEL RELATIONSHIP**
- 4. ALTERNATIVE EMISSION CONTROL MEASURES**

**Prepared for**  
**ENVIRONMENTAL PROTECTION AGENCY**  
**REGION IX - SAN FRANCISCO, CALIFORNIA**

# **AN IMPLEMENTATION PLAN FOR SUSPENDED PARTICULATE MATTER IN THE LOS ANGELES REGION**

## **TECHNICAL SUPPORT DOCUMENTS**

- 1. ANALYSIS OF AIR MONITORING DATA**
- 2. EMISSION INVENTORIES AND PROJECTIONS**
- 3. AIR QUALITY - EMISSION LEVEL RELATIONSHIP**
- 4. ALTERNATIVE EMISSION CONTROL MEASURES**

**Prepared for  
ENVIRONMENTAL PROTECTION AGENCY  
REGION IX - SAN FRANCISCO, CALIFORNIA**

AN IMPLEMENTATION PLAN FOR SUSPENDED  
PARTICULATE MATTER IN THE LOS ANGELES REGION

TECHNICAL SUPPORT DOCUMENT #1

ANALYSIS OF AIR MONITORING DATA

By: K. W. Crawford

J. C. Trijonis

Prepared For

Environmental Protection Agency  
Region IX - San Francisco, California

**TRW** / TRANSPORTATION AND  
ENVIRONMENTAL ENGINEERING  
OPERATIONS

AN IMPLEMENTATION PLAN FOR SUSPENDED  
PARTICULATE MATTER IN THE LOS ANGELES REGION

TECHNICAL SUPPORT DOCUMENT #1

ANALYSIS OF AIR MONITORING DATA

By: K. W. Crawford

J. C. Trijonis

Prepared For

Environmental Protection Agency  
Region IX - San Francisco, California

**TRW** / TRANSPORTATION AND  
ENVIRONMENTAL ENGINEERING  
OPERATIONS

This report was furnished to the Environmental Protection Agency by TRW Transportation and Environmental Operations in fulfillment of Contract Number 68-02-1384. The contents of this report are reproduced herein as received from the contractor. The opinions, findings and conclusions are those of TRW and not necessarily those of the Environmental Protection Agency. Mention of company or product names does not constitute endorsement by the Environmental Protection Agency.

## TABLE OF CONTENTS

	Pages
1.0 INTRODUCTION AND SUMMARY .....	1
1.1 SOME BASIC DEFINITIONS .....	1
1.2 OUTLINE OF SUPPORT DOCUMENT #1 .....	2
1.3 CONCLUSIONS AND RECOMMENDATIONS .....	3
2.0 HI-VOL MONITORING PROCEDURES .....	7
2.1 HIGH VOLUME SAMPLING .....	7
2.1.1 Factors Affecting Hi-Vol Accuracy .....	9
2.1.2 Reproducibility of Hi-Vol Measurements .....	13
2.2 PROCEDURES FOR CHEMICAL ANALYSIS OF HI-VOL SAMPLES .....	14
2.3 HI-VOL SITE LOCATION .....	16
2.4 DESCRIPTION OF APCD, NASN, AND CHESS HI-VOL PROCEDURES .....	20
2.4.1 Los Angeles County Air Pollution Control District .....	21
2.4.2 San Bernardino County APCD .....	22
2.4.3 Orange County APCD .....	23
2.4.4 Riverside County APCD .....	24
2.4.5 Ventura County APCD .....	24
2.4.6 Summary of APCD Procedures .....	25
2.4.7 NASN .....	25
2.4.8 CHESS .....	26
2.4.9 The Effect of Sampling Frequency .....	27
3.0 HI-VOL DATA FOR TOTAL SUSPENDED PARTICULATE MATTER IN THE LOS ANGELES REGION .....	29
3.1 METHODS OF DATA ANALYSIS .....	29
3.2 COMPARISON OF APCD, NASN, AND CHESS HI-VOL DATA .....	35
3.3 FREQUENCY PLOTS FOR REPRESENTATIVE APCD STATIONS .....	43
3.4 HI-VOL LEVELS IN THE METROPOLITAN LOS ANGELES AIR QUALITY CONTROL REGION: ANNUAL GEOMETRIC MEANS FOR BASE YEAR 1972 .....	57

## TABLE OF CONTENTS - continued

		Pages
3.5	HI-VOL LEVELS IN THE METROPOLITAN LOS ANGELES AIR QUALITY CONTROL REGION: EXPECTED MAXIMAL 24 HOUR LEVELS FOR THE BASE YEAR 1972 .....	62
	3.5.1 Seasonal Pattern of Total Particulate Concentrations .....	72
	3.5.2 Analysis of Recent Particulate Episodes	73
4.0	CHARACTERIZATION OF HI-VOL LEVELS IN THE METROPOLITAN LOS ANGELES AIR QUALITY CONTROL REGION .....	79
	REFERENCES .....	83
	APPENDIX A .....	87

# LIST OF TABLES

	Pages
2-1 ADDRESSES OF COUNTY APCD HI-VOL SITES IN THE LOS ANGELES REGION .....	18
2-2 ADDRESSES OF NASN HI-VOL SITES IN THE LOS ANGELES REGION .....	19
2-3 ADDRESSES OF CHESS HI-VOL SITES IN THE LOS ANGELES REGION .....	20
2-4 STATISTICAL ERROR OF APCD, NASN, AND CHESS MONITORING PROGRAMS .....	27
3-1 NATIONAL AMBIENT AIR QUALITY STANDARDS FOR PARTICULATES .....	31
3-2 HI-VOL <sub>3</sub> ANNUAL GEOMETRIC MEANS FOR COUNTY APCD STATIONS ( $\mu\text{g}/\text{m}^3$ ) .....	36
3-3 HI-VOL ANNUAL GEOMETRIC MEANS FOR NASN STATIONS .....	37
3-4 HI-VOL ANNUAL GEOMETRIC MEANS FOR CHESS STATIONS .....	38
3-5 "t" TEST FOR EQUIVALENCE OF APCD AND NASN HI-VOL. DATA .	40
3-6 STATISTICAL PARAMETERS FOR HI-VOL DISTRIBUTIONS AT TWELVE LOS ANGELES REGION SITES, 1972 .....	54
3-7 COMPARISON OF HI-VOL ANNUAL GEOMETRIC MEANS FROM FREQUENCY DISTRIBUTIONS TO PAST MONITORING HISTORY ....	58
3-8 YEARLY MAXIMAL HI-VOL LEVELS IN THE LOS ANGELES REGION.	70
3-9 COMPARISON OF CALCULATED 24 HOUR MAXIMA TO AVERAGE YEARLY MAXIMA FROM 1969-1973 .....	71
3-10 PARTICULATE EPISODES IN THE WEST-CENTRAL BASIN DURING THE 1970's .....	74
3-11 PARTICULATE EPISODES IN THE SAN BERNARDINO AREA 1971 to 1973 .....	77
4-1 CHARACTERISTIC MAXIMAL HI-VOL LEVELS FOR THREE SUBAREAS OF THE METROPOLITAN LOS ANGELES AIR QUALITY CONTROL REGION (FOR BASE YEAR 1972) .....	81



## LIST OF FIGURES

	Pages
1-1 Sub-Areas for Control Strategy Formulation .....	5
2-1 Hi-Vol Sampler .....	8
2-2 Statistical Accuracy of Geometric Mean As A Function of Sampling Frequency .....	28
3-1 Typical Hi-Vol Frequency Distribution San Bernardino (July 1971 - June 1973) .....	32
3-2 Hi-Vol Cumulative Frequency Plot on Log Probability Paper .....	33
3-3 Log-Probability Cumulative Frequency Plots of APCD Data (July 1971 - June 1973) .....	44
3-4 Expected Annual Geometric Mean Hi-Vol Levels for the 1972 Base Year .....	60
3-5 Expected Annual Geometric Means for Suspended Particulate Matter in the Los Angeles Basin for Base Period 1972 (NASN and CHESS Data) .....	61
3-6 Expected 24-Hour Max. Hi-Vol Levels for the 1972 Base Year (for the present APCD Monitoring Frequency) .....	63
3-7 Suspended Particulate Quarterly Geometric Means ( $\mu\text{g}/\text{m}^3$ ) .....	64
4-1 Sub-Areas for Control Strategy Formulation .....	82

## 1.0 INTRODUCTION AND SUMMARY

Under contract to the Environmental Protection Agency, TRW Environmental Services has developed a particulate implementation plan for the Metropolitan Los Angeles Air Quality Control Region. Specifically, TRW has investigated strategies for approaching and achieving the National Ambient Air Quality Standards (NAAQS) for particulates in the Los Angeles Region. The present report is the first of four technical support documents associated with the project. This initial support document reviews the Hi-Vol sampling method for particulates, evaluates actual monitoring procedures in the Los Angeles Region, statistically analyzes existing aerometric data, and characterizes total suspended particulate levels for the Los Angeles Region.

### 1.1 SOME BASIC DEFINITIONS

Throughout this study, the terms, suspended particulates and aerosol, are used interchangeably. Both refer to suspended particles (liquid or solid) in air. The basic measurement unit used herein is total mass concentration ( $\mu\text{g}/\text{m}^3$ ); thus, the details of the particle size distribution are usually neglected.

A distinction is sometimes made here between ambient total suspended particulates and Hi-Vol total suspended particulates. The former refers to the total particulate mass loading in the atmosphere, while the latter refers to the mass loading which is measured by a Hi-Vol monitor. As discussed in Section 2.1.1, Hi-Vol measurements are sometimes not fully representative of ambient conditions.

One very important distinction that is made involves the concept of primary particulates versus secondary particulates, (or alternatively primary aerosol versus secondary aerosol).<sup>\*</sup> Primary aerosols are directly emitted; they enter the atmosphere as particles. Secondary particulates are formed in the atmosphere from the conversion of gases to particles by chemical reaction processes. The four principal types of secondary aerosol are sulfate ( $\text{SO}_4^{=}$ ), nitrate ( $\text{NO}_3^-$ ), ammonium ( $\text{NH}_4^+$ ), and secondary organics. The gaseous precursors of these aerosols are sulfur dioxide ( $\text{SO}_2$ ), nitrogen oxides ( $\text{NO}_x$ ), ammonia ( $\text{NH}_3$ ), and reactive hydrocarbons (RHC), respectively.

## 1.2 OUTLINE OF SUPPORT DOCUMENT #1

This report is organized into four sections. The present section serves as a general introduction and provides a summary of major findings and conclusions. Section 2 reviews monitoring procedures with the objective of establishing error bounds for the aerometric data base. Section 2 begins with a general review of the Hi-Vol sampling method for particulates.<sup>\*\*</sup> Then, the chemical analysis techniques routinely used with Hi-Vol samples are briefly discussed. Finally, the location of measuring sites within the Los Angeles Region and the specific monitoring practices of various agencies are described and evaluated.

Section 3 summarizes the actual Hi-Vol data base for the Los Angeles Region. The section begins with a brief discussion of statistical methods. Then, data from the APCD (County Air Pollution Control Districts), NASN (National Air Surveillance Network), and CHESS (Community Health Environmental Surveillance System) monitoring programs are presented and

<sup>\*</sup> The reader should not confuse this concept with the terms "primary" and "secondary" standards. The national primary and secondary standards refer to the different target levels for total particulate air quality, i.e., each standard applies to the sum of both primary and secondary aerosol.

<sup>\*\*</sup> The NAAQS for total suspended particulates specify the Hi-Vol technique as the appropriate sampling method.

compared. Hi-Vol frequency distributions are given for several stations, and expected annual geometric means (AGM's) and yearly 24 hour maxima are computed for the 1972 base year. Maps are constructed showing the spatial pattern of Hi-Vol AGM's and 24 hour maxima. To help provide a better understanding of the data, the meteorology associated with particularly high Hi-Vol levels is investigated.

Section 4 synthesizes the data to arrive at an overall characterization of Hi-Vol levels in the Los Angeles Region. The particulate spatial pattern (or lack of pattern) is discussed, and the maximal levels for various subregions are established to serve as targets for control strategy reductions.

### 1.3 CONCLUSIONS AND RECOMMENDATIONS

The analysis of Hi-Vol air monitoring data in the Los Angeles Region has resulted in the following conclusions and recommendations:

#### Conclusions

- Hi-Vol filters generally provide a very efficient means of entrapping samples of suspended particulate matter. However, samples are not always fully representative of ambient conditions due to loss of volatile liquids (such as water or organics) and/or gain of adsorbed gaseous pollutants (such as SO<sub>2</sub> or NO<sub>2</sub>). Hi-Vol data do not provide information on particle size distribution.
- Specific monitoring practices can significantly affect Hi-Vol accuracy. Substantially different practices can produce discrepancies on the order of 20%. The reproducibility of individual Hi-Vol measurements using equivalent procedures is around 5% under field conditions.
- The APCD, NASN, and CHESS monitoring programs generally follow the same sampling guidelines. However, deviations exist in certain specific practices such as sampling frequency, calibration procedures, flow rate, analysis delay time, and location. In some cases, these deviations are enough to cause significant differences in measured values.
- The 6 CHESS sites in the Los Angeles Region are located in quiet suburban areas. Measurements from CHESS monitors are generally around 20-40% lower than those from APCD and NASN sites which tend to be in prime exposure urban areas.

- The western part of the basin, near the coast, tends to experience the highest Hi-Vol levels during the winter season. In the eastern part of the basin, the summer/fall period tends to yield the highest Hi-Vol readings. These findings appear to be consistent with the hypothesis that primary particulate (directly emitted) is relatively more important in the western basin while secondary particulate (formed by atmospheric reactions) is relatively more important in the eastern areas.
- The federal secondary air quality standards are exceeded at all monitoring sites which were analyzed. Ventura and Santa Barbara Counties as well as the coastal areas of Los Angeles and Orange Counties typically yield Hi-Vol levels at just about the federal primary standards. Riverside and San Bernardino Counties and the inland areas of Los Angeles and Orange Counties yield Hi-Vol values up to more than twice the federal primary standards.
- In the inland areas of greatest particulate pollution, no general pattern can be discerned in Hi-Vol measurements with the present level of spatial resolution. The location of each monitoring site with respect to local sources appears to be important; this effect produces fluctuations so that no general pattern emerges.

#### Recommendations

- It would be useful to perform experimental studies to gain further information on the differences between Hi-Vol measured particulates and actual ambient particulates. These studies should focus on quantifying the loss of water and volatile organics and the gain of adsorbed gaseous pollutants under actual field conditions.
- A further standardization of Hi-Vol procedures among various monitoring programs is recommended. The establishment of guidelines for site location with respect to local sources is particularly important. This standardization could afford more meaningful comparisons of data from alternative monitoring programs.
- The establishment of an ongoing program of data analysis would allow better use to be made of the considerable quantities of Hi-Vol data being generated in the Los Angeles Region. Such a program should continually examine trends in total suspended particulate levels and in specific aerosol constituents and should compare these results with the expected impact of source growth and emission control policy.
- For the purpose of control strategy formulation, at least three general sub-areas of the Los Angeles Region have been identified (see Figure 1-1). Each sub-area experiences different maximal annual average Hi-Vol levels (the maximum among the monitoring sites in those areas). The sub-areas are: A. Ventura and Santa Barbara Counties (presently just above the national primary standard), B. The 4 County Area except Area C (presently at about twice the national primary standard), and C. The

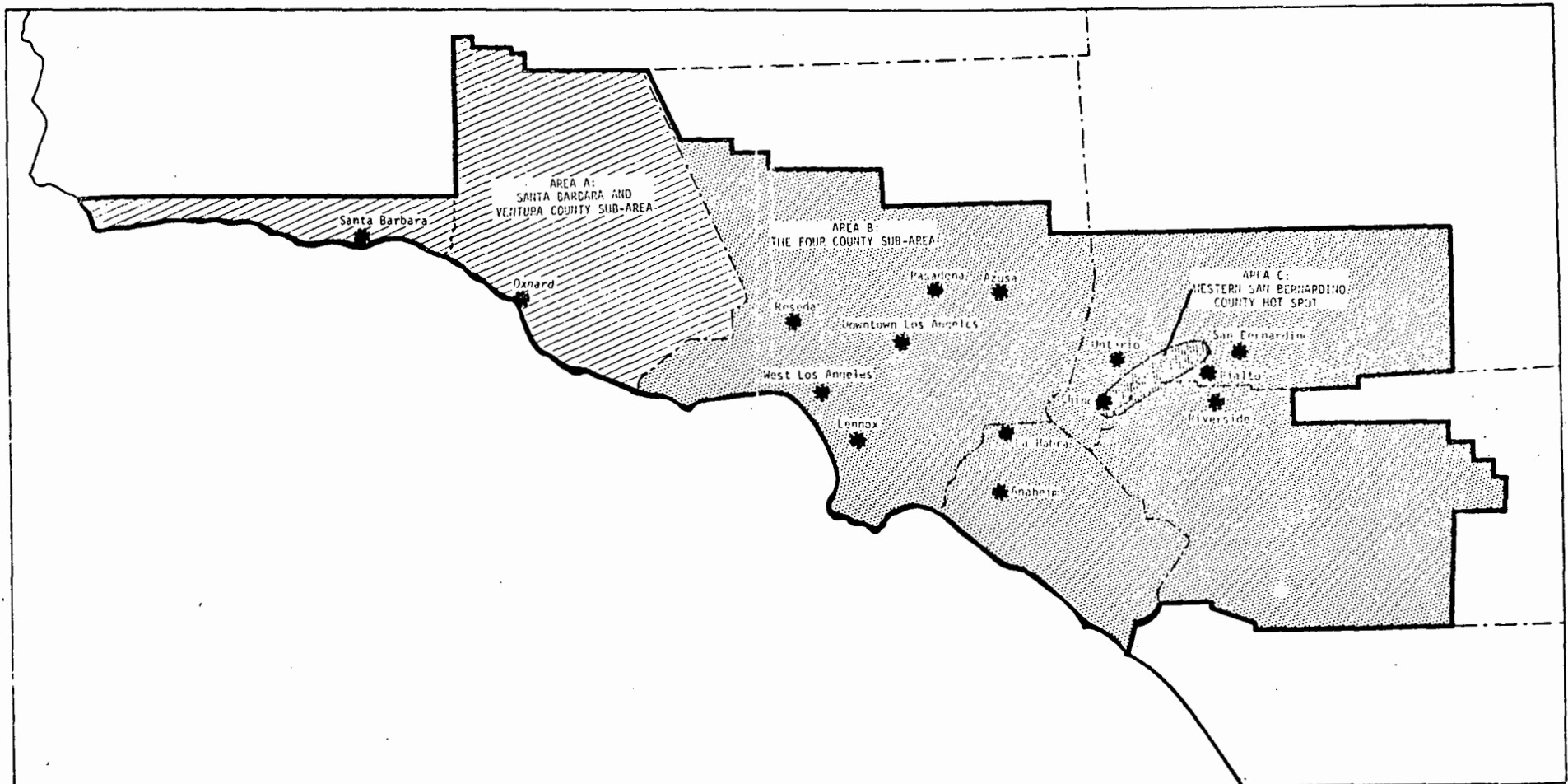


Figure 1-1 Sub-Areas for Control Strategy Formulation

Western San Bernardino County Hot-Spot (presently at about three times the national primary standard). The formulation and evaluation of control strategies should make distinctions among these three areas.

## 2.0 HI-VOL MONITORING PROCEDURES

In order to draw conclusions from Hi-Vol monitoring data, it is important to know how the measurements were made and what the data represent. This section attempts to establish the accuracy of the data base for the Los Angeles Region by reviewing Hi-Vol sampling procedures in general and the practices of Los Angeles monitoring programs in particular.

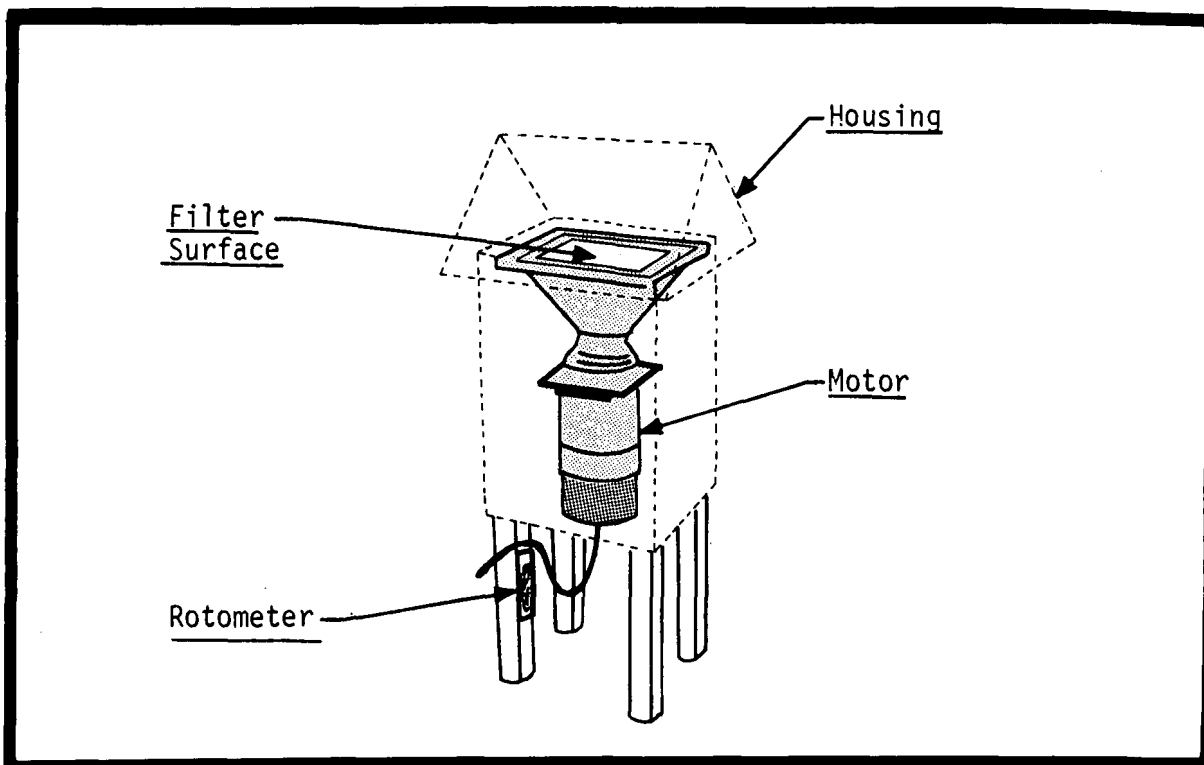
Section 2.1 describes standard Hi-Vol measurement procedures and discusses factors which affect the accuracy and reproducibility of results. Section 2.2 briefly reviews chemical-analytical methods commonly performed on Hi-Vol samples. In Section 2.3, the principles of Hi-Vol site location are described and the specific locations of sites in the Los Angeles Region are reported. Finally, Section 2.4 describes and briefly evaluates the specific procedures of three Hi-Vol monitoring data bases for the Los Angeles Region: the County APCD, NASN, and CHESS programs.

### 2.1 HIGH VOLUME SAMPLING

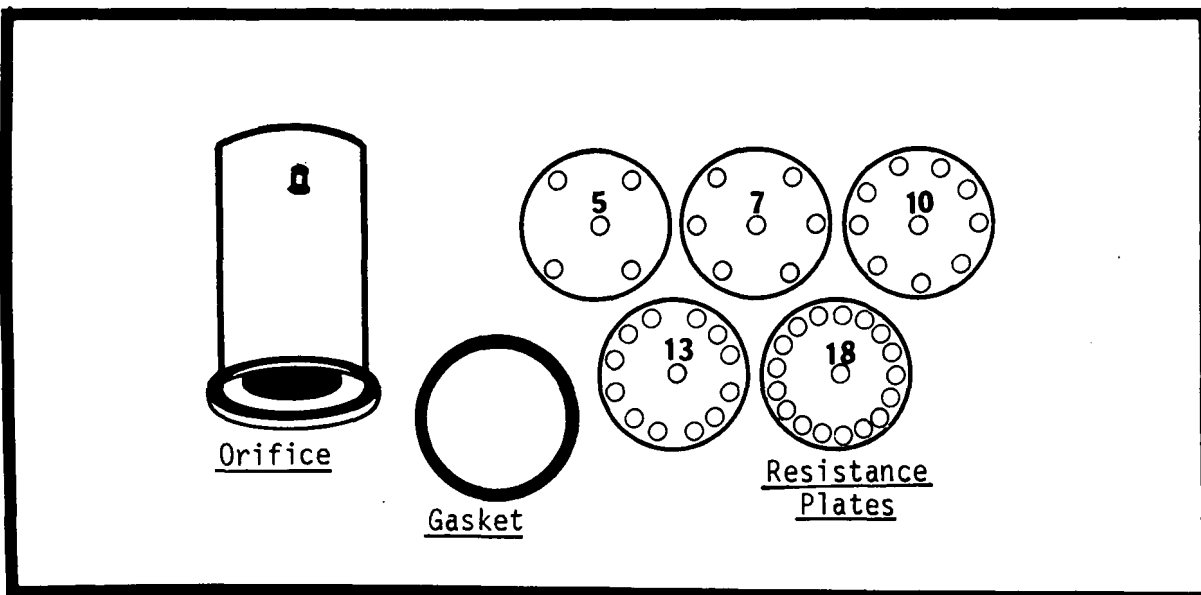
The National Ambient Air Quality Standard for suspended particulates specifies Hi-Vol sampling as the appropriate monitoring method. The official reference procedure is published in the Federal Register Vol. 36, No. 84, Part II, 30 April 1971 (see Appendix A). Comprehensive descriptions of this method are found in References [1] and [2].

A Hi-Vol sampler (illustrated in Figure 2.1) consists of a covered housing, a filter-holder assembly, a vacuum-sweeper motor, and a flow meter. The housing is designed to protect the filter surface from weather and fallout material and to minimize collection of particles larger than 100 microns, (these drop out before reaching the filter surface). Filter





Hi Volume Sampler and Shelter



Orifice Calibration Unit

Figure 2-1  
Hi-Vol Sampler

pads are usually of the glass fiber type to minimize resistance to air flow; however, cellulose pads are also used, in particular for some chemical analyses (such as for certain metals) where high background is a problem with glass pads. The vacuum motor is typically designed to pump 1.1 to 1.7 m<sup>3</sup>/min and is capable of continuous operation without significant drop in flow due to particulate buildup on the filter pad. The flowmeter measures a small but constant fraction of the blower discharge.

Sampling with a Hi-Vol consists of weighing a preconditioned (temperature and humidity) filter pad, drawing air through it for a given time (usually 24 hours), recording the initial and final flow rates and times, and reweighing the pad (again after conditioning to set humidity and temperature). The average concentration of particulate matter is calculated by dividing the weight gain of the filter pad by the total volume of air sampled.

#### 2.1.1 Factors Affecting Hi-Vol Accuracy

Hi-Vol filters generally provide a very efficient means of entrapping samples of suspended particulates. However, the accuracy of Hi-Vol data (as representative of total aerosol mass) depends on other factors besides entrapment efficiency. Volatile, liquid aerosols can be lost in the sampling and analysis procedures, leading to an underestimation of true aerosol mass. Gaseous pollutants can be adsorbed on the filter, leading to an overestimate. Measurement techniques of the deposited mass and air volume are also potential sources for inaccuracy. The factors which affect Hi-Vol accuracy depend on specific monitoring practices. Several key factors will be discussed below.

### Choice of Filter Media

Routine Hi-Vol samples are usually collected on glass fiber filters. The advantages are: (i) low flow resistance while maintaining high collection efficiency, (ii) less tendency to plug under heavy loading than cellulose filters, and (iii) low background for organic material. Some disadvantages are surface alkalinity (which may increase adsorption of acid gases) and often high metals background.

Fiber filters tend to entrap large particles ( $>1$  Micron) by mechanical action and small ones ( $<.1$  Micron) by Brownian Motion. A minimum of collection efficiency is observed in the 0.1 to 1 Micron range. For this reason, and because significant portions of the urban aerosol fall in the .1 to 1 Micron range [55] the EPA reference procedure calls for filter standardization by a DOP smoke test\* to achieve a 99% collection efficiency at a nominal particle diameter of .3 Micron [10]. This level of collection (in the range of minimal efficiency) insures an extremely high overall filter efficiency [9].

The accuracy of glass fiber filters is somewhat dependent on the chemical nature of the test atmosphere. There may be some alkalinity associated with glass, and acid gases such as  $\text{SO}_2$  and  $\text{NO}_2$ , and organic acids may be adsorbed along with particulate matter [11], [12], [13], [14]. An apparent increase in loading may then occur. Acid washed filters are therefore preferred (for example Gelman type A pH6.5 - 7.0). Efficiency of collection on glass (or other fiber filters) is also a function of particle adherence properties. Dry particles are not retained as well as

---

\* Di-Octyl Phthalate smoke is a synthetic organic material which can be used to form a laboratory aerosol with nearly uniform spherical size.

sticky aerosols and those formed under high humidity [12], [15]. Water, oily, or sooty material may also clog filters and lead to reduced flow rate and averaging time errors.

#### Equilibrating Procedures

To obtain reproducible results from Hi-Vol samples, weighing of filter pads must be done after conditioning at controlled humidity and temperature. Relative humidity (RH) of 50% and temperature of 20°C are chosen as the standards for weighing, since most particulate samples lose less than 1% of their weight between equilibrations at 50% and zero RH [17]. Particulate matter from both urban and rural atmosphere can be hygroscopic and adsorb water as humidity increases. Some water may be held even at low relative humidities, perhaps bound to organic acids in surface layers of a particle. [18].

One attempt to measure the amount of water associated with an aerosol as it exists in the atmosphere showed around 10% by weight [15]. This would only represent the water associated with the particulate matter at the end of the sampling period, not the amount that would remain if the sample had been equilibrated at 50% RH [18]. Measurements in situ suggest that the water fraction varies from essentially zero under dry desert conditions to 30-40% under light smog in Los Angeles [16]. It seems, however, that ordinary equilibrated Hi-Vol data reflect only small amounts of weighed water.

Another source of inaccuracy is volatile organic material associated with the particulate matter which may evaporate during the time lag between sampling and weighing [20], [21]. The effect is most pronounced for samples high in organic material. One study showed about 10% of original organic material was lost during the 12 days between sampling

and weighing [5], [22]. A minimum in delay between sampling and weighing is necessary to avoid this source of bias, although the effect on total weight should not exceed a percent or two.

#### Flow Measurement Techniques

Precision of Hi-Vol data depends heavily upon flow rate measurements. Average flow rate is calculated either from an average of initial and final rotometer readings or from an integrated average on instruments equipped with a continuous recorder. The reproducibility of manual rotometer readings [5] is estimated at about  $\pm 2.5\%$ .

In the manual rotometer method, nonlinear flow rates may result in up to 8% bias [6, 7] of the average concentration. Continuous measurement reduces this bias. Accuracy of the calculated average particulate load for the sampling period is also affected by large differences in initial and final flow rate. A heavy loading (i.e. moisture, oily material, or a high episode) at the start of the sampling period may significantly reduce flow rate for the remainder of the period. More than a 20% variation in flow rate and a fourfold variation in concentration during the sampling period are necessary, however, to affect the average by more than a few percent. As mentioned under calibration, pressure and temperature must be similar during sampling and calibration. Again, however, extremes are necessary in order to affect measurement by more than a few percent.

#### Calibration Procedures

The usual procedure for calibration of the flowmeter is with a set of orifice plates and a manometer. The plates themselves are calibrated against a positive displacement flowmeter. A series of air flows, measured by the pressure drop across the orifice calibration unit, are

recorded against rotometer readings at the blower discharge. A calibration curve of rotometer readings vs flow rate is then prepared.

Samplers are calibrated when first set up and usually after replacement of brushes in the motor. The frequency of calibration then depends on such factors as motor age and flow rate during operation. Orifice plates are affected mainly by mechanical wear but are only as good as the original calibration against a flowmeter. This precision is estimated at about  $\pm 4\%$  [3]. If the barometric pressure and/or temperature at the time of calibration of a sampler are different than those when the orifice plates were calibrated, the observed flow rates must be corrected [4].

#### Weight and Time Measurements

Elapsed time is to be measured to approximately  $\pm 4$  min in 24 hours, according to the reference method [8]. Even four times this uncertainty would result in less than  $\pm 1\%$  error in the 24 hour average. Although weights are recorded to the nearest 0.1 mg, actual reproducibility of clean filters is approximately  $\pm 1.0$  mg and exposed filters  $\pm 1.7$  mg [5]. The resulting uncertainty of about  $\pm 2$  mg for a  $1600 \text{ m}^3$  sample containing  $100 \mu\text{g}/\text{m}^3$  would be  $\pm 1.25\%$ , providing samples are weighed at controlled humidity and temperature.

#### 2.1.2 Reproducibility of Hi-Vol Measurements

Several investigators have attempted to estimate the overall reproducibility of Hi-Vol measurements under a variety of conditions. The standard deviation of an individual measurement has been estimated at 3 to 15%, depending on total particulate loading [2]. Lee [23] found that 95% of 450 duplicate Hi-Vols in England were within 5% of each other. Clements [24] compared duplicate Hi-Vols at NASN sites and found an

average precision of about 4.5% (standard deviation of 6%) for routine operation. Precision in this study was less at high loadings, although no difference between filter brands was found. Faoro [25] found duplicate Hi-Vols to have an average deviation of 3% in EPA tests. Cohen [26] observed duplicate Hi-Vols to reproduce within 1% under carefully controlled flow rates. Sixty cfm runs, however, gave 4% lower results than 40 cfm runs. The authors suggest that higher flow rates sweep away more of the smaller particles which might be trapped by Brownian motion at lower flow rates. McKee et. al [61] found a single analysis standard deviation of 3.0% and interlaboratory standard deviation of 3.7% in controlled collaborative tests of the Hi-Vol method. These studies suggest that the precision (1 standard deviation) of an individual Hi-Vol measurement varies from about 2% under carefully controlled conditions to about 6% under actual field conditions.

## 2.2 PROCEDURES FOR CHEMICAL ANALYSIS OF HI-VOL SAMPLES

After Hi-Vol samples have been weighed to determine total aerosol mass, the filters can be aliquoted (divided up) for analysis of metals, inorganic ions, and/or organic material. The procedures used for chemical analysis of each type of material are outlined below.

### Metals

To determine the amount of various metals present, about 25% of the filter pad is carried through one of two possible procedures:

- A) The aliquote is refluxed about 90 minutes in 35% nitric acid, or
- B) The filter aliquote is moistened with  $\text{HNO}_3$ , evaporated to dryness, ashed at  $500^\circ\text{C}$  for 30 minutes, and redissolved in nitric acid.

Analysis for individual metals (lead being the major metal of interest for this project) is done on the resulting  $\text{HNO}_3$  solution by atomic adsorption or spectrography [1]. Lead has also been determined spectrophotometrically using colored dithizone chelate extracted into chloroform. Precision of an individual lead measurement in the above procedure is 4 to 10% [27], [29]. For lead, the ash procedure, (B), may show losses due to volatilization if temperature and time exceed the specifications; low apparent lead values may thus result.

#### Inorganic Ions

About 8% of the exposed filter is refluxed with deionized water for 90 minutes to determine the concentration of inorganic ions. Sulfate ( $\text{SO}_4^{=}$ ) is determined from a portion of this extract by a turbidimetric procedure [28] using  $\text{BaCl}_2$  to form a suspended precipitate of  $\text{BaSO}_4$  (barium sulfate). Precision of this method alone is about 10%.

Nitrate ( $\text{NO}_3^-$ ) is measured spectrophotometrically by either the 2-4 xyleneol procedure [31], or the Brucine alkaloid procedure [32]. Precision estimates for these procedures are about 8% and 7%, respectively.

The water extraction procedure is probably very efficient for  $\text{NO}_3^-$ , since all common nitrates are highly water soluble.  $\text{SO}_4^{=}$  may not be completely extracted, however, since less soluble compounds such as  $\text{PbSO}_4$  might be present in suspended particulate matter [30].

#### Organic Material

For organic analysis, about 50% of the filter pad is refluxed in benzene for 6-8 hours [1]. The solvent is then removed at atmospheric pressure or under vacuum, and the residue is weighed. Cyclohexane [33] may



also be used for extraction of less polar organic compounds. Tetrahydrofuran has been used to extract even larger fractions of the total organic material present than is extracted by benzene [34].

The accuracy of benzene extraction depends on the nature and total amount of organic material present [19]. Extraction efficiency is probably greater for directly emitted organic particulates than for the organic aerosol formed in the atmosphere [40], [60]. It is probable that more than one-half of the highly oxidized secondary organic aerosol material is not extracted with benzene [40].

Benzene soluble fractions may also yield a low estimate of organics because some of the extracted organics may be evaporated with the solvent in the procedure, [35]. There is also the problem, mentioned earlier, that volatile organic material may be lost between the time of sampling and extraction, [20], [21].

### 2.3 HI-VOL SITE LOCATION

Hi-Vol monitoring results are sensitive to the details of sampling location. Several locational factors can affect the measurements. For one, since larger particles have a lower probability of being transported to higher elevations, total particulate loading tends to decrease with height, [41]. For this reason, and because human exposure is mostly associated with air quality near ground level, recommended procedures call for Hi-Vol sampling at 50 feet or less above ground, [42]. Other sampling procedures concerned with Hi-Vol location are listed below:

- Samples should be located away from local sources and not be subject to wind or eddy distortions.

- Pairs of high-vols should be several feet apart in order to avoid sampling each other's exhaust [43]. The exhaust should also be two feet or more off of the ground to avoid stirring up ground dust, etc.
- A sampler should be located away from the side of a building or wall so that representative air will not be inhibited from passing over the sampler, [44].

This report will consider Hi-Vol data from three main sources: County APCD's (Air Pollution Control Districts), NASN (National Air Sampling Network), and CHESS (Community Health Environmental Surveillance System). The location of the sampling sites for each of these sources are listed in Tables 2-1, 2-2, and 2-3, respectively. The reader is referred to Figures 3-4 and 3-5 for an illustration of the position of the stations within the basin. The specifics of the sample locations will be discussed in the next section which describes the Hi-Vol procedures used by the APCD's, NASN, and CHESS.

TABLE 2-1  
ADDRESSES OF COUNTY APCD HI-VOL SITES IN THE LOS ANGELES REGION

<u>COUNTY</u>	<u>NAME</u>	<u>ADDRESS</u>
Los Angeles	Central Los Angeles	434 South San Pedro Street Los Angeles, California
	Lennox	11408 La Cienega Boulevard Lennox, California
	West Los Angeles	2351 Westwood Boulevard West Los Angeles, California
	West San Fernando Valley (Reseda)	18330 Gault Street Reseda, California
	Azusa	803 Loren Avenue Azusa, California
	Pasadena	1196 East Walnut Street Pasadena, California

<u>COUNTY</u>	<u>NAME</u>	<u>ADDRESS</u>
Orange	Anaheim	1010 South Harbor Boulevard Anaheim, California
	La Habra	621 West Lambert Road La Habra, California
	Costa Mesa	2300 Placential Avenue Costa Mesa, California
San Bernardino	San Bernardino	172 West 3rd Street San Bernardino, California
	Ontario	Airport
	Redlands	216 Brookside Avenue Redlands, California
	Rialto	Airport
	Chino	Airport
	Fontana	8384 Cypress Fontana, California
	Upland	201 North 1st Avenue Upland, California
Riverside	Riverside	3575 11th Street Mall Riverside, California (1970-1972) and 5888 Mission Boulevard Rubidoux, California (1972-1974)
Ventura	Oxnard	242 West 2nd Street Oxnard, California
	Ojai	401 Signal Hill Street Ojai, California
	Santa Barbara	4440 Calle Real Santa Barbara, California
	Ventura	3147 Loma Vista Road Ventura, California
	Thousand Oaks	Firehouse-Erbs Road Thousand Oaks, California
	Moore Park	Moore Park College Moore Park, California
	Port Hueneme	Environmental Data Branch Civil Engr. Lab. Port Hueneme, California
	Camarillo	70 Palm Drive Camarillo, California

TABLE 2-2  
ADDRESSES OF NASN HI-VOL SITES IN THE LOS ANGELES REGION

<u>NAME</u>	<u>ADDRESS</u>
Anaheim	1010 South Harbor Boulevard Anaheim, California
Burbank	228 West Palm Avenue Burbank, California
Glendale	145 North Howard Street Glendale, California
Long Beach	2655 Pine Avenue Long Beach, California
Los Angeles	434 South San Pedro Street Los Angeles, California
Ontario	Airport
Pasadena	862 East Valla Street Pasadena, California
Riverside	3575 11th Street Mall Riverside, California
San Bernardino	172 West 3rd Street San Bernardino, California
Santa Ana	645 North Ross Street Santa Ana, California
Torrance	2300 Carson Street Torrance, California

TABLE 2-3  
ADDRESSES OF CHESS HI-VOL SITES IN THE LOS ANGELES REGION

<u>SITE NAME</u>	<u>SITE NUMBER</u>	<u>ADDRESS</u>
Santa Monica	0821	2526 6th Avenue Santa Monica, Calif. 90405
Thousand Oaks	0822	1135 Windsor Drive Thousand Oaks, Calif. 91360
Anaheim	0831	West Cerritos Avenue & Euclid Avenue, S. Anaheim, California 92805
Garden Grove	0832	12181 West Street Garden Grove, Calif. 92640
Glendora	0841	Live Oak & Whitcomb Street Glendora, California 91740
West Covina	0842	820 Phillips West Covina, Calif. 91790

#### 2.4 DESCRIPTION OF APCD, NASN, AND CHESS HI-VOL PROCEDURES

This section outlines the specific monitoring practices of agencies which generate Hi-Vol data for the Metropolitan Los Angeles Air Quality Control Region. Separate descriptions are presented for each of the County APCD's programs and for the federal NASN and CHESS programs. Later parts of this report will employ data from all of these sources. However, heavy emphasis will be placed on the County APCD aerometric data. The reasons for this emphasis will be discussed in Section 3.1; reference will be made there to the monitoring procedures described below.

#### 2.4.1 Los Angeles County Air Pollution Control District

Duplicate Staplex\* Hi-Vol samplers are operated at all Los Angeles APCD sites, with flow rates of 35-45 cfm, [45]. Samplers are calibrated every few months when brushes are replaced or motors serviced. A Meriam Laminar Flow Element is currently used for calibration. In general, samplers tend to produce results within  $\pm 10\%$  or better upon recalibration after a year's use, although linearity of flow with rotometer readings tends to decrease as a sampler ages.

The Los Angeles APCD uses Gelman type A glass fiber filters, (non-acid washed). Until around 1971, samples were equilibrated to 50% RH at 50°C (the equilibration chamber would not maintain humidity at a lower temperature). Since 1971, samples have been equilibrated at 50% RH and 20°C for 24 hours. An individual sample has a 1 to 5 day delay from time of sampling to arrival at Los Angeles, and is then processed within a day or two. Every thirteenth filter pad from a box of 100 is taken as a blank for chemical analysis and inspection.  $\text{SO}_4^{2-}$  and  $\text{NO}_3^-$  are analyzed by the turbidimetric and 2-4 xyleneol procedures, respectively. Pb was analyzed according to high temperature ash method until 1970, when the concentrated  $\text{HNO}_3$  extraction method was introduced. Internal laboratory correlation of results of the two methods was conducted and data for 1970 to the present are reported on a basis consistent with earlier data, conforming to specifications of the California ARB. Organic material on High-Vol samples is not routinely analyzed at this time.

---

\*Staplex Company, Brooklyn, New York

Los Angeles APCD Hi-Vol data have been collected since 1965 at downtown Los Angeles, Lennox, WSFV (West San Fernando Valley-Reseda), and West Los Angeles. The former two sites were sampled on Monday and Wednesday until mid-1971, while the latter two sites were sampled on Wednesday only. From mid-1971 to the present, all stations have been operated every fifth day concurrently. Pasadena and Azusa sites were also added at the mid-1971 switch-over. The addresses of Los Angeles APCD sites are given in Table 2-1..

The sampler at downtown Los Angeles is located on the roof of APCD Headquarters Building, approximately 85 feet off the ground. "In-house" comparisons of concurrent roof and 20 foot level Hi-Vol samples suggest a 14 to 22% low bias at the 85 foot level on days of atmospheric stability. No difference was found on unstable days. The samplers at Azusa, Pasadena, and Reseda, are on roofs away from the street, but less than 20 feet off of the ground. The West Los Angeles and Lennox Station are within a few feet of ground and are set against buildings.

#### 2.4.2 San Bernardino County APCD

The San Bernardino APCD has operated Staplex samples on a 6-day cycle concurrently at several stations in basin since about 1967, [46], [44]. Samplers are calibrated with orifice plates when brushes are changed, and generally reproduce within 5-10%. Older or "slower" Hi-Vols are used at stations within the Metropolitan Los Angeles AQCR; the flow is around 40 cfm. MSA\* (non-acid washed) filter pads are used. Exposed filter pads

---

\*Mine Safety Appliance Corporation, Pittsburgh, Pennsylvania

arrive at the laboratory within five days of sampling and are held until a batch can be analyzed (up to a few weeks). Filters are equilibrated to 50% RH at 20°C. About six blanks are taken from each 100 filters. Chemical analyses for  $\text{SO}_4^{2-}$ ,  $\text{NO}_3^-$ , Pb, Fe, and organics are conducted on quarterly composites.  $\text{NO}_3^-$  is done by the Colorimetric Brucine Method [32]. Pb is analyzed by  $\text{HNO}_3$  extraction followed by atomic absorption determination.

All stations are within 20 feet of ground except downtown San Bernardino, which is on top of the County Building (about 90 feet). Addresses of the stations used in this report are given in Table 2-1.

The stations at Chino, Ontario, and Rialto, are at airports and are generally in open areas close to the ground. Positions were chosen to avoid direct aircraft emissions, however. At Ontario, the NASN sampler is within two feet of APCD sampler, and sits very close to the ground. The station at Redlands is against a wall at the back of a building, somewhat restricting free air flow.

#### 2.4.3 Orange County APCD

General Metal Samplers\* have been operated at Anaheim since 1970 and La Habra since 1971, [47]. Costa Mesa was sampled starting in 1972. Samplers are run every four days concurrently. Orifice plate calibration is done at about two month intervals when motor brushes are replaced. Samplers are operated at line voltage, giving flow rates of about 60 cfm. Comparison of a standard Hi-Vol with an Anderson size fractionating Hi-Vol operated at 20 CFM showed larger collection efficiency at the lower flow rate.

---

\*General Metal Company, Cleveland, Ohio



Gelman Type A non-acid washed filters are used. The standard humidity and temperature equilibration procedure is followed. Some chemical analyses for  $\text{SO}_4$  and  $\text{NO}_3^-$  were conducted intermittently in 1969 and 1970, but no continuous data for these ions are available. Pb has been analyzed routinely on monthly composites by nitric acid extraction and atomic absorption.

The sampler at Anaheim is located atop a building behind APCD Headquarters, about 15 feet above ground. La Habra and Costa Mesa samples are on top of office trailers, about 12 feet off the ground. The addresses of the stations are found in Table 2-1.

#### 2.4.4 Riverside County APCD

Hi-Vol sampling has been conducted by the Riverside APCD since February 1970. The original site at 11th Street Mall, in Riverside, was moved to the roof of APCD Headquarters at 5888 Mission Boulevard, Rubidoux, in July 1972. Since that time, sampling has been conducted every five days. Information available for this study indicates that standard procedures are followed according to [3]. Chemical analyses are not performed on Hi-Vol samples at this time.

Averaged Riverside data used later in this study have been calculated from individual samples. The 1970 and 1971 data are somewhat suspect since the months of February 1970, July 1970, April 1971, and July 1971, are missing from the record.

#### 2.4.5 Ventura County APCD

Micro samplers\* are operated every sixth day concurrently at all stations [59]. Orifice plate calibration is used. Flow rates at line voltage

---

\*Micro Biological Specialities Company, San Francisco, California

are about 50 to 60 cfm. Gelman Type A non-acid washed filters are used. Samples are weighed a few days after collection without temperature or humidity equilibration. Pb is analyzed on the monthly composite at Camerillo.

The stations at Oxnard, Ventura, and Camarillo, are atop buildings, perhaps 35 feet above ground. The sampler at Point Hueneme is closer to ground level and only about 100 yards from the ocean. High levels of hygroscopic sea salt may account for Point Hueneme reporting higher values than other stations in Ventura County.

#### 2.4.6 Summary of APCD Procedures

Since later parts of this report will emphasize APCD data, the various APCD procedures are summarized below for convenient reference:

- Sampling frequencies vary from every fourth to every sixth day in the basin. All stations to be used later in the data section operated continuously between mid-1971 and mid-1973 except Riverside, which was moved in mid-1972.
- All APCD's except Los Angeles County use orifice plate calibration.
- Flow rates are 50 to 60 cfm in Orange and Ventura Counties and 35-45 CFM in San Bernardino and Los Angeles Counties.
- Non-acid washed filter papers are used by all APCD's. Gelman Type A is used by Ventura, Los Angeles, and Orange. MSA is used by San Bernardino.
- Samples are weighed after equilibration at 20°C to 50% R.H. by all APCD's except Ventura County.
- Pb is analyzed by  $\text{HNO}_3$  extraction/atomic absorption at various stations in the basin. Los Angeles APCD reports values correlated to a previous reporting method.

#### 2.4.7 NASN

NASN (National Air Sampling Network) data are available for the stations listed in Table 2-2, and shown in Figure 3-5, [43], [52]. Samples are

taken every 15 days for a total of 24 per year. Operation of Hi-Vols is contracted to local technicians (or APCD's); filter pads (Gelman Type A, non-acid washed) are mailed to RTP in North Carolina for weighing and chemical analysis. Calibration is done intermittently when motor brushes wear out (about 450 running hours) and the sampler is sent back to North Carolina. An approximate three-week delay occurs between sampling and weighing. Other procedures are followed according to Reference [3].

NASN stations at downtown Los Angeles, Riverside, San Bernardino, Pasadena, Long Beach, and Santa Ana, are 25 to 100 feet above ground. The stations at Ontario Airport, Burbank, Glendale, Anaheim, and Torrance, are at or near ground level. The NASN stations usually represent a downtown commercial area (except Ontario Airport).

Further comments about NASN procedures will be found in Section 3 of this report.

#### 2.4.8 CHESS

CHESS (Community Health Environmental Surveillance System) data are available for 1972 and 1973 for stations listed in Table 2-3 and shown in Figure 3-5. Procedures are the same as for NASN, and the guidelines of Reference [3] are followed, [53]. Sampling is usually done every day of the year (although not all days are reported) [54], [40]. A fractionating device is used to differentiate particle size, [62], [55]. The purpose of the CHESS program is to correlate health effects with respirable size distribution. Sites in the basin are at ground level and are generally located in quiet areas and school yards, [53]. The locations could best be described as urban residential or non-commercial.

#### 2.4.9 The Effect of Sampling Frequency

The CHESS program takes more samples per year than APCD's in the Los Angeles basin, which, in turn, take more than the NASN program. Even if there were no errors in any individual Hi-Vol measurements, the calculated annual geometric mean might vary under different sampling programs.

The statistical precision of each monitoring program has been calculated according to the method of Hunt [56] using the "students t" distribution as applied to a log normal distribution. Table 2-4 lists the results. For each monitoring program, the interval about the measured AGM\* for 95% confidence of containing the "true" AGM is given. It should be noted that this is a measure of statistical precision only, not measuring error. As expected, the higher the sampling frequency the better the statistical accuracy. Also, it can be noted that the greater the geometric standard deviation,  $s_g$ , the lower the statistical accuracy for given sampling frequency. These general effects are shown in Figure 2-2.

TABLE 2-4. STATISTICAL ERROR OF APCD, NASN,  
AND CHESS MONITORING PROGRAMS

<u>Data Source</u>	<u>Approx. <math>s_g</math></u>	<u>#Samples Year</u>	<u>Interval About Measured AGM for 95% Confidence (as % of AGM)</u>
L.A. APCD	1.5	70	± 9%
Orange APCD	1.5	90	± 7%
S.B. APCD	1.8	60	± 14%
Riverside APCD	1.6	60	± 12%
NASN	1.4 - 1.8	24	± 13 - 25%
CHESS	1.5 - 1.7	230+	± 1 - 5%

\* Annual Geometric Mean

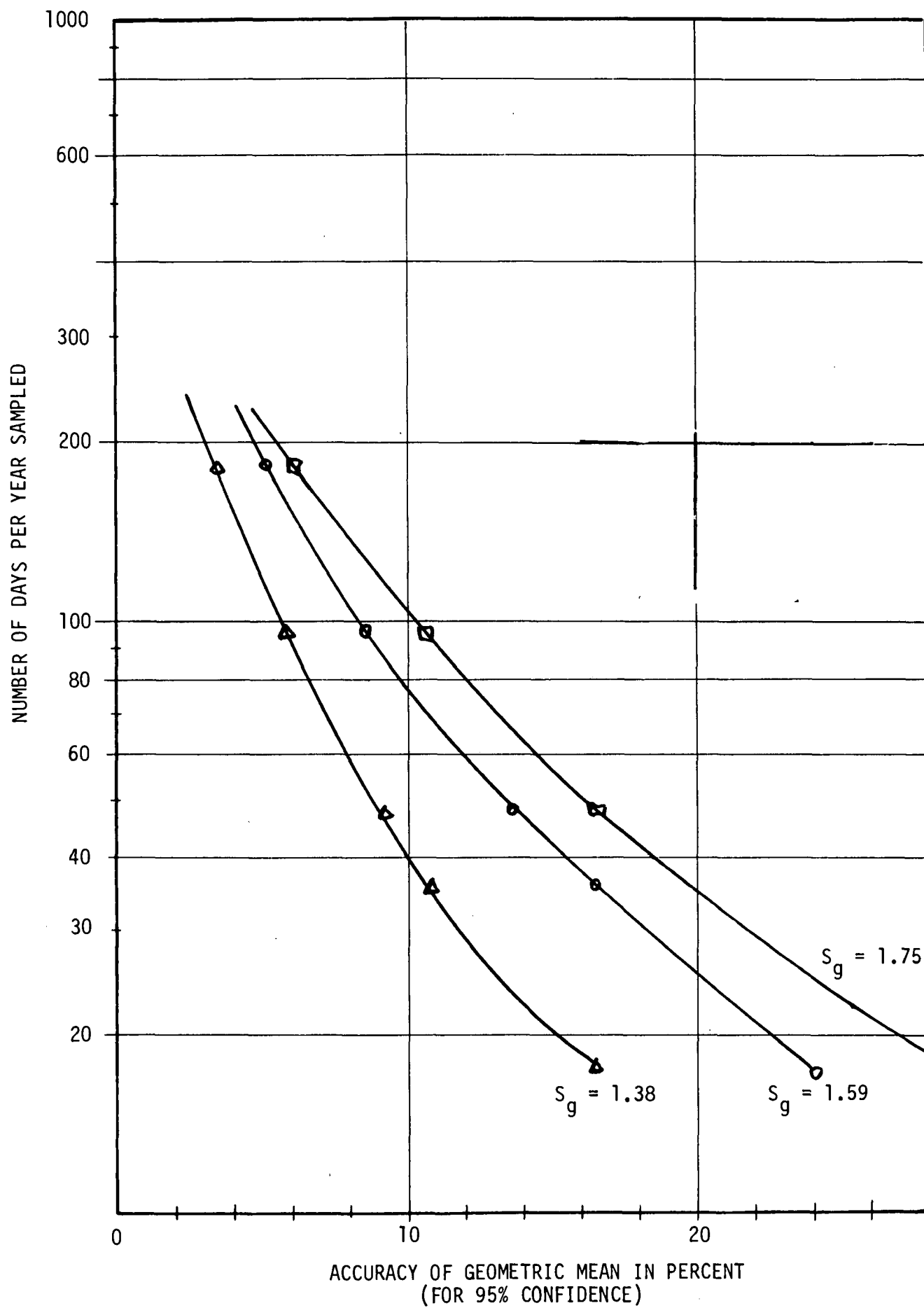


Figure 2-2 Statistical Accuracy of Geometric Mean As A Function of Sampling Frequency

### 3.0 HI-VOL DATA FOR TOTAL SUSPENDED PARTICULATE MATTER IN THE LOS ANGELES REGION

The present section presents and analyzes Hi-Vol data for the Metropolitan Los Angeles Air Quality Control Region. The data are from 28 County APCD, 11 NASN and 6 CHESS monitoring sites within the basin, but most emphasis is placed on APCD measurements. Although data are given for the years 1967 to 1973, the analysis attempts to derive levels typical of 1972, (the base year for the implementation planning phase of this project).

Section 3.1 briefly describes the statistical methodology used to derive expected annual geometric means and yearly 24 hour maxima from the data. The method basically involves the use of log probability plots. Section 3.2 presents and compares measurements from APCD, NASN, and CHESS monitors. The reasons for emphasizing APCD data are discussed. In Section 3.3, log probability frequency plots are given for Hi-Vol data at 12 representative APCD stations. These plots, based on data from mid-1971 to mid-1973, provide a basic indicator of 1972 Hi-Vol levels. Section 3.4 presents and discusses Hi-Vol AGM's for numerous Los Angeles sites for the 1972 base year. Section 3.5 presents expected yearly maxima, again for 1972. A study is also made of the meteorology associated with maximal Hi-Vol levels in various parts of the basin.

#### 3.1 METHODS OF DATA ANALYSIS

Routine Hi-Vol air monitoring data typically represent 24-hour average samples. Because of meteorological fluctuations, the samples for any location occur in the form of a statistical distribution. National

Ambient Air Quality Standards for suspended particulate matter, summarized in Table 3-1, have been established for two parameters of this distribution, the yearly maximal 24-hour value and the annual geometric mean (AGM). In comparing monitoring data to the NAAQS, statistical analyses should be performed to account for the stochastic nature of the data.

In this report, plots on log-probability paper will be used as the basic statistical tool. A straight line on such paper represents a log normal distribution, (the case where the logarithm of the data forms a Gaussian or normal curve). The shapes of aerometric data distributions generally approximate the shape of a log normal curve and are "one-tailed" distributions (no data occur less than zero) [48]. Of course, it is not expected that specific air quality data will be exactly log normal; deviations from log-normality will be reflected in a curved line on log probability paper.

The histogram in Figure 3-1 illustrates a typical distribution of Hi-Vol data. A log-normal distribution, (dashed line), has been plotted for comparison. Figure 3-2 gives a plot of this same data on log-probability paper.

Two statistical parameters are used to characterize a log-normal distribution (the geometric mean,  $m_g$ , and the geometric standard deviation,  $S_g$ ). These are defined for a set of size  $N$  of individual measurements  $c_i$ ,  $i=1, \dots, N$ , as follows:

$$m_g = \left[ \prod_{i=1}^N c_i \right]^{1/N} = \exp \left[ \frac{1}{N} \left( \sum_{i=1}^N \ln c_i \right) \right], \quad (3-1)$$

TABLE 3-1  
NATIONAL AMBIENT AIR QUALITY STANDARDS FOR PARTICULATES

	Annual Geometric Mean	Maximum: Not to be Exceeded More than Once a Year
Primary Standard	75 $\mu\text{g}/\text{m}^3$	260 $\mu\text{g}/\text{m}^3$ for 24 hours
Secondary Standard	60 $\mu\text{g}/\text{m}^3$ *	150 $\mu\text{g}/\text{m}^3$ for 24 hours

\* Guide for attainment of the Secondary 24 hour standard.



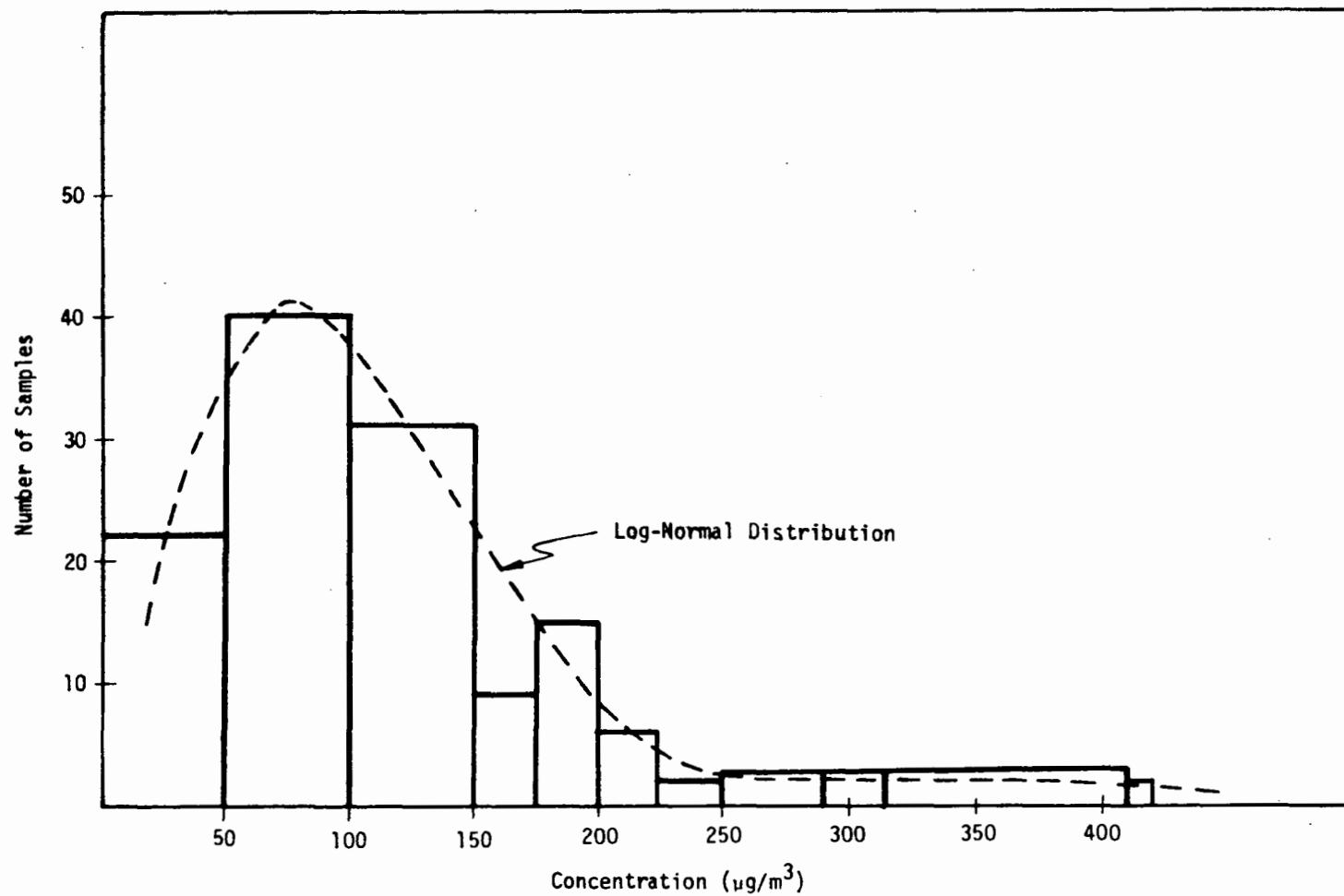


Figure 3-1  
Typical Hi-Vol Frequency Distribution  
San Bernardino (July 1971 - June 1973)

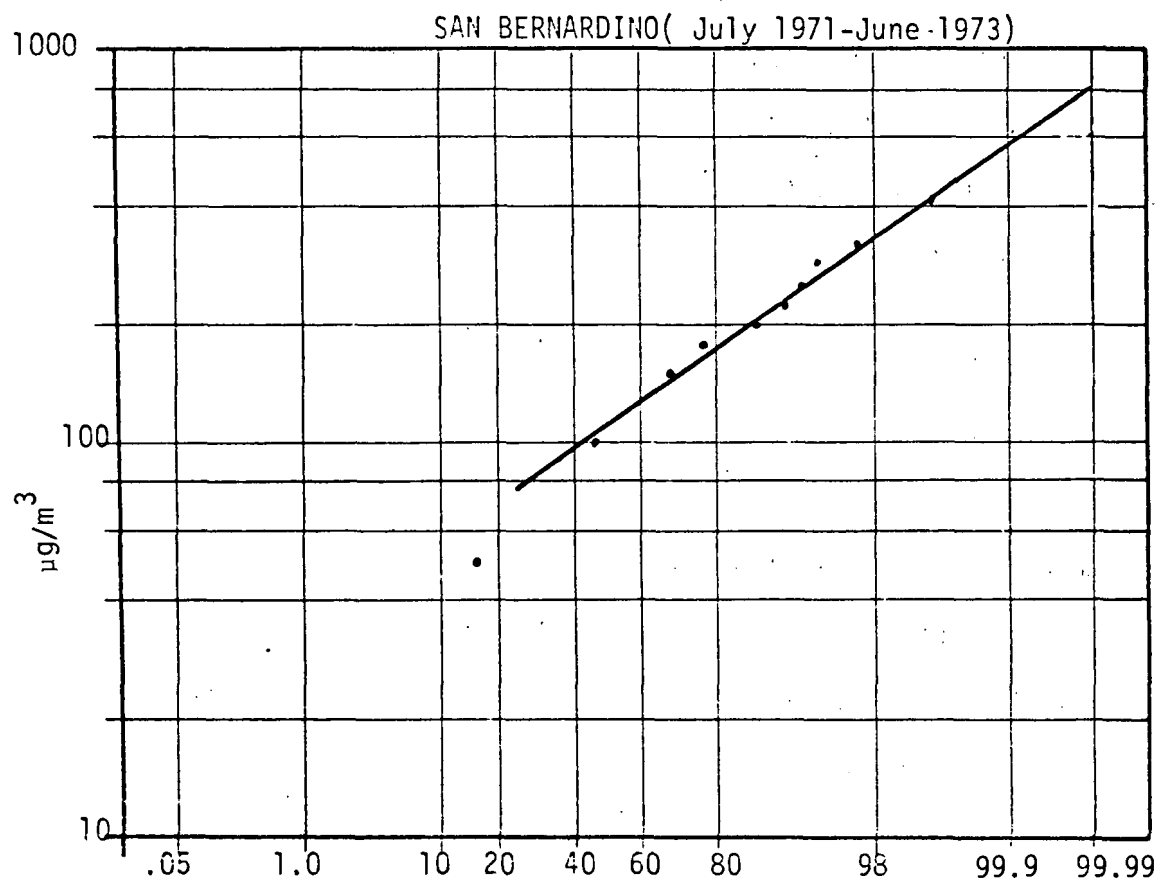


Figure 3-2  
Hi-Vol Cumulative Frequency Plot on Log Probability Paper

and

$$\ln (s_g) = \left[ \frac{1}{N} \sum (\ln c_i - \ln m_g)^2 \right]^{1/2} \quad (3-2)$$

For purposes of this report,  $m_g$  will represent the annual geometric mean of particulate concentrations in micrograms per cubic meter ( $\mu\text{g}/\text{m}^3$ ).  $\ln s_g$ , the slope of the log-normal line, will be used to estimate the maximum expected concentrations measured in a given year as well as the number of days exceeding a given standard.

For a plot such as Figure 3-2, the equation of a best fit straight line has the form

$$\ln (c_i) = \ln (m_g) + z_i \ln (s_g), \quad (3-3)$$

or

$$c_i = m_g s_g^{z_i} \quad (3-4)$$

Here,  $z_i$  represents the number of standard deviations that  $c_i$  occurs away from the geometric mean. One standard deviation, ( $z_i = \pm 1$ ), would represent the 84% or 16% points.  $m_g$  is estimated from the 50% point, ( $z_i = 0$ ). Thus,

$$m_g = c_{50\%}, \quad (3-5)$$

and

$$\ln c_{84\%} = \ln m_g + (1) \ln (s_g),$$

or

$$s_g = \frac{c_{84\%}}{c_{50\%}} = \frac{c_{84\%}}{m_g}. \quad (3-6)$$

The expected maximum value\* for  $n$  measurements is calculated by taking a  $z$  value for  $(1-1/n)$  from a normal error table, [49], i.e.

---

\* Interpreted as the concentration to be exceeded once per year.

$$c_{\max} = m_g s_g z(1-1/n) \quad (3-7)$$

Values of  $z$  for 60, 70, 90, and 365 samples per year are 2.39, 2.45, 2.54, and 2.99 respectively.

### 3.2 COMPARISON OF APCD, NASN, AND CHESS HI-VOL DATA

As noted previously, three principal sources of Hi-Vol data exist in the Metropolitan Los Angeles Air Quality Control Region: the county APCD's and the federal NASN and CHESS programs. The procedures used in each of these monitoring programs are reviewed in Section 2.4. The present section compares the data from these programs, discusses discrepancies, and chooses a specific data set to characterize air quality for the purposes of this study.

Tables 3-2, 3-3, and 3-4 present recent annual geometric means for Hi-Vol data reported by the APCD, NASN, and CHESS programs respectively. Data are available for 28 APCD sites, 11 NASN sites, and 6 CHESS sites. The most striking result of comparing the three data sets is that the CHESS Hi-Vol values are considerably lower in each of the three counties with CHESS stations. For instance, Los Angeles County data typically fall in the range of 75 - 155  $\mu\text{g}/\text{m}^3$  for APCD samples and 75 - 130  $\mu\text{g}/\text{m}^3$  for NASN samples. However, CHESS data in Los Angeles County appear in the range of 50 - 100  $\mu\text{g}/\text{m}^3$ . The most plausible reason for this discrepancy is that the CHESS data are more representative of residential areas rather than prime exposure areas. CHESS sites have been chosen for a health study involving school children and are located in quiet, suburban areas, [53].

TABLE 3-2

HI-VOL ANNUAL GEOMETRIC MEANS<sub>3</sub> FOR COUNTY APCD STATIONS  
( $\mu\text{g}/\text{m}^3$ )

County	Station	1973	1972	1971	1970	1969	1968	1967
Los Angeles	Central LA	114	130	162	136	154	157	145
	Lennox	124	137	154	144	150	148	139
	W. Los Angeles	74	86	85	91	99	92	71
	W. San Fernando Valley (Reseda)	103	143	115	112	117	109	135
	Azusa	121	150	138 <sup>C</sup>	-	-	-	-
	Pasadena	101	110	106 <sup>C</sup>	-	-	-	-
Riverside	Riverside	135 <sup>D</sup>	140 <sup>D</sup>	(136 <sup>D</sup> )	-	-	-	-
San Bernardino	San Bernardino	85	108	117	119	91	121	123
	Ontario	88	110	111	107	134	151	122
	Redlands	89	96	94	102	94	95	133
	Fontana	111	136	100	NA	NA	NA	109
	Rialto	153	170	130	139	NA	151	NA
	Chino	118 <sup>B</sup>	194	178	NA	172	163	144
	Upland	127	-	-	-	-	-	111
Orange	Anaheim	98	105	85	95	105	95	NA
	La Habra	113	120	114	-	-	-	-
	Costa Mesa	66	67	-	-	-	-	-
Ventura	Oxnard	77	77	71	64	-	-	-
	Ojai	66	66	73	-	-	-	-
	Santa Paula	67	76	-	-	-	-	-
	Ventura	73	66	69	51	-	-	-
	Camarillo	80	73	90	-	-	-	-
	Port Hueneme	106	97	-	-	-	-	-
	Simi Valley	74	-	-	-	-	-	-
	Moore Park	62	-	-	-	-	-	-
	Pt. Mugu	58	-	-	-	-	-	-
	Thousand Oaks	81	-	-	65	92	-	-
Santa Barbara	Santa Barbara <sup>A</sup>	NA	66	60	-	-	-	-

A California ARB Data

B Station Moved from Airport to Downtown Chino after 1972

C Represents July to December only

D Calculated from raw data of Riverside APCD

TABLE 3-3

## HI-VOL ANNUAL GEOMETRIC MEANS FOR NASN STATIONS

County	Station	1972	1971	1970	1969	1968	1967
Los Angeles	Central LA	120	133	125	93	129	91
	Pasadena	90	100	111	90	106	-
	Burbank	117	131	123	88	103	-
	Glendale	95	85	87	74	90	75
	Long Beach	96	87	95	104	114	118
	Torrance	73	88	86	68	-	-
Riverside	Riverside	114*	120	119	124	116	-
San Bernardino	San Bernardino	135	104	118	95	92	-
	Ontario	117	111	116	109	116	-
Orange	Anaheim	103	116	114	93	-	-
	Santa Ana	96	140	127	123	95	-

\* 3 Quarters only.

TABLE 3-4

## HI-VOL ANNUAL GEOMETRIC MEANS FOR CHESS STATIONS

County	Station	1973	1972
Los Angeles	Santa Monica	67	69
	Glendora	48	97
	West Covina	64	99
Orange	Anaheim	67	87
	Garden Grove	63	80
Ventura	Thousand Oaks	35	59

A cursory examination of the APCD and NASN values cannot yield a conclusion as to whether or not Hi-Vol values from these two programs are significantly different. A statistical analysis is required to answer the question of equivalency for these data. Below, both an "F" test and "t" test are performed [50],[51]. The "F" statistic\* yields an equivalency test for the geometric standard deviations of the two data distributions. The "t" statistic\*\* provides an equivalency test for sample geometric means. These tests are based on the assumptions that both sets of data are log-normally distributed.

Table 3-5 lists data for geometric means and geometric standard deviations for APCD and NASN Hi-Vols that are maintained at identical locations. An "F" statistic test was performed on the standard deviations

---

\* The "F" statistic is defined as

$$F[(n_1-1), (n_2-1)] = \frac{[\log(s_{g1})]^2}{[\log(s_{g2})]^2},$$

where  $n_1$  and  $n_2$  are the number of individual samples in the two data sets and  $s_{g1}$  and  $s_{g2}$  are the calculated geometric means.

\*\* The "t" statistic is defined by

$$t_{\log} = \frac{\log(m_{g1}) - \log(m_{g2})}{\overline{\log(s_g)}}$$

where

$$\overline{\log(s_g)} \simeq \left[ \frac{\log^2(s_{g1})}{n_1} + \frac{\log^2(s_{g2})}{n_2} \right]^{1/2}$$



TABLE 3-5

"t" TEST FOR EQUIVALENCE OF APCD AND NASN HI-VOL DATA

Note:  $t_{95\%} = 1.98$ 

	Year	AGM		$s_g$		N		$t_{log}$
		APCD	NASN	APCD	NASN	APCD	NASN	
Central Los Angeles	1967	145	91		1.68	70	24	
	1968	157	129		1.33	70	24	
	1969	154	93		1.61	70	24	
	1970	136	125		1.40	70	24	
	1971	162	133		1.42	70	24	
	1972	130	120	1.5 <sup>A</sup>	1.46	70	24	
	Combined 1967-1972	147 <sup>B</sup>	114 <sup>B</sup>	1.5 <sup>A</sup>	1.48 <sup>B</sup>	420	144	6.5
Riverside	1970-1971	136	121	1.43 <sup>A</sup>	1.49	71	48	1.6
San Bernardino	1968	121	92		1.82	60	24	
	1969	91	95		1.96	60	24	
	1970	119	118		1.85	60	24	
	1971	117	104		1.77	60	24	
	1972	108	135	1.68 <sup>A</sup>	1.49	60	24	
	Combined 1968-1972	111 <sup>B</sup>	108 <sup>B</sup>	1.68 <sup>A</sup>	1.77 <sup>B</sup>	300	120	0.5
Ontario	1968	151	116		1.76	60	24	
	1969	134	109		2.16	60	24	
	1970	107	116		1.75	60	24	
	1971	111	111		1.62	60	24	
	1972	110	117		1.43	60	24	
	Combined 1968-1972	121 <sup>B</sup>	114 <sup>B</sup>	1.7 <sup>C</sup>	1.73 <sup>B</sup>	300	120	1.1
Anaheim	1969	105	93	1.54	1.62	90	24	
	1970	95	114	1.37	1.30	90	24	
	1971	85	116	1.63	1.50	90	24	
	1972	105	103	1.53	1.37	90	24	
	Combined 1969-1972	97 <sup>B</sup>	106 <sup>B</sup>	1.51 <sup>B</sup>	1.44 <sup>B</sup>	360	96	2.1

A Estimated from 1971 - 1973 log-probability plots

B Geometric values - all years data combined

C Assumed Value.

for each location. The "F" test indicated that no significant differences could be discerned in the APCD and NASN  $s_g$ 's (a 95% confidence limit was required for a "significant difference").

The right hand side of Table 3-5 lists the results of the "t" test for equivalency of geometric means. The NASN data and the San Bernardino County APCD data at Ontario and San Bernardino are statistically equivalent, although the APCD values are slightly higher at both stations. The Riverside APCD mean is also higher than the NASN mean, but again, the difference is not significant at the 95% confidence level. The Anaheim APCD data are lower than the NASN data, and the difference is just over 95% significant. The one location with an extremely significant discrepancy is downtown Los Angeles; the Los Angeles County APCD values for downtown are around 25% higher than NASN values.

The difference between NASN and APCD data at Anaheim may best be assigned to less frequent calibrations of NASN Hi-Vols, [52]. The large discrepancy at downtown Los Angeles could be due to differences in calibration procedures and/or to the fact that the NASN Hi-Vol was operated as a higher flow rate, [18].

Although all three Hi-Vol data bases will be used in this report, the major emphasis will be placed data from the County APCD's in characterizing air quality for the basin. The reasons for emphasizing APCD data rather than NASN or CHESS data are the following:

- CHESS data tend to represent "clean urban" (quiet residential area) concentrations and as such are considerably lower than APCD data which in many cases represent "prime exposure" areas. One of the major purposes of this report

is to establish how Hi-Vol levels compare to the NAAQS for particulates. The use of APCD data will give a more conservative comparison, (APCD data exceed the standards by much more than CHES data). The addition of the six CHES sites to the 28 APCD sites would add no further binding constraints for designing control strategies to meet the air quality standards.

- APCD samples are taken more frequently (60 - 90 days per year) than NASN samples (24 days per year); they thus provide a better statistical data base. APCD Hi-Vols are usually standardized more frequently than NASN samples. There is a shorter time period between sampling and weighing for APCD samples. Also, several NASN sites are higher above ground than recommended.
- For the areas with the highest Hi-Vol recordings, (Los Angeles, San Bernardino, and Riverside Counties), the APCD results appear somewhat higher than NASN results, (the difference is statistically very significant only at downtown Los Angeles). Thus, the APCD results will give a more conservative comparison of Hi-Vol levels to the federal particulate standards. The addition of the 11 NASN sites to the 28 APCD sites would not add further constraints on the degree of reduction required in control strategies.

### 3.3 FREQUENCY PLOTS FOR REPRESENTATIVE APCD STATIONS

Figures 3-3A through 3-3Q give cumulative frequency distributions of APCD Hi-Vol data, plotted on log-probability paper. The data are intended to be representative of 1972 levels; 1972 will be the base year for the particulate control strategy to be developed in later reports. Actually, to provide a larger statistical base, data were used from July 1971 to June 1973. Plots are presented for the twelve locations listed below:

#### Los Angeles County

Panel A Lennox  
Panel B Downtown Los Angeles  
Panel C West San Fernando Valley (Reseda)  
Panel D West Los Angeles  
Panel E Pasadena  
Panel F Azusa

#### Orange County

Panel G La Habra  
Panel H Anaheim

#### Ventura County

Panel P Oxnard

#### San Bernardino County

Panel I San Bernardino  
Panel J Ontario  
Panel K Rialto  
Panel L Chino

#### Riverside County

Panel M, N, O Riverside -  
Rubidoux

#### Santa Barbara County

Panel Q Santa Barbara

In each case, straight lines have been drawn to fit the raw distributional data. In certain cases, such as West Los Angeles, La Habra, and Anaheim, a straight line fits the data very well, indicating a nearly log-normal distribution. In other cases, particularly Azusa

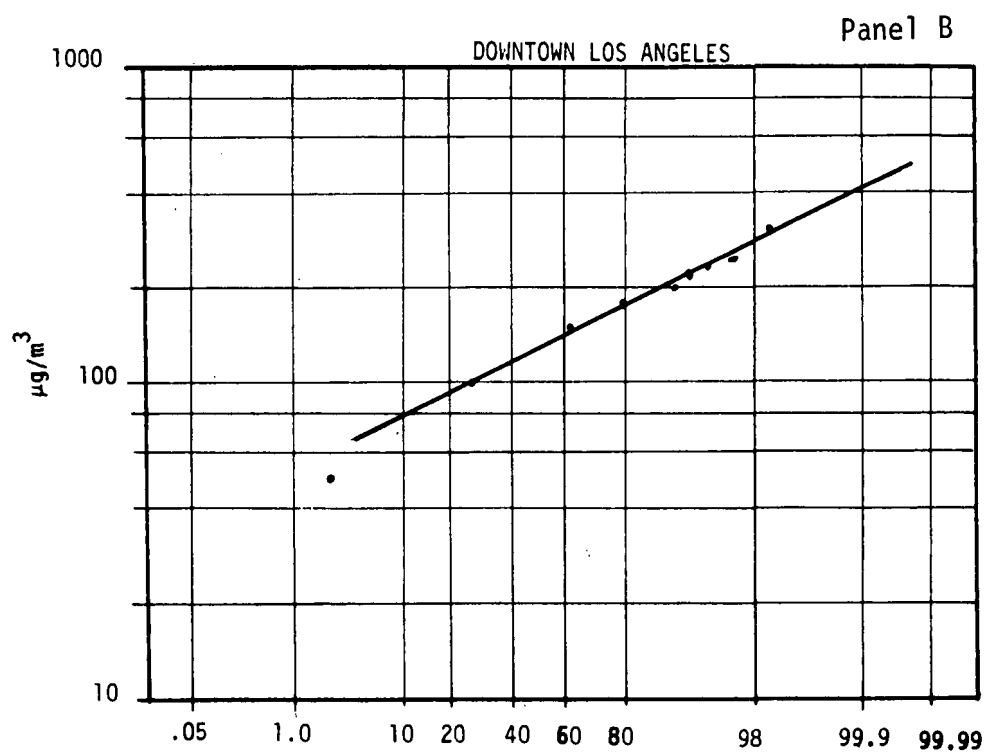
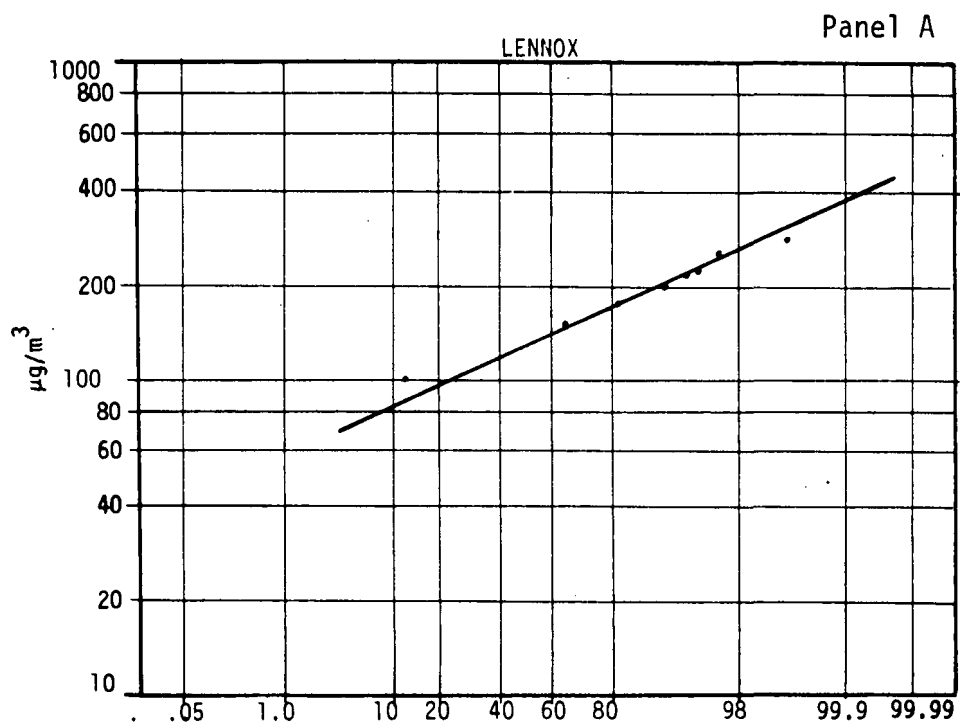


Figure 3-3

Log-Probability Cumulative Frequency Plots of APCD Data  
(July 1971-June 1973)

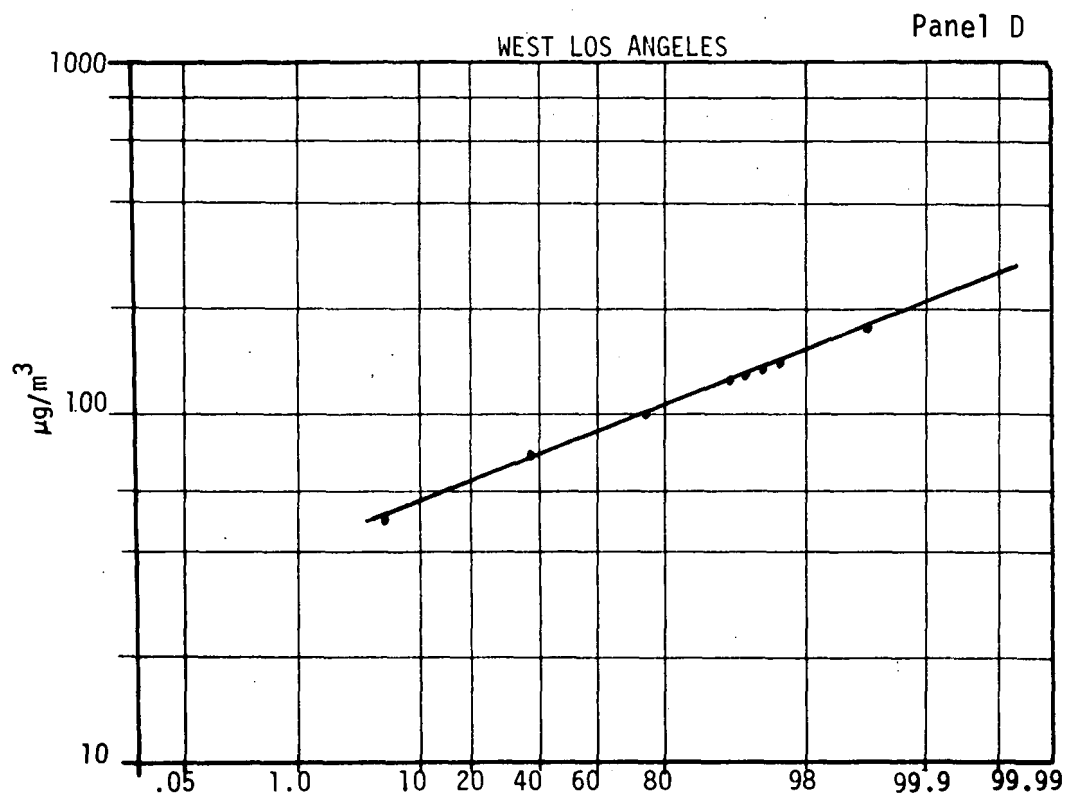
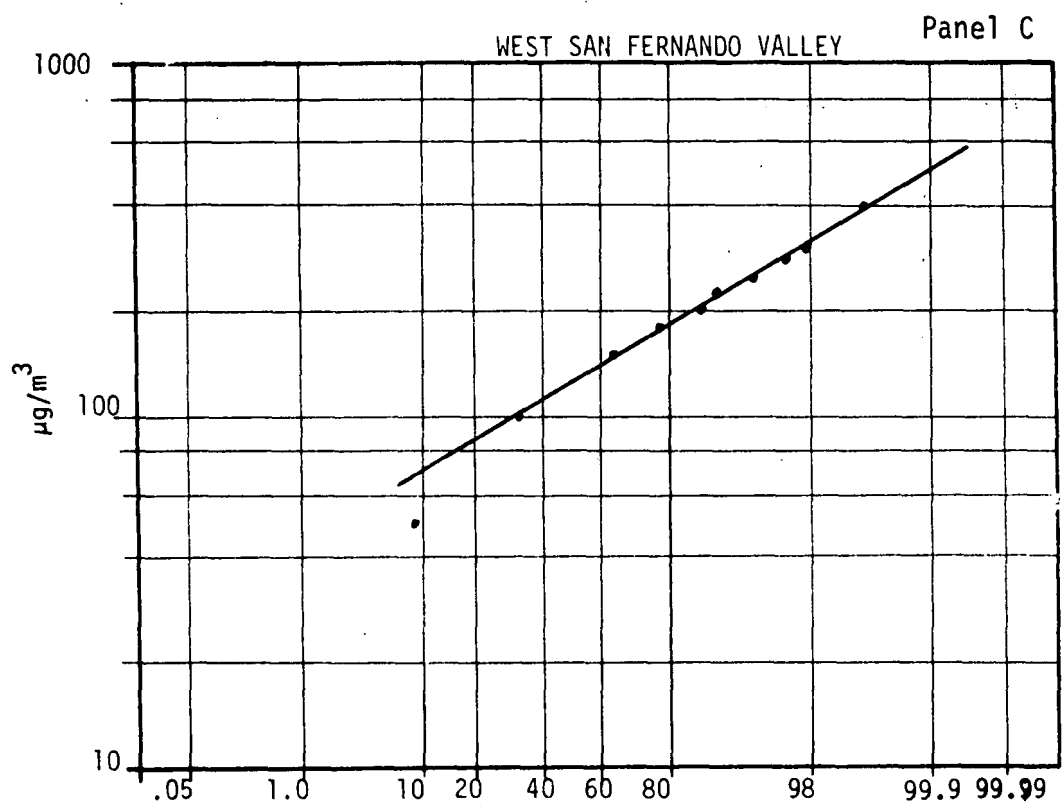


Figure 3-3 - continued

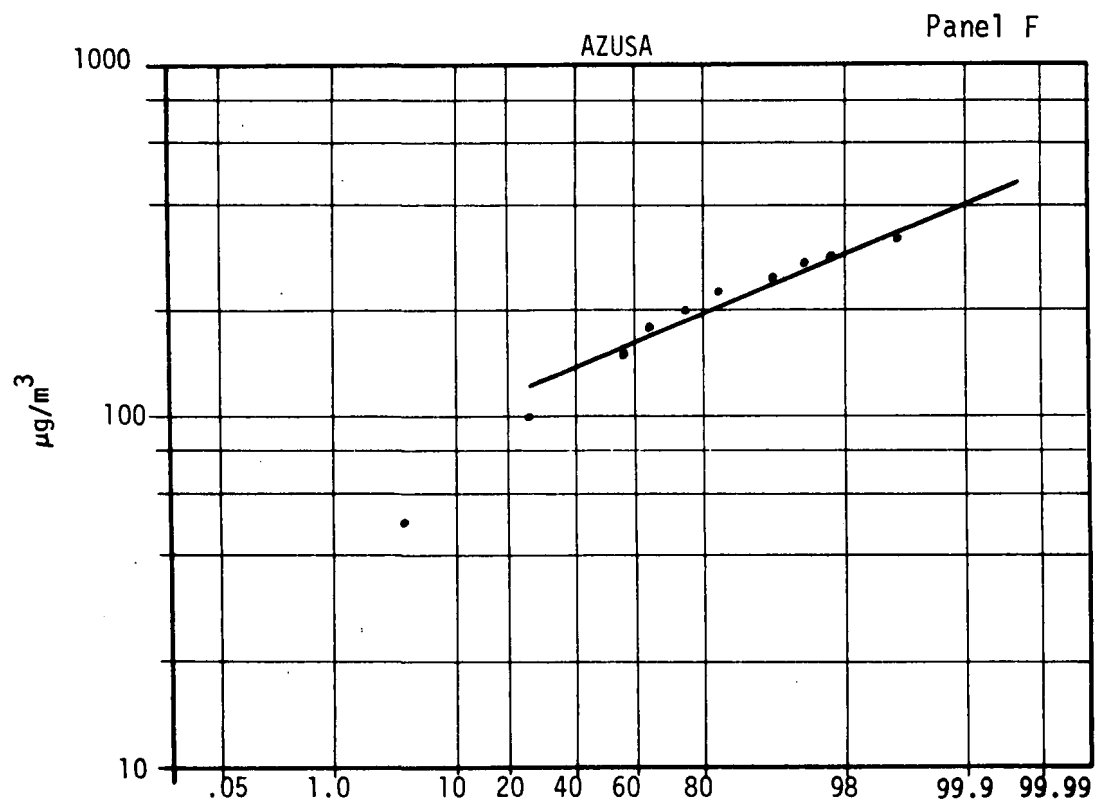
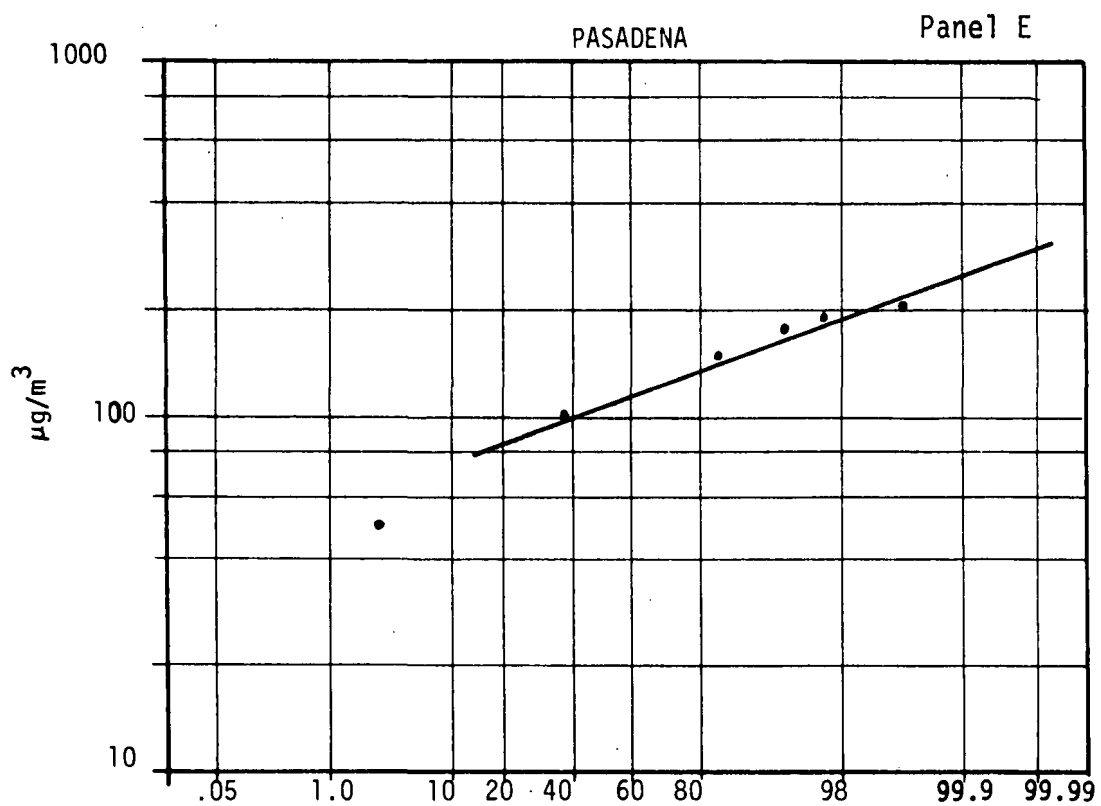


Figure 3-3 - continued

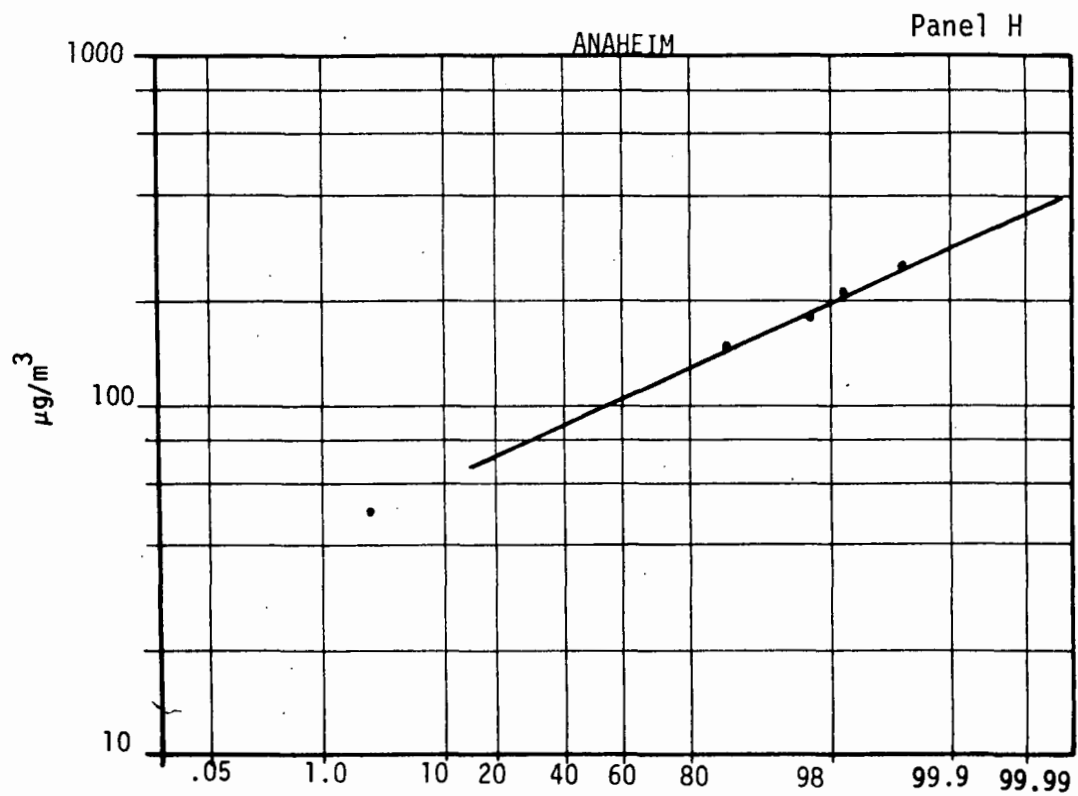
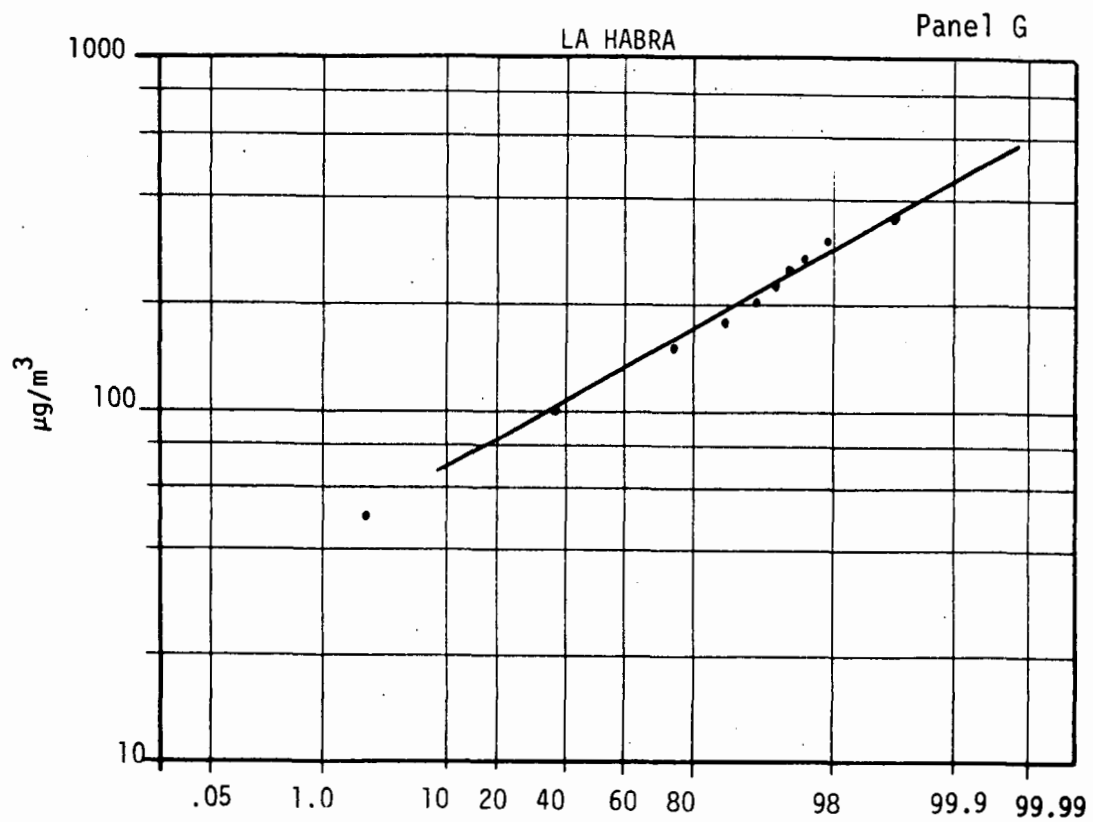


Figure 3-3 - continued



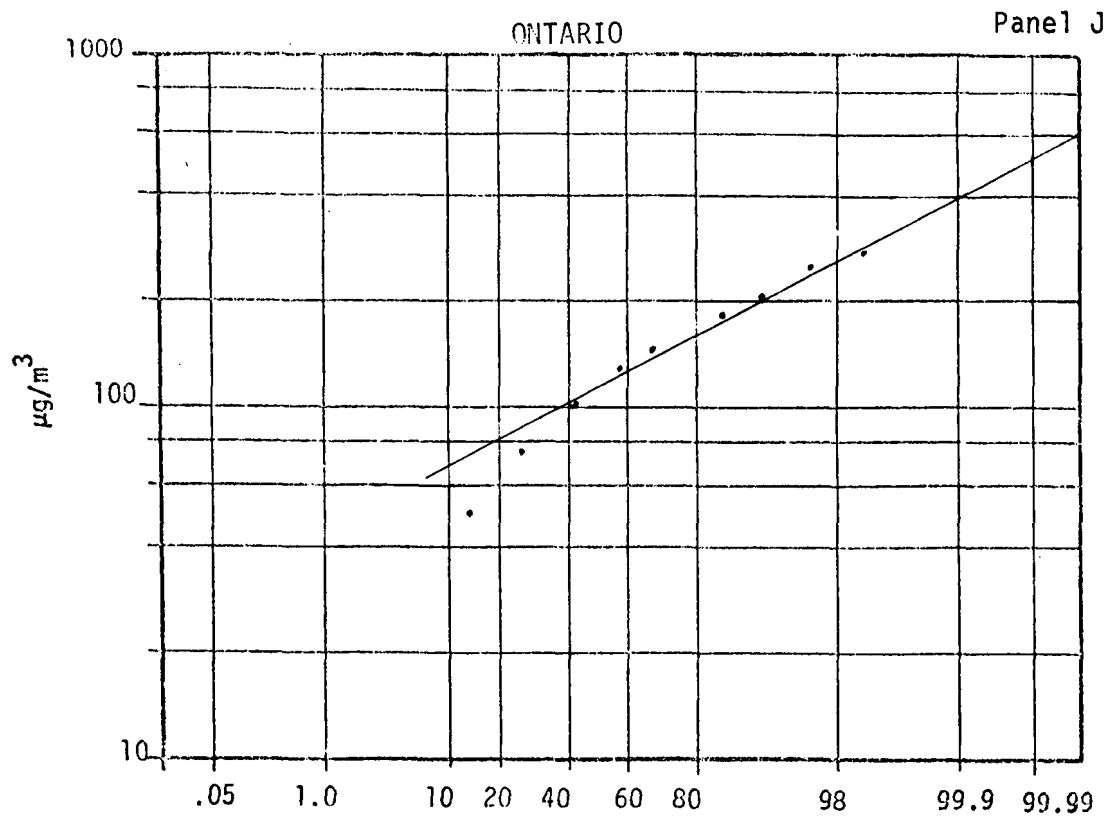
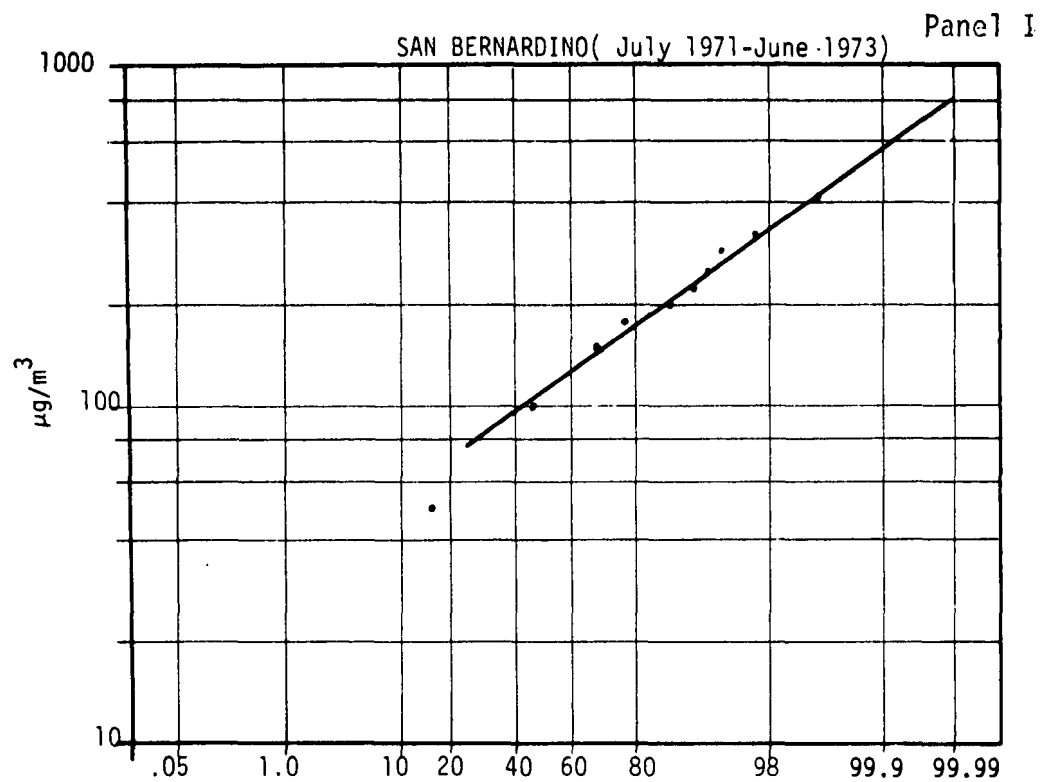


Figure 3-3 - continued

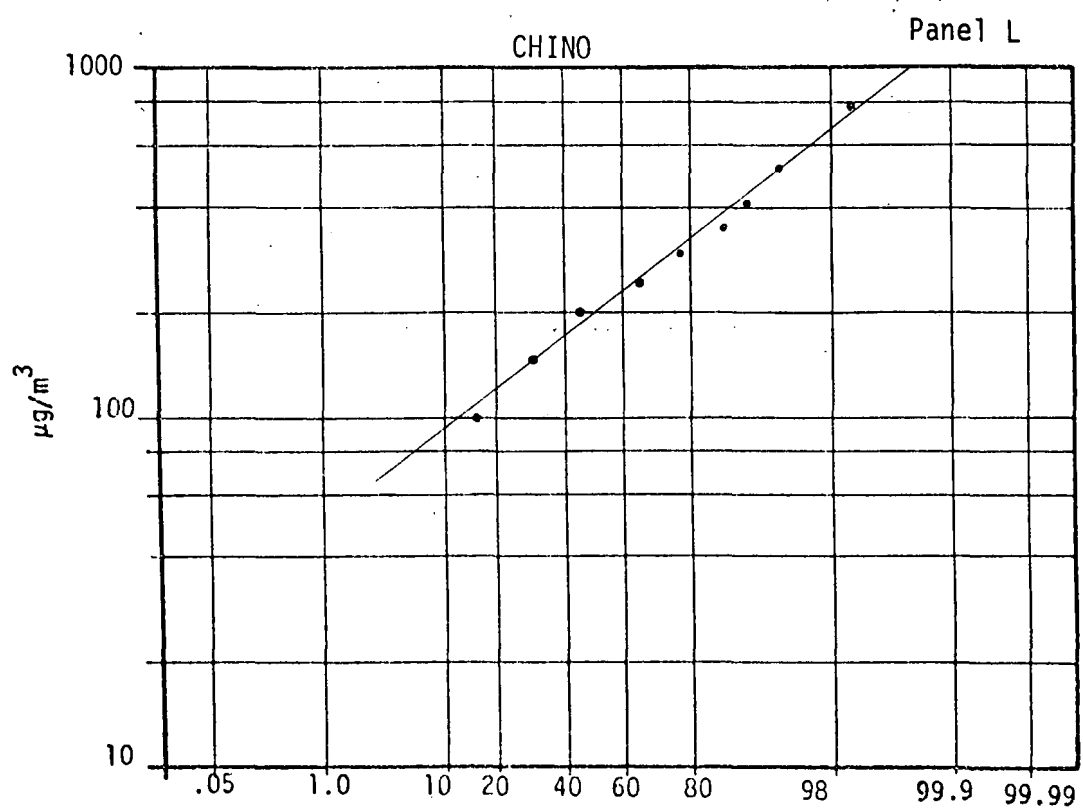
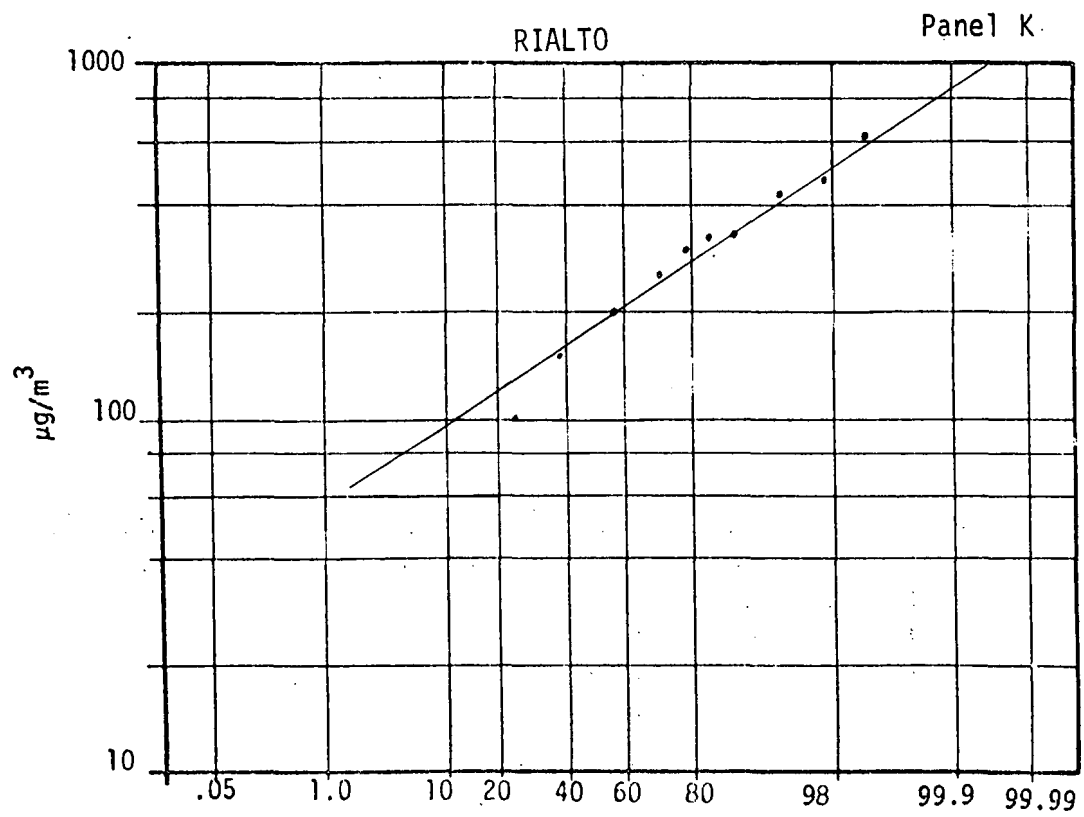


Figure 3-3 - continued

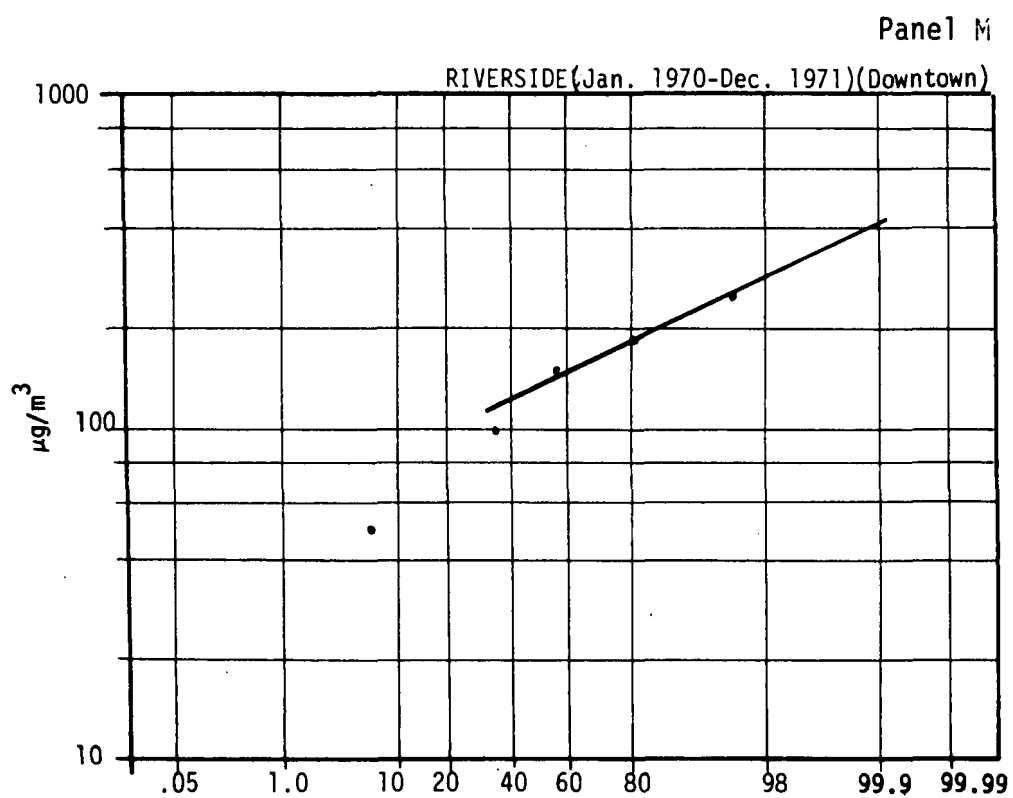


Figure 3-3 - continued

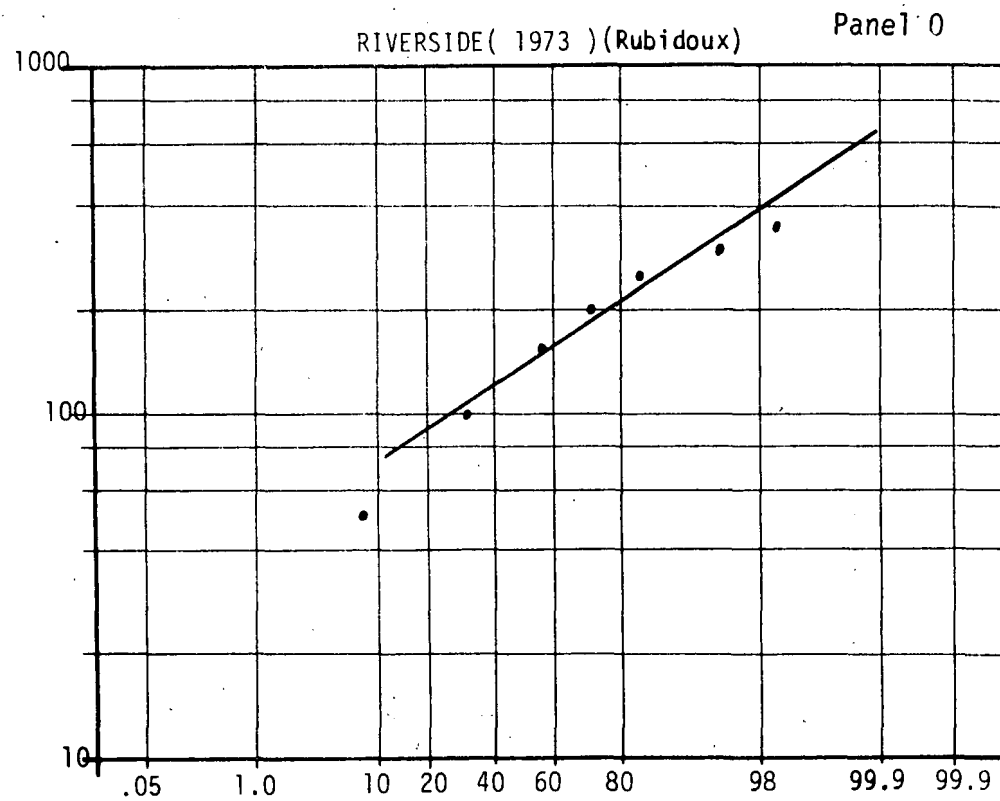
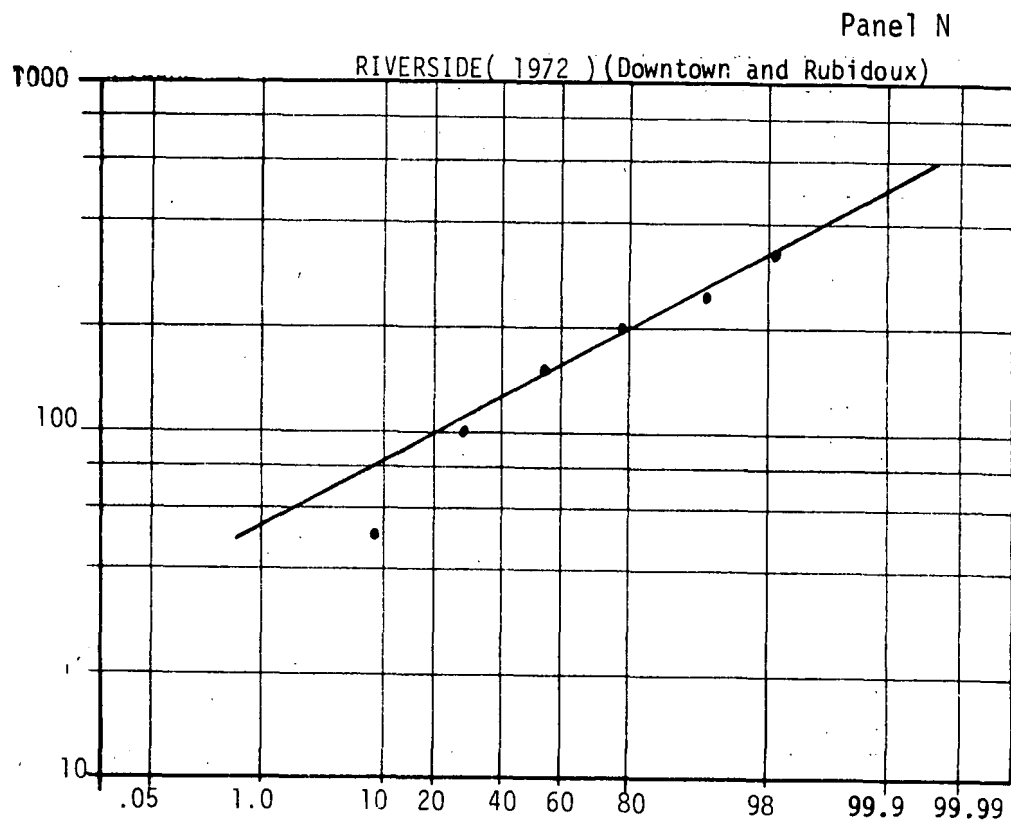
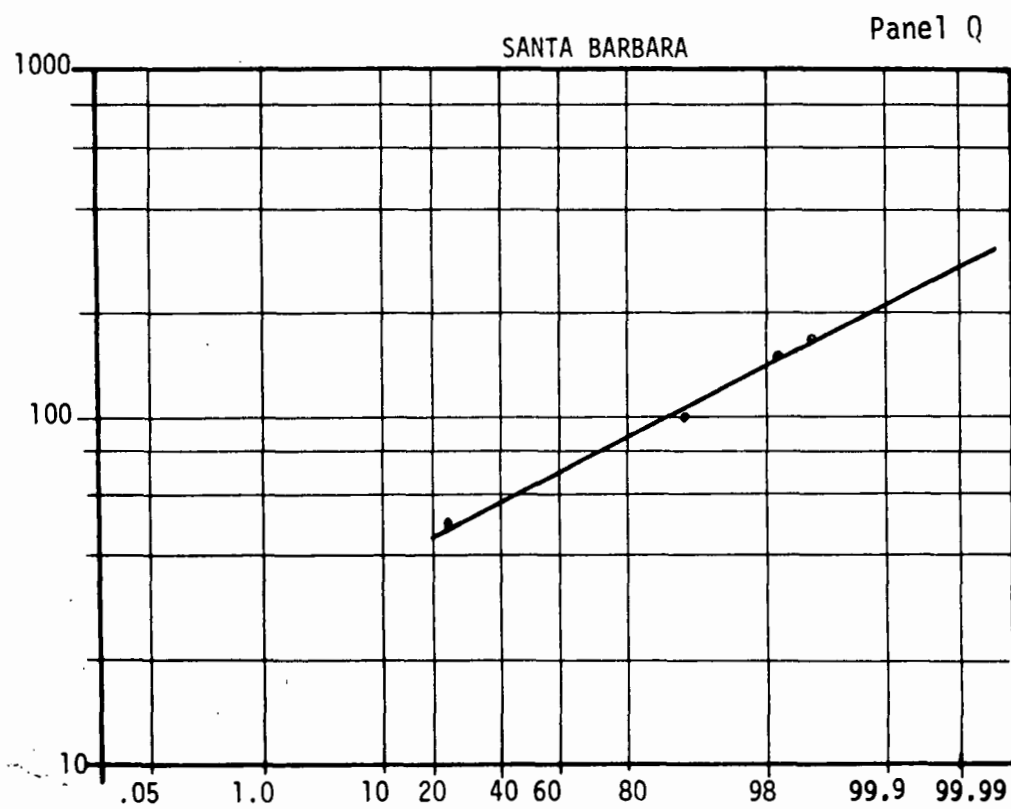
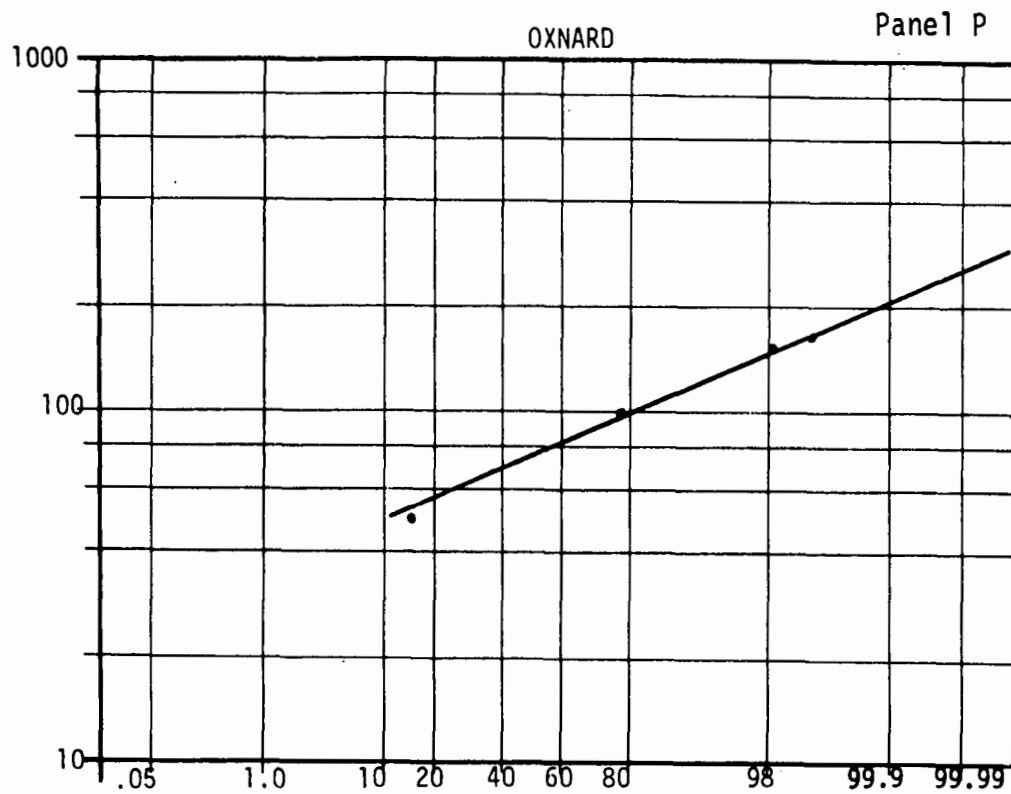


Figure 3-3 - continued



Percent  
Figure 3-3 - continued

and Riverside, the data appear to follow a concave type curve. In these cases, a straight line was fitted to the higher readings to allow projection of maximal Hi-Vol levels.

Table 3-6 summarizes the main results which can be derived from the distribution plots. The reader is referred to Section 3.1 for a discussion of statistical methodology. First, Table 3-6 gives a listing of the cumulative frequency distribution (the percent of time various Hi-Vol levels are exceeded). The parameter  $m_g$  is the annual geometric mean as estimated from the plots, ( $C_{50\%}$ ).  $S_g$  is the geometric standard deviation.  $C_{365}$  is the expected yearly maximal Hi-Vol reading, assuming sampling is done every day.  $C_{70}$  is the expected yearly maximal Hi-Vol reading, assuming that current practices of approximately 70 samples per year are followed. Values for each of these parameters are presented in Table 3-6 for all twelve locations.

The sections which follow will compare and discuss the actual Hi-Vol levels for these and other locations in the Los Angeles Region. Section 3.4 will discuss annual geometric means. Section 3.5 will deal with 24 hour maximal levels.

TABLE 3-6

STATISTICAL PARAMETERS FOR HI-VOL DISTRIBUTIONS  
AT TWELVE LOS ANGELES REGION SITES, 1972

CENTRAL L.A. CONC $\mu\text{g}/\text{m}^3$ %	LENNOX CONC $\mu\text{g}/\text{m}^3$ %	WEST L.A. CONC $\mu\text{g}/\text{m}^3$ %
50 2.1	50 12	50 5.7
100 26	100 12	75 37
150 61	150 65	100 73
175 79	175 81	125 91.5
200 90	200 90.9	127 92.9
218 92.0	217 93.1	132 95.0
236 94.2	226 95.2	140 97.2
249 96.4	259 97.2	
C <sub>365</sub> = 414	C <sub>365</sub> = 340	C <sub>365</sub> = 200
C <sub>70</sub> = 336	C <sub>70</sub> = 290	C <sub>70</sub> = 172
M <sub>g</sub> = 129	M <sub>g</sub> = 134	M <sub>g</sub> = 84
S <sub>g</sub> = 1.48	S <sub>g</sub> = 1.37	S <sub>g</sub> = 1.34
WEST SAN FERN. VALLEY CONC $\mu\text{g}/\text{m}^3$ %	AZUSA CONC $\mu\text{g}/\text{m}^3$ %	PASADENA CONC $\mu\text{g}/\text{m}^3$ %
50 7.9	50 4.2	50 2.8
100 31	100 25	100 38
150 64	150 55	150 84
175 78	175 63	175 93.6
200 86	200 74	183 95.0
225 89	225 83	187 97.2
250 94.2	250 91.7	
278 96.4	255 93.0	
302 97.8	272 95.1	
	280 97.2	
C <sub>365</sub> = 446	C <sub>365</sub> = 380	C <sub>365</sub> = 247
C <sub>70</sub> = 356	C <sub>70</sub> = 323	C <sub>70</sub> = 210
M <sub>g</sub> = 128	M <sub>g</sub> = 150	M <sub>g</sub> = 108
S <sub>g</sub> = 1.52	S <sub>g</sub> = 1.37	S <sub>g</sub> = 1.32

TABLE 3-6 - continued

ANAHEIM		LA HABRA		SAN BERNARDINO	
CONC $\mu\text{g}/\text{m}^3$	%	CONC $\mu\text{g}/\text{m}^3$	%	CONC $\mu\text{g}/\text{m}^3$	%
50	2.8	50	2.3	50	16
100	54	100	37	100	46
150	87	150	74	150	69
175	96.7	175	86	175	76
176	97.22	200	90.9	200	87
210	98.3	225	93.1	225	91.1
		250	94.9	250	92.6
		270	96.0	284	94.8
		301	97.7	317	97.0
$C_{365}$ = 290		$C_{365}$ = 460		$C_{365}$ = 540	
$C_{90}$ = 240		$C_{90}$ = 360		$C_{70}$ = 411	
$M_g$ = 95		$M_g$ = 116		$M_g$ = 116	
$S_g$ = 1.46		$S_g$ = 1.59		$S_g$ = 1.68	
ONTARIO		RIALTO		CHINO	
CONC $\mu\text{g}/\text{m}^3$	%	CONC $\mu\text{g}/\text{m}^3$	%	CONC $\mu\text{g}/\text{m}^3$	%
50	14	50	7.6	100	15
75	26	100	27	150	31
100	40	150	38	200	46
125	58	200	59	250	66
150	70	250	72	300	78
175	86	300	79	324	82
200	92.3	324	85	345	87
213	94.5	350	90.2	404	91.2
249	96.7	432	95.7	533	95.6
275	98.9	463	97.8	768	98.9
		610	98.9		
$C_{365}$ = 360		$C_{365}$ = 780		$C_{365}$ = 1100	
$C_{70}$ = 270		$C_{70}$ = 550		$C_{70}$ = 710	
$M_g$ = 112		$M_g$ = 174		$M_g$ = 200	
$S_g$ = 1.52		$S_g$ = 1.72		$S_g$ = 1.78	



TABLE 3-6 - continued

RIVERSIDE		OXNARD		SANTA BARBARA	
CONC $\mu\text{g}/\text{m}^3$	%	CONC $\mu\text{g}/\text{m}^3$	%	CONC $\mu\text{g}/\text{m}^3$	%
<u>1973</u>					
50	7.8	50	15	50	23
100	30	100	78	100	90.5
150	56	150	98.1	150	98.3
200	71				
250	83				
299	95.5				
$C_{365}$	= 620	$C_{365}$	= 200	$C_{365}$	= 200
$C_{70}$	= 470	$C_{70}$	= 166	$C_{70}$	= 164
$M_g$	= 140	$M_g$	= 76	$M_g$	= 64
$S_g$	= 1.67	$S_g$	= 1.38	$S_g$	= 1.47

### 3.4 HI-VOL LEVELS IN THE METROPOLITAN LOS ANGELES AIR QUALITY CONTROL REGION: ANNUAL GEOMETRIC MEANS FOR BASE YEAR 1972

The previous section presented Hi-Vol frequency distributions for twelve stations in the Los Angeles Region. These distributions were derived from individual 24-hour APCD data for the period July 1971 to June 1973. Annual geometric means (AGM's) representative of 1972 were calculated from these distributions and were presented in Table 3-6.

To check that July 1971 - June 1973 was not an extremely unusual meteorological period for Hi-Vol geometric means, the AGM's which were calculated from the distribution are compared to historical values in Table 3-7. Table 3-7 indicates that the calculated AGM's are generally in agreement with historical values. The only possible exceptions are the following:

- 1972 was an unusually high year for Hi-Vol data at Reseda (and possibly Azusa). The AGM's calculated from the July 1971 to June 1973 distribution may be slightly higher than what would be expected for more typical meteorology. The more typical Reseda AGM may be in the 110 - 125  $\mu\text{g}/\text{m}^3$  range rather than the calculated 128  $\mu\text{g}/\text{m}^3$ . The data base for Azusa is very limited, (monitoring began in July 1971). The calculated Azusa AGM of 150  $\mu\text{g}/\text{m}^3$  may be slightly higher than typical values.
- 1972 and 1973 gave atypically low values for Hi-Vol data in downtown Los Angeles. This may be due to control implementation but may also be due to unusual meteorology. If the latter is the case, the calculated AGM of 129  $\mu\text{g}/\text{m}^3$  would be a low estimate; a value in the 140 to 155  $\mu\text{g}/\text{m}^3$  range might be more appropriate for downtown Los Angeles.

TABLE 3-7

COMPARISON OF HI-VOL ANNUAL GEOMETRIC MEANS FROM  
FREQUENCY DISTRIBUTIONS TO PAST MONITORING HISTORYHI-VOL ANNUAL GEOMETRIC MEANS ( $\mu\text{g}/\text{m}^3$ )

County	Station	Calculated from Distribution for 6/1971 - 6/1973	1973	1972	Yearly Measured AGM				
					1971	1970	1969	1968	1967
Los Angeles	Central L.A.	129	114	130	162	136	154	157	145
	Lennox	134	124	137	154	144	150	148	139
	W. Los Angeles	84	74	86	85	91	99	92	71
	W. San Fernando Valley (Reseda)	128	103	143	115	112	117	109	135
	Azusa	150	121	150	138 <sup>A</sup>	-	-	-	-
	Pasadena	108	101	110	106 <sup>A</sup>	-	-	-	-
San Bernardino	San Bernardino	116	85	108	117	119	91	121	-
	Ontario	112	99	110	124	109	135	-	-
	Realto	174	163	176	136	117	112	-	-
	Chino	200	-	212	191	-	172	163	-
Riverside	Riverside	140	135	140	-	136 <sup>B</sup>	-	-	-
Orange	Anaheim	95	98	105	85	95	105	95	-
	La Habra	116	113	120	114	-	-	-	-
Oxnard	Oxnard	76	77	77	71	64	-	-	-
Santa Barbara	Santa Barbara	64	NA	66	60	NA	-	-	-

Federal Primary Standard 75  $\mu\text{g}/\text{m}^3$ .Federal Secondary Standard 60  $\mu\text{g}/\text{m}^3$ .<sup>A</sup> Represents July to December Only.<sup>B</sup> Represents 1970 and 1971 combined geometric mean.

The annual geometric means for the twelve Los Angeles Region Stations listed in Table 3-7 are plotted on a map in Figure 3-4.

Chino and Rialto yielded unusually high annual Hi-Vol levels of  $200 \text{ ug/m}^3$  and  $174 \text{ ug/m}^3$  (AGM) respectively. Preliminary investigations of the cause of these exceptional values has been conducted by the San Bernardino APCD, [58]. This investigation pointed out that the Chino and Rialto stations were directly in line with the large Kaiser Steel-Edison Electric complex for the typical sea-land breeze wind pattern. The high Rialto and Chino values appear to reflect the local importance of that major emission source.

For comparison with the above data, 1972, Hi-Vol AGM values for NASN, CHESS, and Ventura APCD (other than Oxnard) stations are mapped in Figure 3-5. These data are generally lower than the APCD data in Figure 3-4. As noted in Section 3.2, the CHESS sites are in quiet, isolated, suburban areas. The CHESS stations tend to measure urban background particulate levels rather than the levels found in urban centers. The discrepancies between NASN and APCD data were also discussed in Section 3.2.

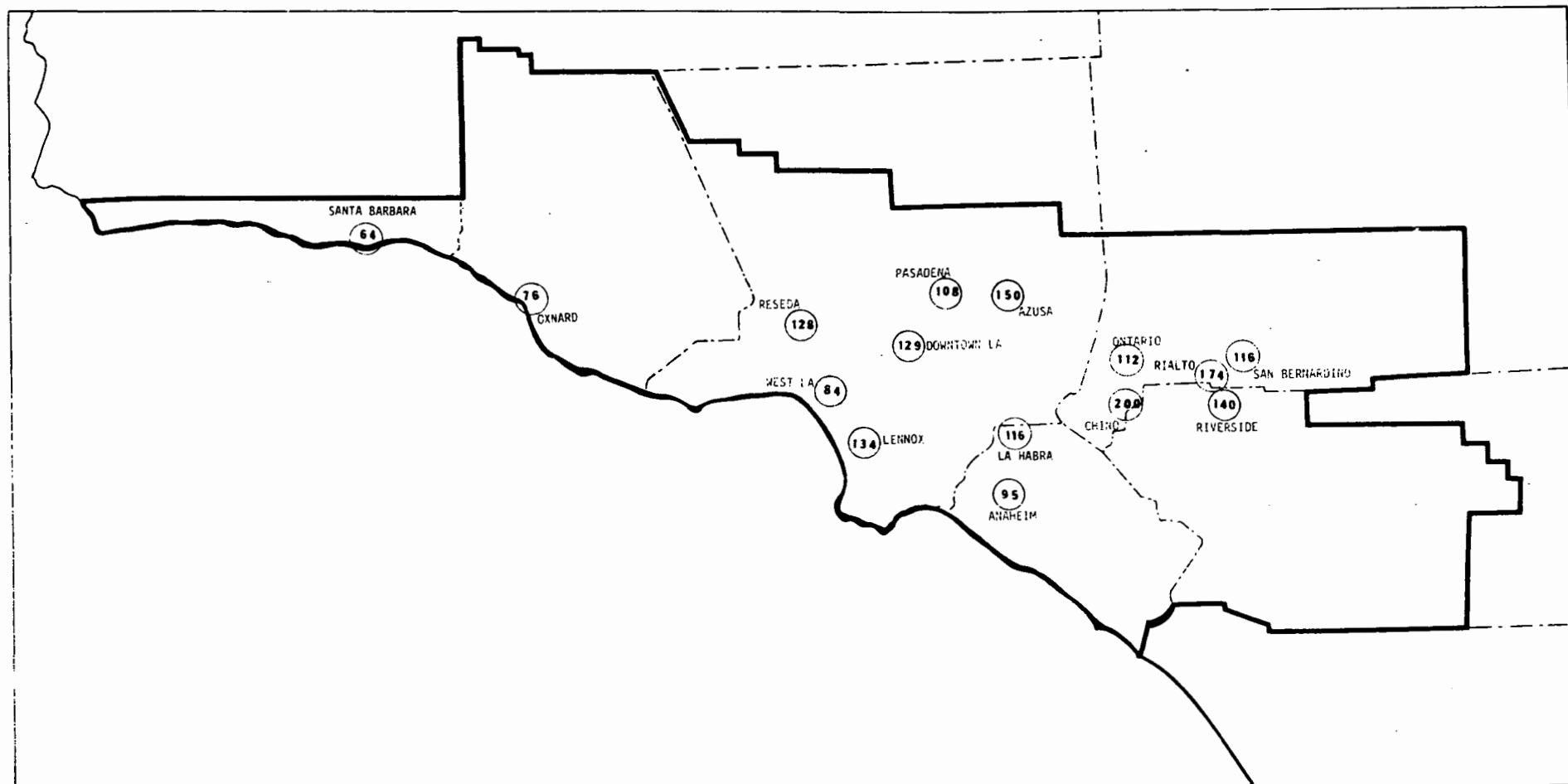


Figure 3-4. Expected Annual Geometric Mean Hi-Vol Levels for the 1972 Base Year

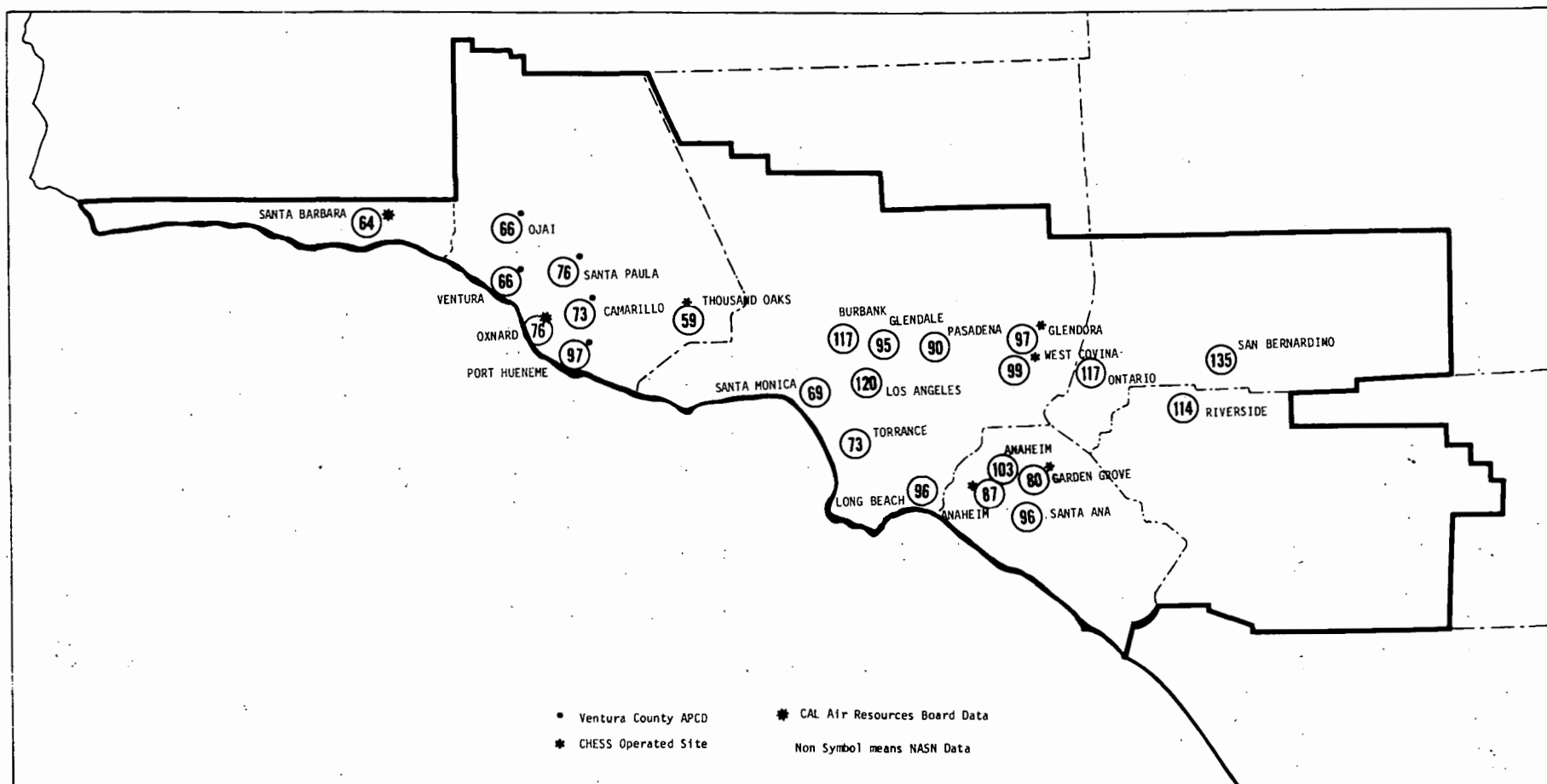


Figure 3-5

Expected Annual Geometric Means for Suspended Particulate Matter  
in the Los Angeles Basin for Base Period 1972  
(NASN and CHESS Data)

### 3.5 HI-VOL LEVELS IN THE METROPOLITAN LOS ANGELES AIR QUALITY CONTROL REGION: EXPECTED MAXIMAL 24 HOUR LEVELS FOR THE BASE YEAR 1972

Section 3.3 derived expected yearly maximal 24 hour Hi-Vol levels at twelve Los Angeles Region stations from frequency distributions based on data from the period July 1971 to June 1973. These data are mapped in Figure 3-6. As a check on these results, the statistically derived expected yearly maximum are compared to historical values in Table 3-8. In the table,  $C_{70}$  is the calculated expected yearly 24 hour maximum, assuming 70 samples are taken per year (current APCD procedures). The actual APCD measured maxima are listed for the years 1966 to 1973; NASN data are included for a comparison.  $C_{365}$  in the table is the calculated yearly maximum assuming that samples would be taken every day.

A cursory examination of Table 3-8 indicates that the calculated expected maxima in Los Angeles County, ( $C_{70}$ 's based on the 7/71-6/73 distributions), appear to be somewhat lower than the typical observed yearly maxima. This is especially true if the 20 August 1973 data are included, (on that day maximas ranging from 233-686  $\mu\text{g}/\text{m}^3$  occurred in Los Angeles County). To check this conclusion Table 3-9 compares the calculated  $C_{70}$  to the average measured maxima for 1969-1973. Table 3-9 reveals a consistent underestimate of the yearly maxima in Los Angeles County. This inconsistency could be due any of three factors: (1) the 7/71-6/73 distributions for Los Angeles County were not representative at greater Hi-Vol levels because of unusual meteorology, (2) the projection of the Los Angeles County distributions at the high end was not well represented by a straight line, or (3) the actual maximas from 1969 to 1973 were atypically high and were not representative of the

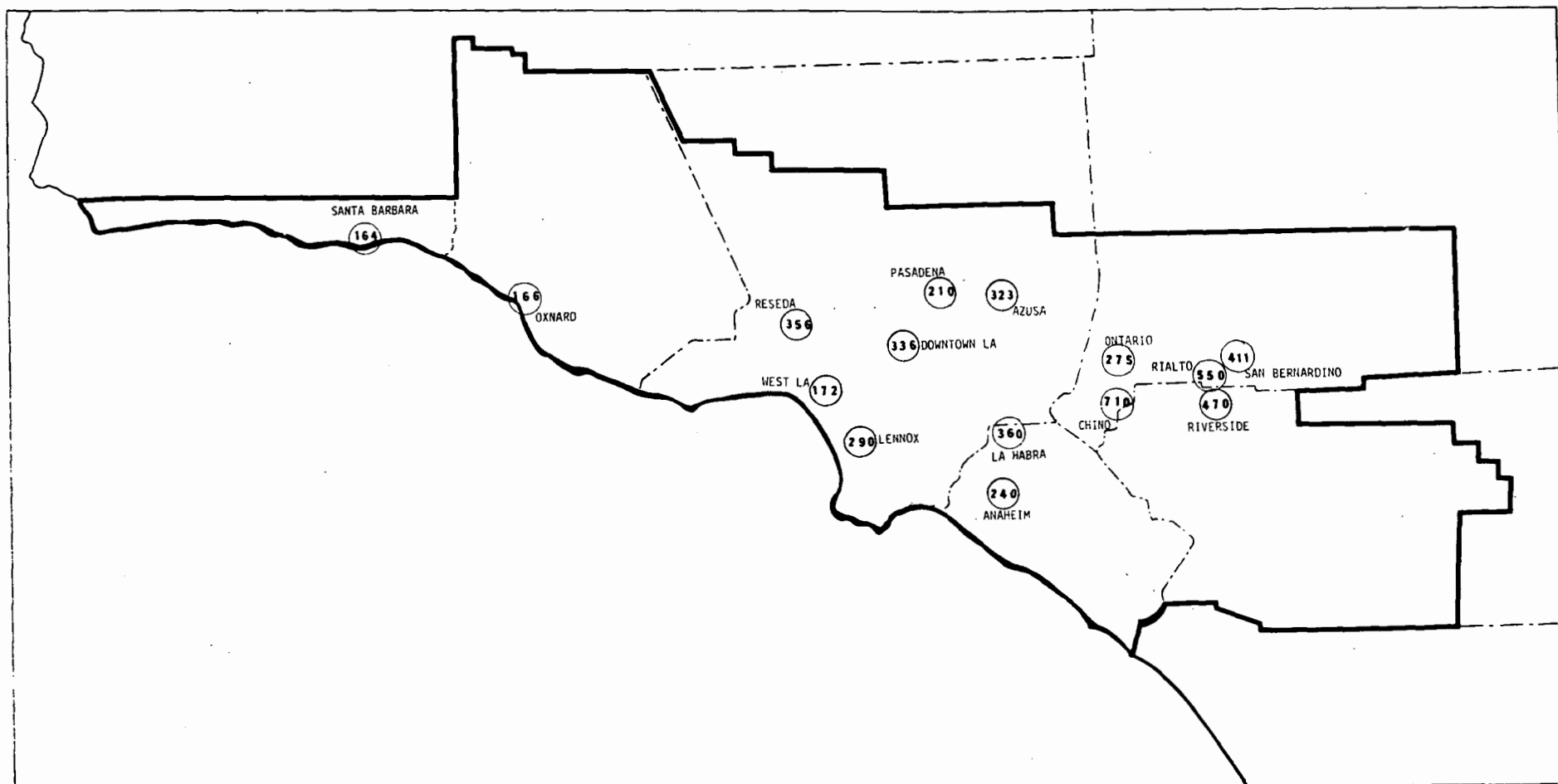


Figure 3-6. Expected 24-Hour Max. Hi-Vol Levels for the 1972 Base Year  
(for the present APCD Monitoring Frequency)



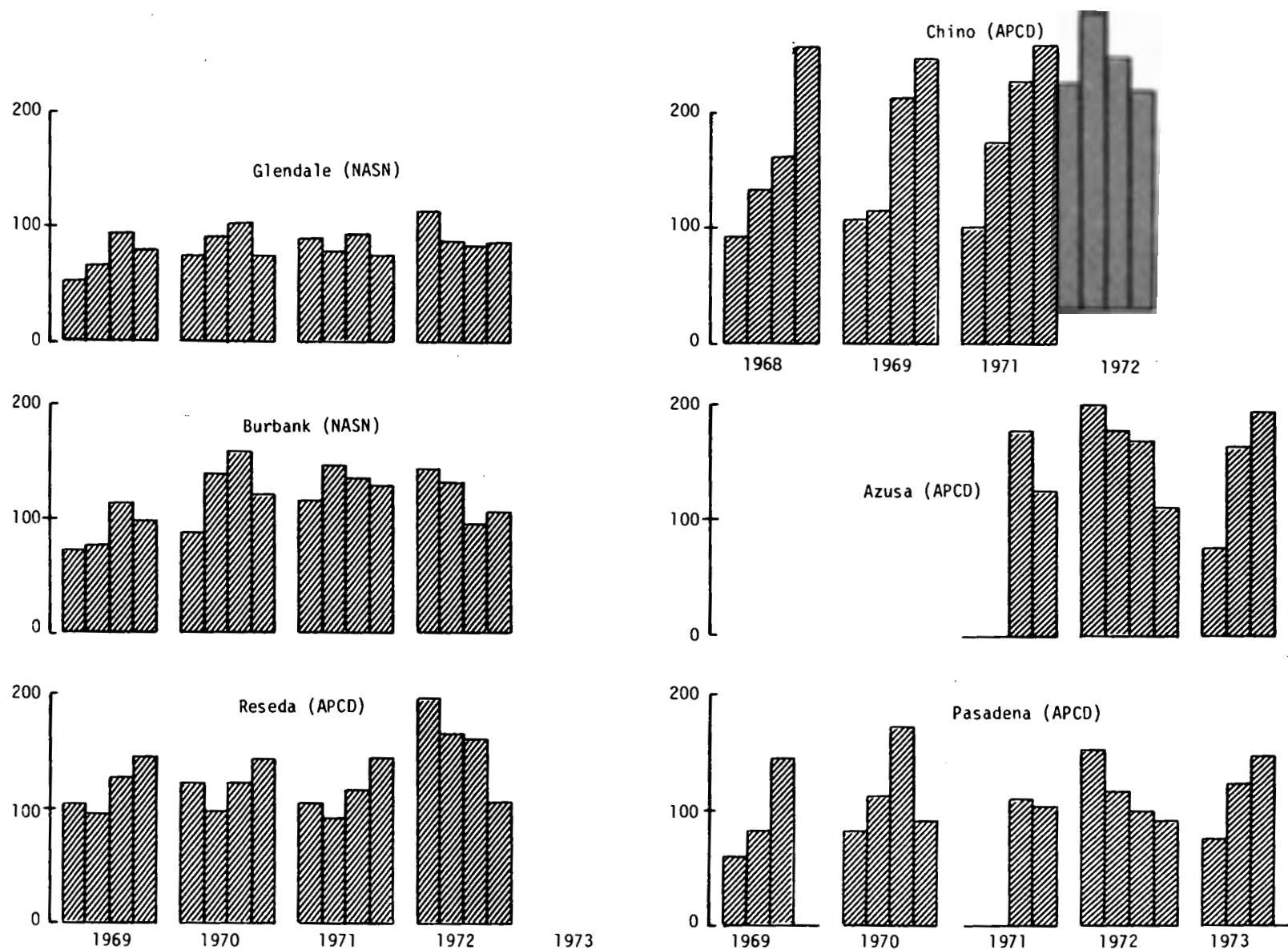


Figure 3-7  
Suspended Particulate Quarterly Geometric Means ( $\mu\text{g}/\text{m}^3$ )

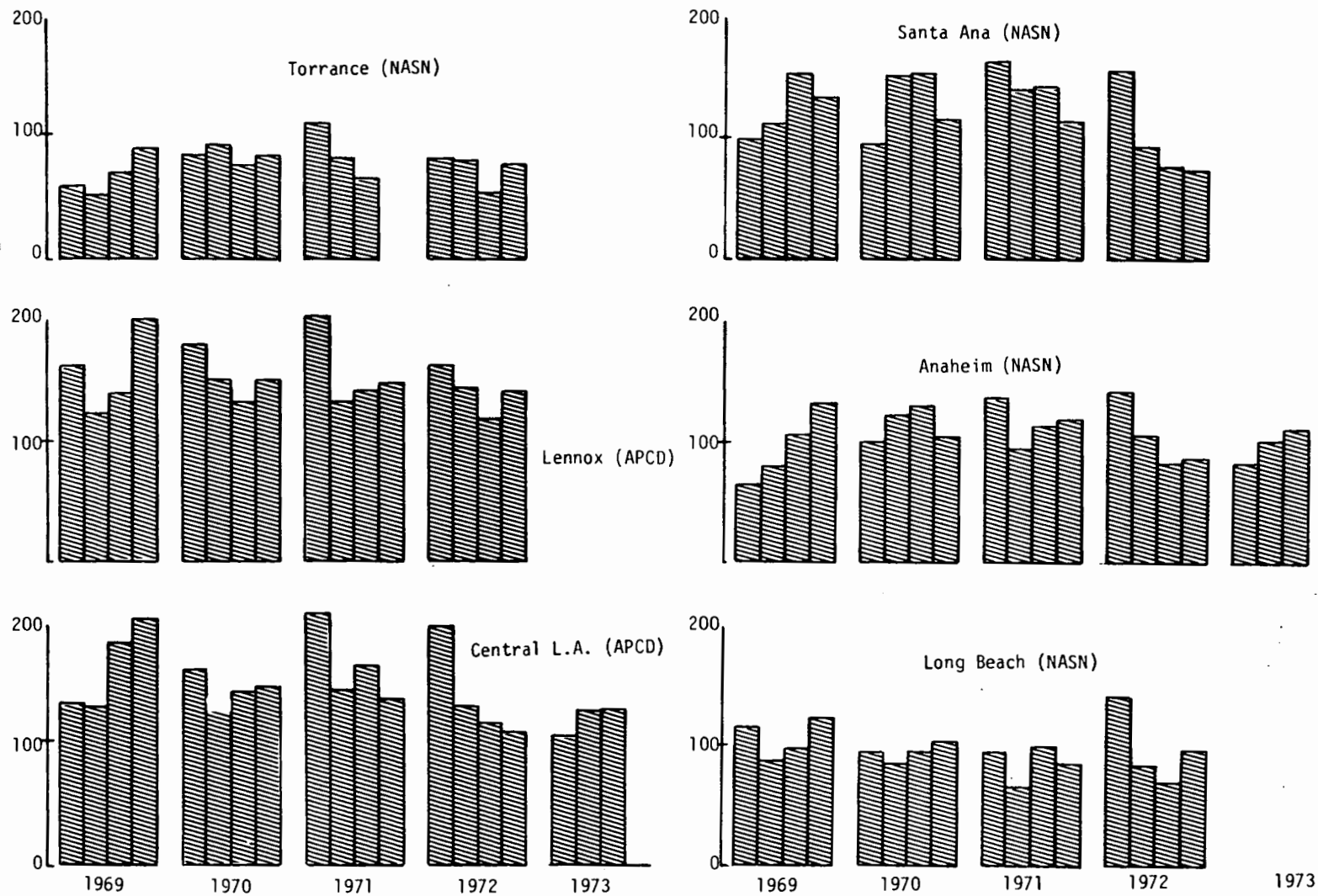


Figure 3-7 - Continued

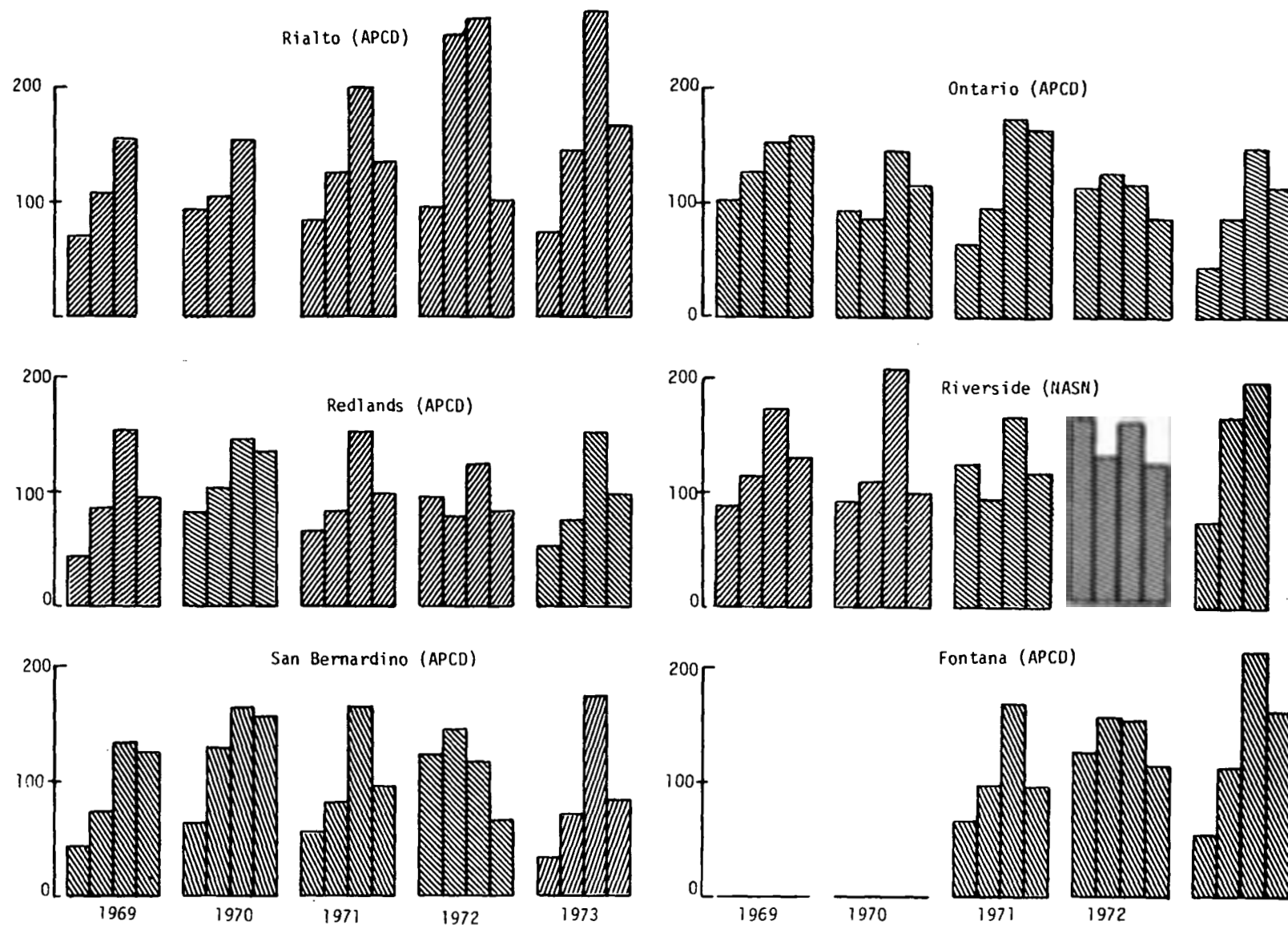


Figure 3-7 - Continued

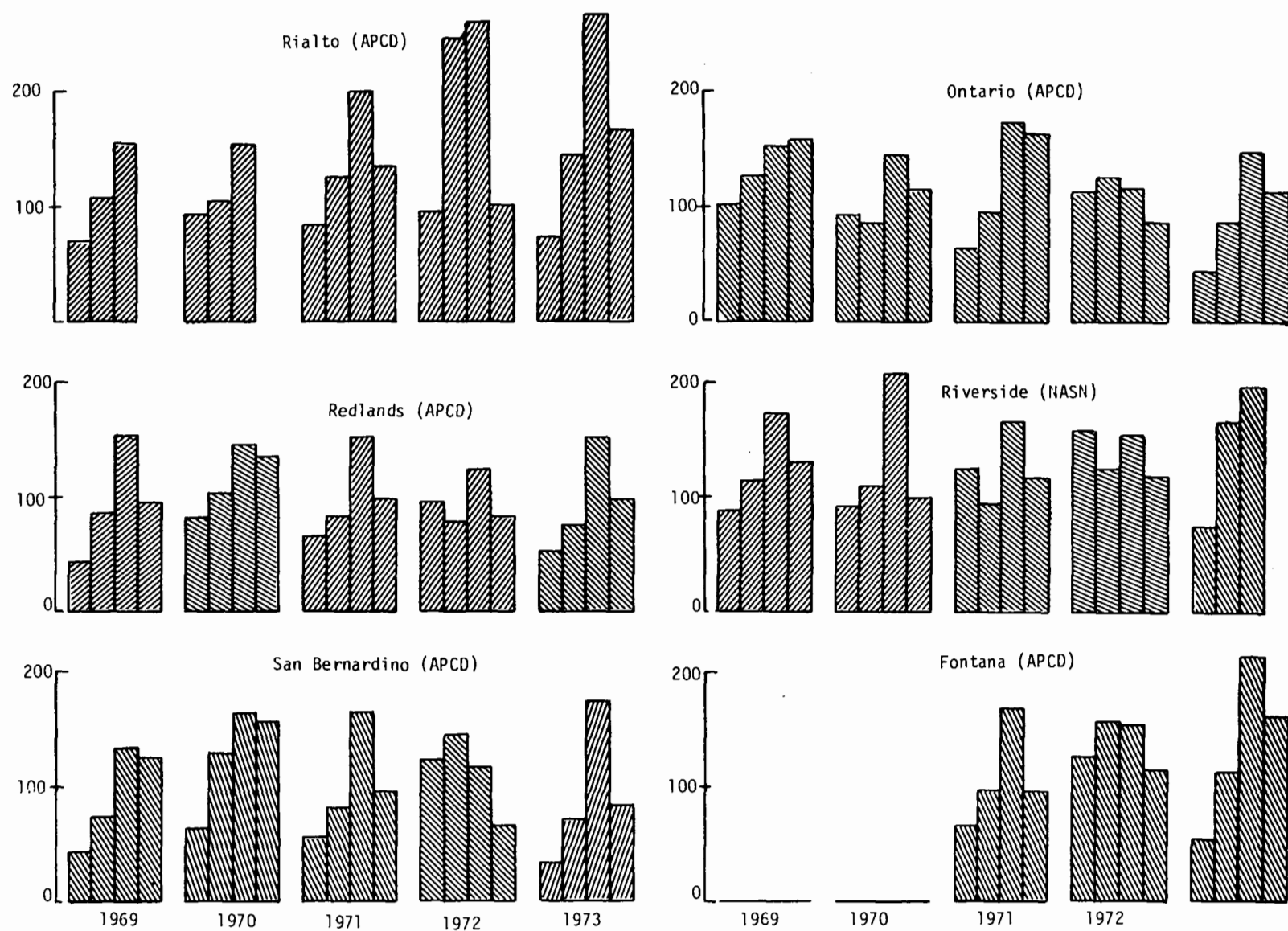


Figure 3-7 - Continued

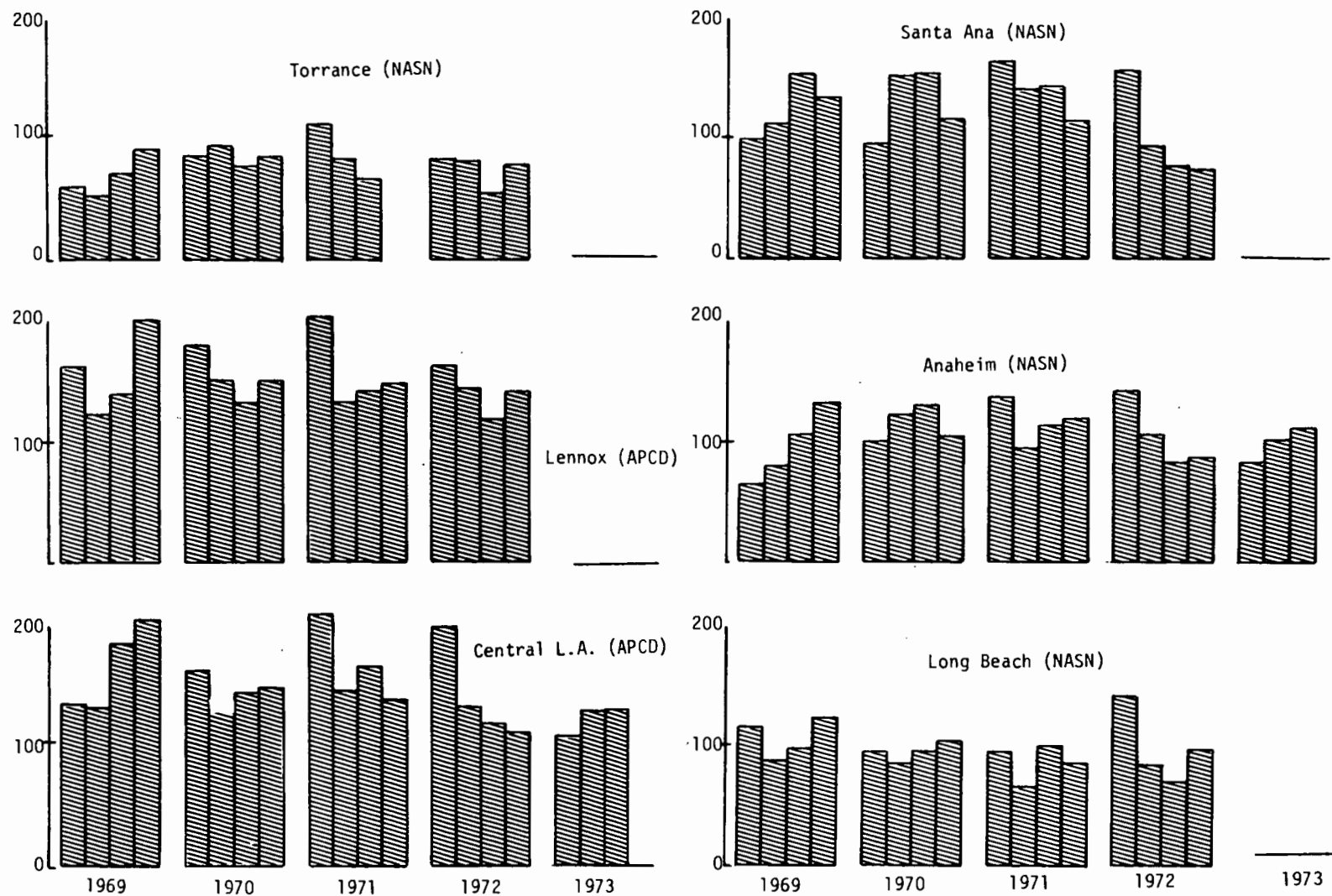


Figure 3-7 - Continued

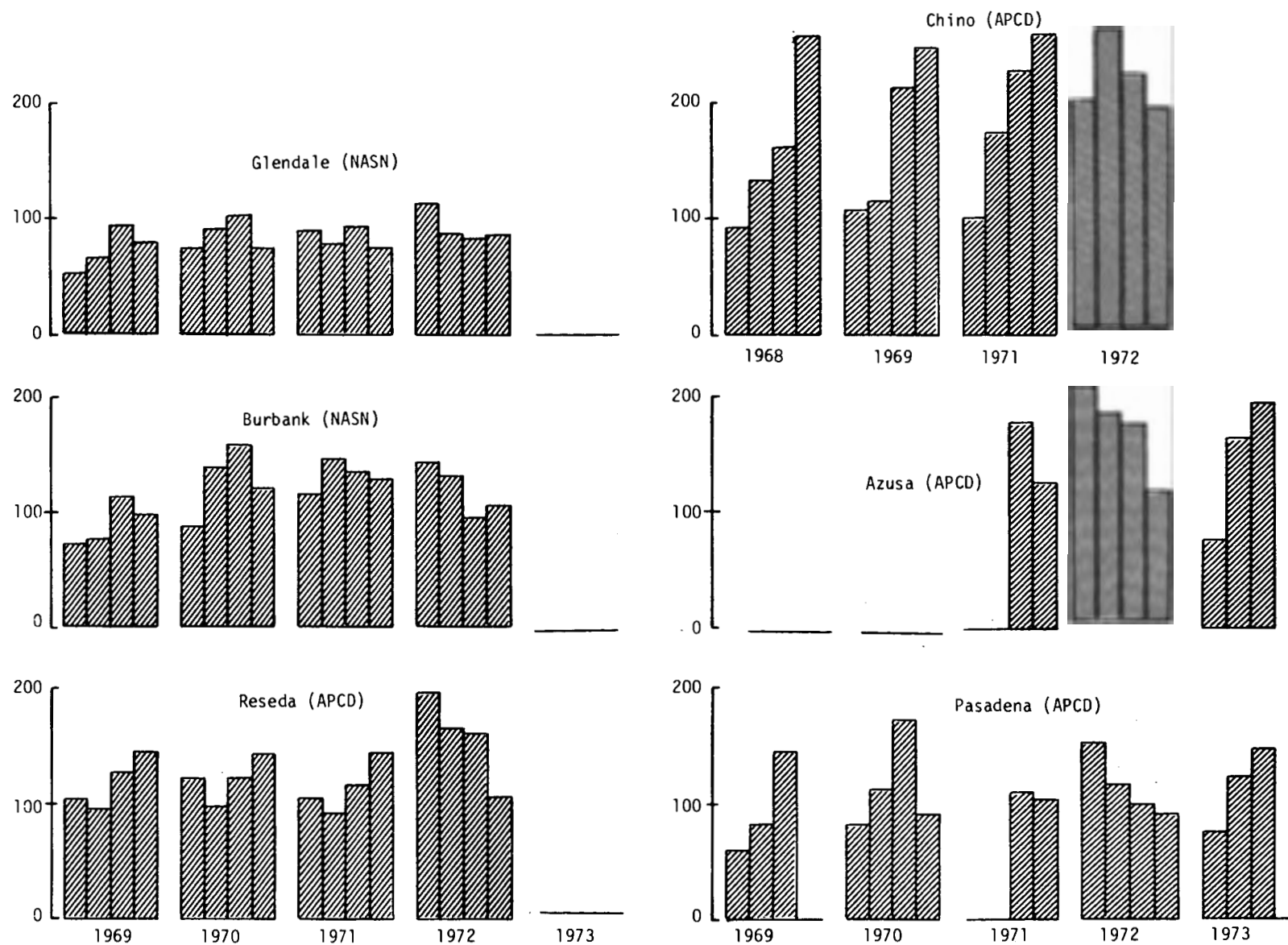


Figure 3-7  
Suspended Particulate Quarterly Geometric Means ( $\mu\text{g}/\text{m}^3$ )

TABLE 3-8  
YEARLY MAXIMAL HI-VOL LEVELS IN THE LOS ANGELES REGION

County	Station	C <sub>70</sub> Calculated 7/71 to 6/73								Calculated C <sub>365</sub>
			1973	1972	1971	1970	1969	1968	1967	
Los Angeles	Central L. A.	APCD 336	412(386) <sup>A</sup>	310	408	365	375	295	327	414
		NASN		604	275	203	280			
	Lennox	APCD 290	262	358	367	356	291	281	289	340
	West L.A.	APCD 172	233(134) <sup>A</sup>	177	227	250	322	198	224	200
	W. San Fer Valley	APCD 356	536(307) <sup>A</sup>	350	450	312	480	190	332	446
	Azusa	APCD 323	686(298) <sup>A</sup>	315	430	-	-	-	-	-
	Pasadena	APCD 210	624(205) <sup>A</sup>	207	240		-	-	-	-
Orange	Anaheim	APCD 240	345	259	294	357	266	-	-	290
		NASN		260	325	224	261	-	-	
	La Habra	APCD 360	252	301	356	-	-	-	-	460
San Bernardino	San Bernardino	APCD 411	360	437	419	-	-	-	-	540
		NASN		308	241	314	245	-	-	
	Ontario	APCD 275	455	342	211	230	391	-	-	360
	Rialto	APCD 550	620	610	247	276	462	-	-	780
	Chino	APCD 710	402	768	333	248	600	-	-	1100
Riverside	Riverside APCD	APCD 395	370	359	609 (366) <sup>B</sup>	246	-	-	-	499
		NASN		242	241	314	245	-	-	
Oxnard	Oxnard	APCD 166	176	166	149	114	-	-	-	200
Santa Barbara	Santa Barbara	APCD 147	NA	NA	NA					200

<sup>A</sup> The number in parenthesis is the next highest day in 1973. All high values from the L.A. APCD in 1973 occurred in the same unusually high day, 20 August 1973. On 20 August 1973 a rare meteorological condition occurred with extremely high winds (up to 100 miles per hour) blowing in the South-East desert area for a short time. It has been postulated that these winds carried dust into the Los Angeles Basin where settling accounted for extreme Hi-Vol levels, [64].

<sup>B</sup> The next highest value in 1971.

TABLE 3-9  
COMPARISON OF CALCULATED 24 HOUR MAXIMA TO  
AVERAGE YEARLY MAXIMA FROM 1969 - 1973

County	Station	C <sub>70</sub> Distribution from Distribution 7/71 - 6/73	Average of Yearly APCD Maxima <sup>c</sup> 1969 - 1973
Los Angeles	Central L.A.	336	369
	Lennox	290	327
	West L.A.	172	222
	W. San Fer. Valley	356	380
	Azusa	323	348 <sup>a</sup>
	Pasadena	210	217 <sup>a</sup>
Orange	Anaheim	240	304
	La Habra	360	303 <sup>a</sup>
San Bernardino	San Bernardino	411	405
	Ontario	275	326
	Rialto	550	443
	Chino	710	470
Riverside	Riverside	395	396 <sup>b</sup>
Ventura	Oxnard	166	151 <sup>b</sup>

<sup>a</sup> Data available only from 1971 to 1973.

<sup>b</sup> Data available only from 1970 to 1973.

<sup>c</sup> Excludes data on August 20, 1973 in Los Angeles County.



the expected maxima. It is not certain which of these factors prevail. This problem will be discussed further in Section 4.0 where the typical basin-wide maximum will be characterized.

The following two sections will try to provide some insight into the meteorology associated with high particulate readings. Section 3.5.1 will discuss seasonal Hi-Vol patterns at various locations. Section 3.5.2 will provide data on specific episodes of exceptional ambient particulate levels.

### 3.5.1 Seasonal Pattern of Total Particulate Concentrations

Figure 3-7 presents the quarterly Hi-Vol geometric means at 18 Los Angeles Region stations for the period 1969 to 1971. These quarterly plots give a rough indication of seasonal particulate mass distribution. The seasonal distributions fluctuate considerably from year to year because of the statistical limitations involving the few number of Hi-Vol measurements taken each season. However, a close examination of the data reveals the following conclusions:

- The stations in the southwest part of the basin near the coast (Torrance, Lennox, Downtown Los Angeles, Reseda, Anaheim, Santa Ana, and Long Beach) tend to have high values in the winter, typically during the first quarter.
- The stations in the central valleys (Glendale, Burbank and Pasadena) do not appear to exhibit strong seasonal patterns.
- The stations in the inland eastern-most parts of the basin (Azusa, Chino, Rialto, Ontario, Riverside, Redlands, San Bernardino, and Fontana) tend to have high readings in the summer and fall months, typically the third quarter.

These qualitative conclusions are very consistent with known facts about particulate origins, meteorology, and pollution distributions in the Los Angeles Region. The Los Angeles aerosol is composed of both

primary (directly emitted) particulate and secondary (formed in the atmosphere by chemical-physical processes) particulate. The primary and secondary sources are of the same order of magnitude, (Report #3 of this project will discuss the relative contribution of various sources in detail). Now, it is known that primary contaminants (e.g. CO) reach maximal levels in the southwest portion of the basin and that the highest levels occur during the winter. It is also known that photochemical smog, a principle source of secondary contaminants, is most intense in the inland (downwind) portions of the basin and that summer-fall is the "in-season" for photochemical pollution. The high values for particulate in the southwest basin during the winter appear to reflect the importance of the primary aerosol, (particularly to coastal areas). The high summer-fall values for particulate in the eastern basin reflect the importance of the secondary aerosol, (particularly to the eastern area). The fact that the intermediate, central valley stations demonstrate no strong seasonal pattern suggests a close overall balance there between primary and secondary contributions. This evidence does not imply that the western basin has very little secondary aerosol nor that the eastern basin has very little primary aerosol; it just an indication of the overall balance between the two particulate sources and the trend for secondary pollutants to become relatively more important in downwind areas.

### 3.5.2 Analysis of Recent Particulate Episodes

To shed further light on the types of days associated with maximal Hi-Vol levels, data were compiled concerning specific particulate episodes. Table 3-10 lists data on eight episodes which have occurred during the 1970's in the west-coastal portions of the basin, (Los Angeles

TABLE 3-10  
PARTICULATE EPISODES IN THE WEST-CENTRAL  
BASIN DURING THE 1970's

Date	Conc. μg/m <sup>3</sup>	SO <sub>4</sub> <sup>=</sup>	NO <sub>3</sub> <sup>-</sup>	Pb	OX CO (PPM)	Weather & Comments
01-21-70						
Central L.A.	365	45	21	5.8	.03 26	Low oxident, high humidity, morning surface inversion, overcast day <u>Forecast</u> - Night & morning low clouds and fog, hazy afternoon sunshine <u>Forecast</u> - Orange County: Dense fog through midmorn(s)
Lennox	245	32	3.1	2.9	.03 21	
West L.A.	250	36	3.8	5.4	.04 18	
WSFV	312	28	5.3	16.6	.14 22	
Anaheim (1-22-70)	324	43	50	NA	.04 10	
<u>11-18-70</u>						
Central	310	22	31	12	.04 28	Low oxident, tail end of a period of morning surface inversions <u>Forecast</u> - Strong gusty winds in foothill & valley areas, moderate wind over most of basin
West L.A.	200	13.0	14.4	12	.07 24	
<u>11-09-71</u>						
Central	305	40	24	11	<.08 24	Low oxidant, low inversion <u>Forecast</u> - night & morning low clouds, fog, hazy sunshine in afternoon
Lennox	277	1.8	2.5	9	.08 32	
West L.A.	223	36	10	12	.10 19	
WSFV	218	27	10	11	.07 33	
Azusa	415	44	43	10	.19 13	
<u>02-17-72</u>						
Central	295	35	19	9	NA 11	Low-medium oxidant, low inversion, night and morning low clouds & fog.
WSFV	280	26	18	13	.16 17	
Azusa	320	30	26	8	.15 10	
<u>02-13-72</u>						
Azusa	280	27	34	8	.05 13	Low oxidant, high CO, low inversion for wintertime, high humidity, night and morning low clouds & fog
WSFV	350	36	27	15	.06 29	
Pasadena	204	26	21	6	.05 11	
<u>08-10-72</u>						
WSFV	300	24	22	4	.17 4	Medium oxidant, low inversion in morning, hazy afternoon sunshine
Azusa	290	27	20	3	.24 5	
<u>08-20-73</u>						
Central	412	12	-	5	.09 13	Low oxidant, surface inversion, morning inversion highs had been lowering for several days, cloudy. Followed a long smog period.
Azusa	686	7.7	-	2	.05 4	
WLA	223	6.3	-	3	.03 10	
WSFV	536	27	-	6	.08 9	
Pasadena	624	12	-	3	.06 8	

and Orange Counties). Measured Hi-Vol levels are listed for stations which experienced exceptional levels, (relative to that station). Also given are particulate composition data, oxidant levels, maximal CO one hour concentrations, and a weather brief, (obtained from the National Weather Service).

Table 3-10 reveals that six of the eight episodes in the west-coastal area occurred during the winter. This corroborates the conclusion of the previous section that Hi-Vol levels reach a maximum in this area during the winter season. A low inversion consistently occurred on the six days. There also appears to be high humidity on all days but one. Oxidant values are low and CO values are high.

The low inversions, high CO levels, and low OX levels appear to indicate that primary particulates are probably the major source for these episodes. This conclusion is supported by atypically high lead levels, (see Report #3, for average Pb values). However, the presence of high humidity and large amounts of sulfate ( $\text{SO}_{4,+}^-$ ) and nitrate ( $\text{NO}_3^-$ ) may imply that non-photochemical secondary aerosol is also important on these days. The interaction of water vapor with  $\text{SO}_2$ ,  $\text{NO}_2$ , and ammonia is a very plausible source of high sulfate and nitrate components in the aerosol, [63].

The other two episodes in the west-coastal basin occurred in August. The relatively low CO and Pb levels do not point toward primary particulate sources. Photochemical aerosol may have been dominant on these days. 8-10-72 exhibited medium oxidant, and although 8-20-73 had low oxidant, it followed a period of intense photochemical smog.

Table 3-11 presents data on recent particulate episodes in the eastern part of the basin at San Bernardino. Hi-Vol composition data are not available for these episodes.\* There does not appear to be a strong, consistent pattern in these data. The episode days do not necessarily occur in the summer-fall months as did the quarterly maximums. The fall and winter high days are accompanied by low oxidant and strong inversions as in the case of the west-coastal basin. The spring "highs" of 1973 may be associated with photochemical activity. There is a possibility that these episodes are due to the influence of local industrial sources. This could account for the lack of overall pattern since the important weather variable might just be wind direction.

---

\* The San Bernardino APCD performs chemical analysis on quarterly composites only.

TABLE 3-11  
PARTICULATE EPISODES IN THE SAN BERNARDINO AREA  
1971 to 1973

Date	(Conc.) $\mu\text{g}/\text{m}^3$	OX One Hour Max. PPM	CO Max.	Weather & Comments
10-14-71	313	.11	8	Medium-low oxidant, low level inversion
10-27-71	413	.04	18	Low oxidant, cloudy day
01-21-72	341	.02	15	Low oxidant, strong winter inversion
03-07-72	317	.05	9	Low oxidant, cloudy
03-13-72	437	.06	10	Low oxidant, average inversion
04-26-73	284	.21	4	Medium oxidant, inversion lifting
05-22-73	245	.20	6	Medium oxidant, inversion falling
06-16-73	360	.16	4	Medium oxidant, tail end of an inversion period

#### 4.0 CHARACTERIZATION OF HI-VOL LEVELS IN THE METROPOLITAN LOS ANGELES AIR QUALITY CONTROL REGION

Sections 3.4 and 3.5 summarized base year (1972) Hi-Vol levels in the Metropolitan Los Angeles Air Quality Control Region. Figures 3-4 and 3-5 presented data on annual geometric means. Figure 3-6 gave results for expected yearly 24 hour maxima. The measured Hi-Vol levels will be discussed and analyzed below with particular attention given to a comparison with the National Ambient Air Quality Standards.

Figures 3-4 through 3-6 reveal that Hi-Vol levels do not follow a consistent large scale spatial pattern throughout the basin. It is true that coastal (generally upwind) areas and Ventura and Santa Barbara Counties are consistently lower in measured particulate levels. However, the inland stations show no well defined pattern and it is not possible to draw meaningful pollution contour maps to the Hi-Vol data at the present level of spatial resolution (over 30 sites). For instance, in the eastern Los Angeles County - western San Bernardino County region, within a radius of about 10 miles, the following scatter of AGM's is reported:

Azusa	150 $\mu\text{g}/\text{m}^3$	(Los Angeles APCD)
Glendora	97 $\mu\text{g}/\text{m}^3$	(CHESS)
West Covina	99 $\mu\text{g}/\text{m}^3$	(CHESS)
Ontario	110 $\mu\text{g}/\text{m}^3$	(San Bernardino APCD)
Chino	194 $\mu\text{g}/\text{m}^3$	(San Bernardino APCD)

The explanation for this lack of general spatial pattern involves the origins of the Los Angeles aerosol. A significant portion of suspended particulates are primary particulates, (emitted as an aerosol). It is known that for primary contaminants, such as carbon monoxide, that measured levels can be very

sensitive to the location of the monitoring instrument; significant local distortions in ambient levels are produced by nearby sources. Thus, an explanation for the discrepancy between Glendora and Chino is that the Glendora site is located in an isolated suburban area, while Chino is influenced by strong primary sources (probably the Kaiser-Edison complex) in the western San Bernardino area, [57], [58]. A similar situation exists in the southwest coastal area of Los Angeles County. Lennox, downwind of a power plant, refinery, and airport and near a busy intersection, shows an AGM of  $134 \mu\text{g}/\text{m}^3$  while more "out of the way" stations at Santa Monica, Torrance, and West Los Angeles yield only 69, 73, and  $84 \mu\text{g}/\text{m}^3$  respectively.

Some of the aerosol is secondary in nature, (formed by transformation of gaseous pollutants). It might be expected that this part of the aerosol would follow more consistent large scale patterns. For the secondary gaseous pollutant, oxidant, researchers have shown that fairly well defined contour maps can be drawn. However, it appears for particulates that the material of primary origin produces local fluctuations which conceal any general spatial pattern.

Another reason for the lack of pattern could be inconsistencies in monitoring techniques. Section 3.3 pointed out that NASN and APCD data at the same location are sometimes significantly different. Discrepancies in sampling procedures at different sites undoubtedly do produce some fluctuations; however, the major reason for the spatial variations would seem to be the influence of local sources as discussed above.

As seen in Figures 3-4 through 3.6, the federal secondary air quality standards ( $60 \mu\text{g}/\text{m}^3$  annual average and  $150 \mu\text{g}/\text{m}^3$  24 hr. maximum) are presently violated at all monitoring sites in the Los Angeles Region (except for the CHESS site at Thousand Oaks). Nearly all sites in



Los Angeles, Orange, Riverside, and San Bernardino Counties also violate the primary annual standard ( $75 \mu\text{g}/\text{m}^3$ , AGM). The only exceptions are Torrance ( $73 \mu\text{g}/\text{m}^3$  NASN), Santa Monica ( $69 \mu\text{g}/\text{m}^3$  CHES), and Costa Mesa ( $67 \mu\text{g}/\text{m}^3$  Orange APCD). The maximum AGM value occurs at Chino ( $200 \mu\text{g}/\text{m}^3$ ), with Rialto second at  $174 \mu\text{g}/\text{m}^3$ . About 2/3 of the stations in the four county sub-area report values in the  $95\text{-}140 \mu\text{g}/\text{m}^3$  range. Ventura County AGM values tend to fall very near to the primary standard.\* Santa Barbara ( $64 \mu\text{g}/\text{m}^3$ ) is below the primary annual standard.

The expected maximum 24 hour values have been calculated only for 12 stations due to data availability. Indications are that 24 hour maxima fall well below the primary standard ( $260 \mu\text{g}/\text{m}^3$ ) in Ventura and Santa Barbara Counties. In the four county area, Chino ( $710 \mu\text{g}/\text{m}^3$ ), Rialto ( $550 \mu\text{g}/\text{m}^3$ ), Riverside ( $470 \mu\text{g}/\text{m}^3$ ), and San Bernardino ( $411 \mu\text{g}/\text{m}^3$ ) show particularly high values above the 24 hour standard. As noted in Section 3.5, the method used to estimate expected maxima appears to give low values for Los Angeles County data. Maxima around  $375 \mu\text{g}/\text{m}^3$  would be a more conservative estimate for the highest L.A. County station, (See Table 3-9).

For the purposes of control strategy formulation, it is useful to determine an overall measured level of particulate mass that characterizes the basin. The object of control policy is then to reduce this level to the air quality standards. Of course, since there is such great spatial variation in aerosol mass, no one level really characterizes the entire basin. A number of characteristic levels for several subareas thus

---

\* The only exception is Port Hueneme ( $97 \mu\text{g}/\text{m}^3$ ); the probable major source there is sea salt.

seems appropriate. In choosing an explicit number of areas a balance should be struck between simplicity and realism. The fewer the subareas the easier it is to formulate, implement, and administer a control program. The greater the number of areas, the more specific and efficient the control program.

Tentatively, a three-area classification of Hi-Vol levels is proposed (See Figure 4-1). Table 4-1 lists the three areas along with the characteristic maximal AGM's and 24 hour extrema. It should be emphasized that the characteristic values in Table 4-1 are not the typical values for the area but rather the expected high values among all sites in the area. These characteristic expected maximal values are approximate; the numbers are rounded to reflect their approximate nature.

TABLE 4-1  
CHARACTERISTIC MAXIMAL HI-VOL LEVELS FOR THREE SUBAREAS OF THE  
METROPOLITAN LOS ANGELES AIR QUALITY CONTROL REGION  
(FOR BASE YEAR 1972)

<u>Area</u>	Characteristic Maximal AGM	Characteristic Maximal 24 Hour Extremum
	Primary Standard $75 \mu\text{g}/\text{m}^3$ <u>Secondary Standard    <math>60 \mu\text{g}/\text{m}^3</math></u>	Primary Standard $260 \mu\text{g}/\text{m}^3$ <u>Secondary Standard    <math>150 \mu\text{g}/\text{m}^3</math></u>
A-Ventura and Santa Barbara Counties	$80 \mu\text{g}/\text{m}^3$	$180 \mu\text{g}/\text{m}^3$
B-Los Angeles, Orange, San Bernardino, and Riverside Counties (except area C below)	$150 \mu\text{g}/\text{m}^3$	$470 \mu\text{g}/\text{m}^3$
C-East San Bernardino County "Hot-Spot"	$200 \mu\text{g}/\text{m}^3$	$710 \mu\text{g}/\text{m}^3$

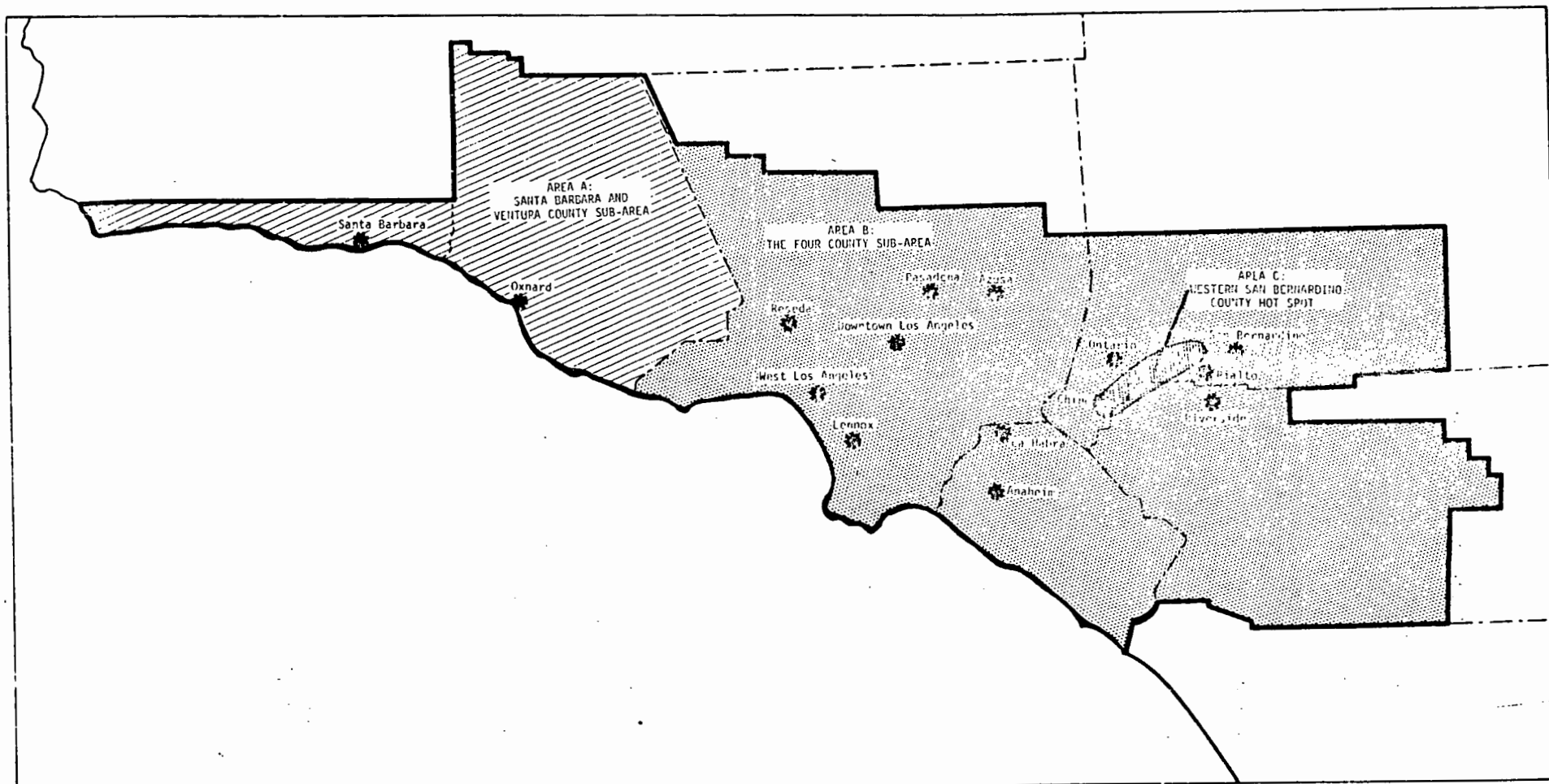


Figure 4-1 Sub-Areas for Control Strategy Formulation

## REFERENCES

1. Jutze, G. A., and Foster, K.E., "Recommended Standard Method for Atmospheric Sampling of Fine Particulate Matter by Filter-Media/High Volume Sampling," Air Pollution Control Association J., 17 (1), p 17 (1967).
2. Methods of Air Sampling and Analysis, Intersociety Committee, American Public Health Association, Inc., p 365 (1972).
3. "Guideline for the Development of a Quality Assurance Program for High-Volume Sampling," U. S. Environmental Protection Agency R4-73-028b, June 1973, p 25.
4. IBID (3) p 26.
5. IBID, p 66.
6. Robson, C.D., and Foster, K.E., "Evaluation of Air Particulate Sampling Equipment," Am. Ind. Hygiene Assoc. J., 23, p 404-410 (1962).
7. Op. Cit. (3) p 70
8. Op. Cit. (3) p 66.
9. "Air Quality Criteria for Particulate Matter," U.S. Dept. of Health, Education and Welfare, Jan. 1969, p 19.
10. Pate, J.B., Tabor, E.C., "Analytical Aspects of the Use of Glass Fiber Filters for Collection and Analysis of Atmospheric Particulate Matter," Am. Ind. Hygiene Assoc. J., 23, 144 (1962).
11. Op. Cit.(3) p 35.
12. Mueller, P.K., "Selection of Filter Media: An Annotated Outline," 13th Conf. Methods On Air Pollution and Industrial Hygiene, Univ. of Calif. at Berkeley, October 30-31, 1972.
13. Lee, R.E., and Wagman, J., "A Sampling Anomaly In the Determination of Atmospheric Sulfates," Am. Ind. Hygiene Assoc. J., Vol. 27: 266-71 (1966).
14. Burton, R.M., et al, "Field Evaluation of Hi-Volume Particulate Fractionating Cascade Impactor," 65th Annual Meeting of Air Pollution Control Association, June 18-22 (1972), Miami Beach, Florida;
15. Hidy, et al, "Characterization of Aerosols in California (ACHEX), Interm Report, Phase I, Rockwell International Science Center, California ARB Contract #358 (1974) p. 283.
16. IBID (15) p 339.

17. Tierney, G.P., and Conner, W.D., "Hygroscopic Effects on Weight Determination of Particles Collected on Glass Fiber Filters," Am. Industrial Hygiene Assoc. J. Vol. 28, p 363 (1967).
18. Margil Wadley, Chemist, LA APCD, Private Conversation 4/19/74.
19. Op . cit. (15), p 307.
20. Op . cit. (3), p 65.
21. Peter Mueller, Region IX, EPA, Private Conversation 3/28/74.
22. Op . cit.(3) p 65.
23. Lee, R.E., et al, "Evaluation of Methods of Measuring Suspended Particulates in the Atmosphere," 162nd National Meeting of the American Chemical Society, Washington, D.C., Dec. 12-17, 1971.
24. Clements, H.A., et al, "Reproducibility of the Hi-Vol Sampling Method Under Field Conditions," J. Air Pollution Control Asso., Vol. 22, #12 p. 955 (1972).
25. Faora, R., "Collaborative Study of The Reference Method for Determination of Suspended Particulates in the Atmosphere," U.S. Environmental Protection Agency, APTD-0302, PB 205-892 (1972).
26. Cohen, A.L., et al., "Dependence of Hi-Vol Measurements on Airflow Rate," Environmental Science and Technology, Vol. 7, #1, p 61 (1973).
27. Rainwater, L.E., and Moyers, J.L., "Atomic Adsorption Procedure for Analysis of Metals in Atmospheric Particulate Matter," Environmental Science & Technology, Vol. 8, #2, p 152, February (1974).
28. Op. cit. (2) p.305.
29. Keenan, R.G., et al., "USPHS Method for Determining Lead in Air and In Biological Materials," Am. Ind. Hyg. Assoc. J, 24, 481-91 (1963).
30. Op. cit. (2) p 442.
31. Op. cit. (2) p 332.
32. Brown, E. et al, "Collection and Analysis of Water Samples for Dissolved Minerals and Gases," U.S. Geological Survey Publication, p 119.
33. Op. cit. ( 3 ) p. 305.
34. Holmes, John, "Photochemical Aerosol Formation in The Atmosphere and In An Environmental Chamber," presented at 167th Material Meeting of American Chemical Society, March 31- April 5, 1974, Los Angeles, Calif.

35. Op. cit. (15) p 388.
36. Op. cit.(15) p 387.
37. National Air Sampling Network Data, U.S. Environmental Protection Agency, 1968.
38. San Bernardino County APCD data, 1969-1973.
39. Op. cit. (15), p 285-289.
40. John Holms, Chemist with California Air Resources Board, private conversation, 4/4/74.
41. Whitdy, K.T., and Liu, B.Y., "Atmospheric Particulate Data - What Does It Tell Us About Air Pollution," 11th Conf./ Methods of Air Pollution and Ind. Hygiene, Berkeley, California, 1970.
42. Op. cit. (1), p 18.
43. Steven Bromberg, U.S. Environmental Protection Agency, private conversation, 4/1/74.
44. Gerald Brown, Sr., Instrument Tech. San Bernardino APCD, private conversation, 4/11/74.
45. Margil Wadley, Chief Chemist, L.A. APCD, private conversations.
46. George Sanderson, chemist, San Bernardino APCD, private conversations.
47. William Bope, chemist, Orange County APCD, private conversations.
48. Larsen, R.I., "A Mathematical Model for Relating Air Quality Measurements to Standards," U.S. Environmental Protection Agency Office of Air Programs Publication #AP-89, November 1971.
49. Walker, H.M. and Lev, J., "Elementary Statistical Methods," 3rd Edition, Holt, Rinehart, and Winston, Inc. 1969, p 353.
50. IBID, p 260.
51. IBID, p 164.
52. Thomas Hartledge, Environmental Protection Agency, private conversation, 4/4/74.
53. Thompson, R., University of California Riverside, private conversation, 4/5/74.
54. Jose Sun , Environmental Protection Agency, private conversation, 4/2/74.

55. Burton, R.M., et al, "Field Evaluation of Hi-Volume Particulate Fractionating Cascade Impactor," 65th Annual Meeting of Air Pollution Control Association, Miami Beach, Florida, June 18-22 (1972).
56. Hunt, W.F., "Precision Associated with Sampling Frequency of Log-Normally Distributed Air Pollutant Measurements," J. Air Pollution Control Assoc, Vol. 22 #9, 687 (1972).
57. Zeldin, M.D., "Oxidant Distribution and Analysis in the San Bernardino Basin," Technical Report #73-1, San Bernardino APCD, March, 1973.
58. Zeldin, M.D., and Sanderson, G., private conversations 4/11/74.
59. Molnar, Dean, Ventura APCD private conversation 5/2/74.
60. Grosjean, Daniel, Caltech, private conversation 4/14/74.
61. McKee, C.H., et al, "Collaboration Testing of Methods to Measure Air Pollutants", J. Air Pollution Control Association, Vol. 22, #5 342(1972).
62. Whitby, K.T., Hursar, R.B., Liu, Y.H., J. Colloid Interface Sci. 39,117 (1972).
63. Appell, Bruce, State Industrial Hygiene Laboratories, private conversation, 4/74.
64. Duckworth, Spencer, Meteorologist, California Air Resources Board, Personal communication, June 1974.

## APPENDIX A

### REFERENCE METHOD FOR THE DETERMINATION OF SUSPENDED PARTICULATES IN THE ATMOSPHERE (HIGH VOLUME METHOD)

Reproduced from Appendix B, "National Primary and Secondary  
Ambient Air Standards," *Federal Register*, Vol 36, No. 84, Part II,  
Friday, April 30, 1971.

#### APPENDIX B—REFERENCE METHOD FOR THE DETERMINATION OF SUSPENDED PARTICULATES IN THE ATMOSPHERE (HIGH VOLUME METHOD)

##### 1. Principle and Applicability.

1.1 Air is drawn into a covered housing and through a filter by means of a high-flow-rate blower at a flow rate (1.13 to 1.70 m.<sup>3</sup>/min.; 40 to 60 ft.<sup>3</sup>/min.) that allows suspended particles having diameters of less than 100  $\mu$ m. (Stokes equivalent diameter) to pass to the filter surface. (1) Particles within the size range of 100 to 0.1  $\mu$ m. diameter are ordinarily collected on glass fiber filters. The mass concentration of suspended particulates in the ambient air ( $\mu$ g./m.<sup>3</sup>) is computed by measuring the mass of collected particulates and the volume of air sampled.

1.2 This method is applicable to measurement of the mass concentration of suspended particulates in ambient air. The size of the sample collected is usually adequate for other analyses.

##### 2. Range and Sensitivity.

2.1 When the sampler is operated at an average flow rate of 1.70 m.<sup>3</sup>/min. (60 ft.<sup>3</sup>/min.) for 24 hours, an adequate sample will be obtained even in an atmosphere having concentrations of suspended particulates as low as 1  $\mu$ g./m.<sup>3</sup>. If particulate levels are unusually high, a satisfactory sample may be obtained in 8 to 8 hours or less. For determination of average concentrations of suspended particulates in ambient air, a standard sampling period of 24 hours is recommended.

2.2 Weights are determined to the nearest milligram, airflow rates are determined to the nearest 0.03 m.<sup>3</sup>/min. (1.0 ft.<sup>3</sup>/min.), times are determined to the nearest 2

minutes, and mass concentrations are reported to the nearest microgram per cubic meter.

##### 3. Interferences.

3.1 Particulate matter that is oily, such as photochemical smog or wood smoke, may block the filter and cause a rapid drop in airflow at a nonuniform rate. Dense fog or high humidity can cause the filter to become too wet and severely reduce the airflow through the filter.

3.2 Glass-fiber filters are comparatively insensitive to changes in relative humidity, but collected particulates can be hygroscopic. (2)

##### 4. Precision, Accuracy, and Stability.

4.1 Based upon collaborative testing, the relative standard deviation (coefficient of variation) for single analyst variation (repeatability of the method) is 3.0 percent. The corresponding value for multi-laboratory variation (reproducibility of the method) is 3.7 percent. (3)

4.2 The accuracy with which the sampler measures the true average concentration depends upon the constancy of the airflow rate through the sampler. The airflow rate is affected by the concentration and the nature of the dust in the atmosphere. Under these conditions the error in the measured average concentration may be in excess of  $\pm 50$  percent of the true average concentration, depending on the amount of reduction of airflow rate and on the variation of the mass concentration of dust with time during the 24-hour sampling period. (4)

##### 5. Apparatus.

###### 5.1 Sampling.

5.1.1 Sampler. The sampler consists of three units: (1) the faceplate and gasket, (2) the filter adapter assembly, and (3) the motor unit. Figure B1 shows an exploded view of these parts, their relationship to each

other, and how they are assembled. The sampler must be capable of passing environmental air through a 406.5 cm.<sup>2</sup> (63 in.<sup>2</sup>) portion of a clean 20.3 by 25.4 cm. (8- by 10-in.) glass-fiber filter at a rate of at least 1.70 m.<sup>3</sup>/min. (60 ft.<sup>3</sup>/min.). The motor must be capable of continuous operation for 24-hour periods with input voltages ranging from 110 to 120 volts, 50-60 cycles alternating current and must have third-wire safety ground. The housing for the motor unit may be of any convenient construction so long as the unit remains airtight and leak-free. The life of the sampler motor can be extended by lowering the voltage by about 10 percent with a small "buck or boost" transformer between the sampler and power outlet.

5.1.2 Sampler Shelter. It is important that the sampler be properly installed in a suitable shelter. The shelter is subjected to extremes of temperature, humidity, and all types of air pollutants. For these reasons the materials of the shelter must be chosen carefully. Properly painted exterior plywood or heavy gauge aluminum serve well. The sampler must be mounted vertically in the shelter so that the glass-fiber filter is parallel with the ground. The shelter must be provided with a roof so that the filter is protected from precipitation and debris. The internal arrangement and configuration of a suitable shelter with a gable roof are shown in Figure B2. The clearance area between the main housing and the roof at its closest point should be 580.5  $\pm$  133.5 cm.<sup>3</sup> (90  $\pm$  30 in.<sup>3</sup>). The main housing should be rectangular, with dimensions of about 29 by 36 cm. (11  $\frac{1}{2}$  by 14 in.).

5.1.3 Rotameter. Marked in arbitrary units, frequently 0 to 70, and capable of being calibrated. Other devices of at least comparable accuracy may be used.



**8.1.4 Orifice Calibration Unit.** Consisting of a metal tube 7.6 cm. (3 in.) ID and 18.9 cm. (6 3/4 in.) long with a static pressure tap 8.1 cm. (3 1/8 in.) from one end. See Figure B3. The tube end nearest the pressure tap is flanged to about 10.5 cm. (4 1/4 in.) OD with a male thread of the same size as the inlet end of the high-volume air sampler. A single metal plate 9.2 cm. (3 5/8 in.) in diameter and 0.24 cm. (1 1/2 in.) thick with a central orifice 2.9 cm. (1 1/4 in.) in diameter is held in place at the air inlet end with a female threaded ring. The other end of the tube is flanged to hold a loose female threaded coupling, which screws onto the inlet of the sampler. An 18-hole metal plate, an integral part of the unit, is positioned between the orifice and sampler to simulate the resistance of a clean glass-fiber filter. An orifice calibration unit is shown in Figure B3.

**8.1.5 Differential Manometer.** Capable of measuring to at least 40 cm. (16 in.) of water.

**8.1.6 Posttype Displacement Meter.** Calibrated in cubic meters or cubic feet, to be used as a primary standard.

**8.1.7 Barometer.** Capable of measuring atmospheric pressure to the nearest mm.

## 8.2 Analysis.

**8.2.1 Filter Conditioning Environment.** Balance room or desiccator maintained at 15° to 35°C. and less than 50 percent relative humidity.

**8.2.2 Analytical Balance.** Equipped with a weighing chamber designed to handle unfolded 20.3 by 25.4 cm. (8- by 10-in.) filters and having a sensitivity of 0.1 mg.

**8.2.3 Light Source.** Frequently a table of the type used to view X-ray films.

**8.2.4 Numbering Device.** Capable of printing identification numbers on the filters.

## 6. Reagents.

**6.1 Filter Media.** Glass-fiber filters having a collection efficiency of at least 99 percent for particles of 0.3 µm. diameter, as measured by the DOP test, are suitable for the quantitative measurement of concentrations of suspended particulates, (5) although some other medium, such as paper, may be desirable for some analyses. If a more detailed analysis is contemplated, care must be exercised to use filters that contain low background concentrations of the pollutant being investigated. Careful quality control is required to determine background values of these pollutants.

## 7. Procedure.

### 7.1 Sampling.

**7.1.1 Filter Preparation.** Expose each filter to the light source and inspect for pinholes, particles, or other imperfections. Filters with visible imperfections should not be used. A small brush is useful for removing particles. Equilibrate the filters in the filter conditioning environment for 24 hours. Weigh the filters to the nearest milligram; record tare weight and filter identification number. Do not bend or fold the filter before collection of the sample.

**7.1.2 Sample Collection.** Open the shelter, loosen the wing nuts, and remove the faceplate from the filter holder. Install a numbered, preweighed, glass-fiber filter in position (rough side up), replace the faceplate without disturbing the filter, and fasten securely. Undertightening will allow air leakage, overtightening will damage the sponge-rubber faceplate gasket. A very light application of talcum powder may be used on the sponge-rubber faceplate gasket to prevent the filter from sticking. During inclement weather the sampler may be removed to a protected area for filter change. Close the roof of the shelter, run the sampler for about 5 minutes, connect the rotameter to the nipple on the back of the sampler, and read the rotameter ball with rotameter in a vertical position. Estimate to the nearest whole number. If the ball is fluctuating rapidly, tip the rotameter and slowly straighten it

until the ball gives a constant reading. Disconnect the rotameter from the nipple; record the initial rotameter reading and the starting time and date on the filter folder. (The rotameter should never be connected to the sampler except when the flow is being measured.) Sample for 24 hours from midnight to midnight and take a final rotameter reading. Record the final rotameter reading and ending time and date on the filter folder. Remove the faceplate as described above and carefully remove the filter from the holder, touching only the outer edges. Fold the filter lengthwise so that only surfaces with collected particulates are in contact, and place in a manila folder. Record on the folder the filter number, location, and any other factors, such as meteorological conditions or razing of nearby buildings, that might affect the results. If the sample is defective, void it at this time. In order to obtain a valid sample, the high-volume sampler must be operated with the same rotameter and tubing that were used during its calibration.

**7.2 Analysis.** Equilibrate the exposed filters for 24 hours in the filter conditioning environment, then reweigh. After they are weighed, the filters may be saved for detailed chemical analysis.

### 7.3 Maintenance.

**7.3.1 Sampler Motor.** Replace brushes before they are worn to the point where motor damage can occur.

**7.3.2 Faceplate Gasket.** Replace when the margins of samples are no longer sharp. The gasket may be sealed to the faceplate with rubber cement or double-sided adhesive tape.

**7.3.3 Rotameter.** Clean as required, using alcohol.

### 8. Calibration.

**8.1 Purpose.** Since only a small portion of the total air sampled passes through the rotameter during measurement, the rotameter must be calibrated against actual airflow with the orifice calibration unit. Before the orifice calibration unit can be used to calibrate the rotameter, the orifice calibration unit itself must be calibrated against the positive displacement primary standard.

**8.1.1 Orifice Calibration Unit.** Attach the orifice calibration unit to the intake end of the positive displacement primary standard and attach a high-volume motor blower unit to the exhaust end of the primary standard. Connect one end of a differential manometer to the differential pressure tap of the orifice calibration unit and leave the other end open to the atmosphere. Operate the high-volume motor blower unit so that a series of different, but constant, airflows (usually six) are obtained for definite time periods. Record the reading on the differential manometer at each airflow. The different constant airflows are obtained by placing a series of loadplates, one at a time, between the calibration unit and the primary standard. Placing the orifice before the inlet reduces the pressure at the inlet of the primary standard below atmospheric; therefore, a correction must be made for the increase in volume caused by this decreased inlet pressure. Attach one end of a second differential manometer to an inlet pressure tap of the primary standard and leave the other open to the atmosphere. During each of the constant airflow measurements made above, measure the true inlet pressure of the primary standard with this second differential manometer. Measure atmospheric pressure and temperature. Correct the measured air volume to true air volume as directed in 9.1.1, then obtain true airflow rate,  $Q$ , as directed in 9.1.3. Plot the differential manometer readings of the orifice unit versus  $Q$ .

**8.1.2 High-Volume Sampler.** Assemble a high-volume sampler with a clean filter in place and run for at least 5 minutes. Attach a rotameter, read the ball, adjust so that the ball reads 65, and seal the adjusting mech-

anism so that it cannot be changed easily. Shut off motor, remove the filter, and attach the orifice calibration unit in its place. Operate the high-volume sampler at a series of different, but constant, airflows (usually six). Record the reading of the differential manometer on the orifice calibration unit, and record the readings of the rotameter at each flow. Measure atmospheric pressure and temperature. Convert the differential manometer reading to  $m^3/min.$ ,  $Q$ , then plot rotameter reading versus  $Q$ .

**8.1.3 Correction for Differences in Pressure or Temperature.** See Addendum B.

### 9. Calculations.

#### 9.1 Calibration of Orifice.

**9.1.1 True Air Volume.** Calculate the air volume measured by the positive displacement primary standard.

$$V_s = \frac{(P_s - P_m)}{P_s} (V_m)$$

$V_s$  = True air volume at atmospheric pressure,  $m^3$

$P_s$  = Barometric pressure, mm. Hg.

$P_m$  = Pressure drop at inlet of primary standard, mm. Hg.

$V_m$  = Volume measured by primary standard,  $m^3$

#### 9.1.2 Conversion Factors.

Inches Hg.  $\times 25.4$  = mm. Hg.

Inches water  $\times 73.48 \times 10^{-6}$  = inches Hg.

Cubic feet air  $\times 0.0284$  = cubic meters air.

#### 9.1.3 True Airflow Rate.

$$Q = \frac{V_s}{T}$$

$Q$  = Flow rate,  $m^3/min.$

$T$  = Time of flow, min.

#### 9.2 Sample Volume.

**9.2.1 Volume Conversion.** Convert the initial and final rotameter readings to true airflow rate,  $Q$ , using calibration curve of 8.1.2.

#### 9.2.2 Calculate volume of air sampled

$$V = \frac{Q_1 Q_2}{2} \times T$$

$V$  = Air volume sampled,  $m^3$

$Q_1$  = Initial airflow rate,  $m^3/min.$

$Q_2$  = Final airflow rate,  $m^3/min.$

$T$  = Sampling time, min.

**9.3 Calculate mass concentration of suspended particulates**

$$S.P. = \frac{(W_1 - W_2) \times 10^6}{V}$$

$S.P.$  = Mass concentration of suspended particulates,  $\mu g/m^3$

$W_1$  = Initial weight of filter, g.

$W_2$  = Final weight of filter, g.

$V$  = Air volume sampled,  $m^3$

$10^6$  = Conversion of g. to  $\mu g$ .

### 10. References.

- (1) Robson, C. D., and Foster, K. E., "Evaluation of Air Particulate Sampling Equipment", *Am. Ind. Hyg. Assoc. J.* 24, 404 (1963).
- (2) Tierney, G. P., and Conner, W. D., "Hygroscopic Effects on Weight Determinations of Particulates Collected on Glass-Fiber Filters", *Am. Ind. Hyg. Assoc. J.* 28, 333 (1967).
- (3) Unpublished data based on a collaborative test involving 12 participants, conducted under the direction of the Methods Standardization Services Section of the National Air Pollution Control Administration, October, 1970.
- (4) Harrison, W. K., Nader, J. S., and Fugman, F. S., "Constant Flow Regulators for High-Volume Air Sampler", *Am. Ind. Hyg. Assoc. J.* 31, 114-120 (1960).

AN IMPLEMENTATION PLAN FOR SUSPENDED  
PARTICULATE MATTER IN THE LOS ANGELES REGION

TECHNICAL SUPPORT DOCUMENT #2

EMISSION INVENTORIES AND PROJECTIONS

By: R. L. Tan

R. Y. Wada

Prepared For

Environmental Protection Agency

Region IX - San Francisco, California

**TRW** / TRANSPORTATION AND  
ENVIRONMENTAL ENGINEERING  
OPERATIONS

AN IMPLEMENTATION PLAN FOR SUSPENDED  
PARTICULATE MATTER IN THE LOS ANGELES REGION

TECHNICAL SUPPORT DOCUMENT #2

EMISSION INVENTORIES AND PROJECTIONS

By: R. L. Tan

R. Y. Wada

Prepared For  
Environmental Protection Agency  
Region IX - San Francisco, California

**TRW** / TRANSPORTATION AND  
ENVIRONMENTAL ENGINEERING  
OPERATIONS

#### DISCLAIMER

This report was furnished to the Environmental Protection Agency by TRW Transportation and Environmental Operations in fulfillment of Contract Number 68-02-1384. The contents of this report are reproduced herein as received from the contractor. The opinions, findings, and conclusions are those of TRW and not necessarily those of the Environmental Protection Agency. Mention of company or product names does not constitute endorsement by the Environmental Protection Agency.

## TABLE OF CONTENTS

	<u>Page</u>
1.0 INTRODUCTION AND SUMMARY . . . . .	1
2.0 1972 EMISSION INVENTORY FOR THE METROPOLITAN LOS ANGELES AIR QUALITY CONTROL REGION . . . . .	19
2.1 Sources of Data . . . . .	19
2.2 Policies and Assumptions . . . . .	20
2.2.1 Air Pollution Control District Inventories . . . . .	20
2.2.2 National Emissions Data System (NEDS) Inventory. . . . .	21
2.2.3 Stationary Source NO <sub>x</sub> Emissions . . . . .	21
2.2.4 Motor Vehicle Emission Factors for Exhaust Particulates . . . . .	22
2.2.5 Motor Vehicle Emission Factors for Gaseous Precursors . . . . .	22
2.2.6 Aircraft Emissions . . . . .	22
2.2.7 Suspended Particulate Inventory . . . . .	22
2.2.8 The 4-County Sub-Area . . . . .	23
2.2.9 Hydrocarbon Reactivity Factors . . . . .	23
2.3 1972 Inventory of Particulate Matter Emissions . . . . .	24
2.3.1 Stationary Sources . . . . .	27
2.3.2 Gasoline-Powered Motor Vehicles-Exhaust Particulates . . . . .	28
2.3.3 Other Mobile Source Particulate Emissions . . . . .	32
2.4 Inventory of Gaseous Precursor Emissions . . . . .	33
2.4.1 Stationary Sources . . . . .	33
2.4.2 Motor Vehicle Emissions . . . . .	33
2.5 Locational Considerations . . . . .	37
2.6 Present Control Program for Stationary Source Emissions . . . . .	48
3.0 EMISSION PROJECTIONS . . . . .	53
3.1 Sources of Data . . . . .	53
3.1.1 Stationary Sources and Aircraft . . . . .	53
3.1.2 Motor Vehicles . . . . .	54
3.1.3 Uncontrolled Vehicles . . . . .	55

TABLE OF CONTENTS  
(continued)

	<u>Page</u>
3.2 Policies and Assumptions . . . . .	55
3.3 Emission Inventory Projection Under Present Controls . . . . .	60
3.3.1 Petroleum Industry Emissions . . . . .	60
3.3.2 Organic Solvent Users . . . . .	60
3.3.3 Chemical, Metallurgical and Mineral . . . . .	61
3.3.4 Agriculture and Incineration . . . . .	62
3.3.5 Steam Electric Power Plant Fuel Combustion Emissions . . . . .	62
3.3.6 Domestic and Commercial Fuel Combustion . . . . .	65
3.3.7 Other Industrial Fuel Combustion . . . . .	66
3.3.8 Aircraft Emissions . . . . .	75
3.3.9 Mobile Source Projection (other than Aircraft). . . . .	80
3.4 Projected Emission Inventory Under EPA Promulgated Controls . . . . .	80
3.5 Projected Emission Inventory Summary Table . . . . .	81
3.6 Discussion . . . . .	90
APPENDIX A: LOCAL AGENCY EMISSION INVENTORIES . . . . .	A-1
APPENDIX B: SUMMARY OF RECENT CHANGES IN LOCAL RULES AND REGULATIONS . . . . .	B-1
APPENDIX C: MOTOR VEHICLE EMISSIONS ESTIMATION PROCEDURE . . . . .	C-1
APPENDIX D: LOW LEAD AND UNLEADED GASOLINE . . . . .	D-1
APPENDIX E: CATALYTIC MUFFLERS . . . . .	E-1

## LIST OF TABLES

<u>Table</u>	<u>Page</u>
1-1 1972 Emission Inventory Summary - Entire Air Basin . . .	2
1-2 1972 Emission Inventory Summary - Four County Area . . .	3
1-3 1977 Emission Inventory Summary for the Entire Air Basin Under Present Controls . . . . .	7
1-4 1977 Emission Inventory Summary for the Entire Air Basin Under the EPA Oxidant Plan . . . . .	8
1-5 1977 Emission Inventory Summary for the Four County Sub-Area Under Present Controls . . . . .	9
1-6 1977 Emission Inventory Summary for the Four County Sub-Area Under the EPA Oxidant Plan . . . . .	10
1-7 1980 Emission Inventory Summary for the Entire Air Basin Under Present Controls . . . . .	11
1-8 1980 Emission Inventory Summary for the Entire Air Basin Under EPA Oxidant Plan . . . . .	12
1-9 1980 Emission Inventory Summary for the Four County Sub-Area Under Present Controls . . . . .	13
1-10 1980 Emission Inventory Summary for the Four County Sub-Area Under the EPA Oxidant Plan . . . . .	14
2-1 Alternative Hydrocarbon Reactivity Assumptions . . . . .	24
2-2 1972 Particulate Matter Inventory . . . . .	25
2-3 Power Plant Emissions . . . . .	27
2-4 Suspension Factors for Particulate Emissions . . . . .	29
2-5 Automotive Exhaust Particulate Emissions Factors . . . . .	30
2-6 Vehicle Population and VMT Distribution as of June, 1972	31
2-7 Inventory of Gaseous Precursors . . . . .	35
2-8 South Coast Basin Rules Summary . . . . .	50
2-9 Percentage Control of Stationary Sources in the South Coast Air Basin . . . . .	52

LIST OF TABLES  
(continued)

<u>Table</u>	<u>Page</u>
3-1 Summary of Assumptions Used for Baseline Data (1972) Projections to 1977 and 1980 . . . . .	57
3-2 Projected Emissions of Particulates, NO <sub>x</sub> and SO <sub>2</sub> from SCE Steam Electric Plants in the Basin . . . . .	63
3-3 Generating Capacities of SCE (in the Air Basin), DWP and GPB . . . . .	63
3-4 Electric Generating Capacity Ratios . . . . .	63
3-5 Projected Emissions from Steam Electric Plants in the Air Basin . . . . .	65
3-6 Pacific Lighting Companies Natural Gas Usage Pre- dictions . . . . .	68
3-7 Long Beach Natural Gas Predictions . . . . .	68
3-8 Breakdown of 1973 SC Gas Company Sales in Air Basin . . . . .	69
3-9 Breakdown of 1973 Pacific Lighting Companies Sales to Air Basin Portion of SC Gas . . . . .	69
3-10 Summary of Pacific Lighting Companies Breakdown of Sales to Southern California Gas Company . . . . .	70
3-11 Projection of Firm Sales in the Air Basin from SC Gas and Long Beach . . . . .	71
3-12 Projection of Interruptible Sales in the Air Basin from SC Gas and Long Beach . . . . .	71
3-13 Firm and Interruptible Gas Sales Projection in the Air Basin . . . . .	72
3-14 Projected Emissions from Domestic and Commercial Fuel Combustion . . . . .	73
3-15 Projected Emissions from Industrial Fuel Combustion. . . . .	73
3-16 Emission Factors for Natural Gas Combustion . . . . .	74
3-17 Airports in the Air Basin . . . . .	77



LIST OF TABLES  
(continued)

<u>Table</u>	<u>Page</u>
3-18 Los Angeles County Aircraft Emissions . . . . .	78
3-19 Orange County Aircraft Emissions . . . . .	78
3-20 Riverside County Aircraft Emissions . . . . .	78
3-21 San Bernardino County Aircraft Emissions . . . . .	79
3-22 Santa Barbara County Aircraft Emissions . . . . .	79
3-23 Ventura County Aircraft Emissions . . . . .	79
3-24 1977 Inventory of Particulate Emissions Under Present Controls . . . . .	82
3-25 1977 Inventory of Gaseous Precursor Emissions Under Present Controls . . . . .	83
3-26 1977 Inventory of Particulate Emissions Under the EPA Oxidant Control Plan . . . . .	84
3-27 1977 Inventory of Gaseous Precursor Emissions Under the EPA Oxidant Control Plan . . . . .	85
3-28 1980 Inventory of Particulate Emissions Under Present Controls . . . . .	86
3-29 1980 Inventory of Gaseous Precursor Emissions Under Present Controls . . . . .	87
3-30 1980 Inventory of Particulate Emissions Under the EPA Oxidant Control Plan . . . . .	88
3-31 1980 Inventory of Gaseous Precursor Emissions Under EPA Oxidant Control Plan . . . . .	89
3-32 Entire Air Basin Summary Inventory Under Present Controls . . . . .	91
3-33 Entire Air Basin Summary Inventory Under EPA Oxidant Control Plan . . . . .	91
3-34 4-County Sub-Area Summary Inventory Under Present Controls . . . . .	92

LIST OF TABLES  
(continued)

<u>Table</u>		<u>Page</u>
3-35	4-County Sub-Area Summary Inventory Under EPA Oxidant Control Plan . . . . .	92
A-1	1972 Emissions, Los Angeles County Portion of the South Coast Basin . . . . .	A-2
A-2	1972 Emissions, All Counties of the South Coast Air Basin . . . . .	A-4
C-1	LARTS VMT . . . . .	C-4
C-2	Los Angeles Basin Gasoline Vehicle Emissions Per Million (VMT) . . . . .	C-5
C-3	Los Angeles Basin Gasoline Vehicle Emissions . . . . .	C-5
D-1	Vehicle Age Distribution in the Air Basin . . . . .	D-3
D-2	Vehicle Age Distribution in the Air Basin in 1977 . . . . .	D-3
D-3	Vehicle Age Distribution in Air Basin in 1980 . . . . .	D-3
E-1	Particulate Emissions from New Cars Equipped with Catalytic Mufflers . . . . .	E-3
E-2	Particulate Emission Factors from Old Cars Retrofitted with Catalytic Mufflers . . . . .	E-3

## LIST OF FIGURES

	<u>Page</u>
1-1     Particulate Emissions in the Entire Los Angeles Basin. . . . .	15
1-2     Gaseous Precursor Emissions in the Entire Los Angeles Air Basin. . . . .	16
1-3     Particulate Emissions in the Four County Sub-Area. . .	17
1-4     Gaseous Precursor Emissions in the Four County Sub- Area. . . . .	18
2-1     Topographical Reference Map for the Metropolitan Los Angeles AQCR. . . . .	38
2-2     Power Plant Density Map . . . . .	39
2-3     Petroleum Refinery Density Map. . . . .	40
2-4     Industry Density Map. . . . .	41
2-5     Vehicle Miles Traveled Density Map. . . . .	42
2-6     Aircraft Activity Density Map . . . . .	43
2-7     Particulate Emissions Density Map . . . . .	44
2-8     Reactive Hydrocarbon Emission Density Map . . . . .	45
2-9     Sulfur Oxides Emission Density Map. . . . .	46
2-10    Nitrogen Oxides Emission Density Map. . . . .	47

## 1.0 INTRODUCTION AND SUMMARY

Under contract to the Environmental Protection Agency, TRW Environmental Services has developed a particulate implementation plan for the Metropolitan Los Angeles Air Quality Control Region. Specifically, TRW has investigated strategies for approaching and achieving the National Ambient Air Quality Standards (NAAQS) for particulates in the Los Angeles Region. The present report, which compiles and projects emission inventories for the Los Angeles Region, is the second of four technical support documents associated with the project.

Several types of emissions are relevant to pollution by airborne particles, (alternatively called aerosol or particulate pollution). This report compiles emission inventories for both primary particulates (emitted as particles) as well as for gaseous precursors of secondary particulates (formed in the atmosphere by the chemical-physical transformation of gases). For primary particulates a further distinction is made between total emissions and the fraction of the total that tends to remain suspended. Tables 1-1 and 1-2 summarize the emission inventories for the 1972 base year. Breakdowns by source category are given for total particulates, suspended particulates, and gaseous precursors (reactive hydrocarbons, nitrogen oxides, and sulfur oxides). Table 1-1 is for the entire air basin. Table 1-2 presents results for the four county sub-area, (Los Angeles, Orange, San Bernardino, and Riverside counties), where the highest values of atmospheric particulate tend to occur (see Report #1).

The emission inventories have been projected to 1977 and 1980, target years for control strategy formulation. The projections have been made by a study of individual source categories; included in the analysis are factors such as source growth rate, source attrition, scheduled control implementation, and changes in process or fuel type. Two scenarios have been considered: (1) controls presently scheduled by County APCD's and the federal new car control program, and (2) the above

TABLE 1-1. 1972 EMISSION INVENTORY SUMMARY - ENTIRE AIR BASIN

<u>Source Category</u>	<u>Total Parti- culates</u>	<u>Suspended Parti- culates</u>	<u>SO<sub>2</sub></u>	<u>NO<sub>x</sub></u>	<u>RHC</u>
Petroleum	1%	1%	12%	5%	6%
Organic Solvent	7	7	-	-	4
Chemical	*	*	20	-	-
Metallurgical	5	6	3	-	-
Mineral	13	13	1	-	-
Incineration	1	1	-	-	-
Fuel Combustion	20	24	49	22	-
Agricultural	3	4	-	-	1
Stationary Source Total	50%	56%	85%	27%	11%
Light Duty Vehicles	25%	23%	8%	55%	75%
Heavy Duty Vehicles	1	1	-	2	3
Diesel	2	2	2	9	1
Aircraft	7	8	2	1	1
Ships & Railroads	1	1	3	2	-
Miscellaneous (Motor- cycles, off-road, etc.)	2	2	-	4	8
Motor Vehicle Tire Wear	13	7	-	-	-
Mobile Source Total	50%	44%	15%	73%	89%
Total Inventory	250 tons/ day	213 tons/ day	492 tons/ day	1423 tons/ day	1155 tons/ day

\*Emissions are included under the organic solvent category.

TABLE 1-2. 1972 EMISSION INVENTORY SUMMARY - FOUR COUNTY AREA

<u>Source Category</u>	<u>Total Parti- culates</u>	<u>Suspended Parti- culates</u>	<u>SO<sub>2</sub></u>	<u>NO<sub>x</sub></u>	<u>RHC</u>
Petroleum	1%	2%	13%	5%	6%
Organic Solvent	8	9	-	-	4
Chemical	*	*	22	-	-
Metallurgical	6	7	3	-	-
Mineral	5	6	-	-	-
Incineration	1	1	-	-	-
Fuel Combustion	21	25	46	20	-
Agricultural	1	1	-	-	-
Stationary Source Total	43%	51%	84%	25%	10%
Light Duty Vehicles	28%	27%	9%	56%	76%
Heavy Duty Vehicles	1	-	-	2	3
Diesel	2	2	2	9	1
Aircraft	7	8	3	1	1
Ships & Railroads	1	-	2	2	-
Miscellaneous, (Motor- cycles, off-road, etc.)	3	3	-	5	8
Motor Vehicle Tire Wear	15	9	-	-	-
Mobile Source Total	57%	49%	16%	75%	90%
Total Inventory	211 tons/ day	178 tons/ day	444 tons/ day	1345 tons/ day	1094 tons/ day

\*Emissions are included under the organic solvent category.

controls plus the effect of the EPA implementation plan that has been promulgated for the oxidant air quality standard. Tables 1-3 through 1-10 present the projected emissions for both scenarios and for both the entire air basin and the Four County sub-area. Figures 1.3 and 1.4 illustrate the emission projections for primary particulates and gaseous aerosol precursors in the Four County sub-area while Figures 1.1 and 1.2 are projections for the entire basin.

## 1.1 OUTLINE OF SUPPORT DOCUMENT #2

This report is organized in three sections. The present section serves as a general introduction and provides a summary of the major results. Section 2 deals with the compilation of the 1972 base year inventory. Section 3 provides the projections to 1977 and 1980.

The compilation and projection of comprehensive emission inventories is a task involving considerable uncertainty for virtually every single source category. In many cases, two or more conflicting emissions estimates may result from different, reasonable estimation procedures. Often, available information is not sufficient to assess the confidence level of one estimate as opposed to another. Thus, the need for broad guidelines in this regard was recognized, and a set of policies to be used during the course of this study was assembled. The policies employed and the assumptions made concerning the base year inventory of particulate matter and gaseous precursor emissions are described in Section 2.2 of this report. An analogous description of policies and assumptions used for the projected inventories is contained in Section 3.2.

A unique feature of the inventory presented here is the preparation of maps indicating the geographical distribution of source types and total emissions. The maps presented in Section 2.5 are pertinent to the locational aspects of control strategy formulation.

## 1.2 CONCLUSIONS AND RECOMMENDATIONS

The emission inventory and projection analysis for the Los Angeles Region has resulted in the following conclusions and recommendations:

## Conclusions

- Numerous alternative data sources are available for compiling the 1972 base year inventory of primary suspended particulates,  $\text{SO}_2$ ,  $\text{NO}_x$ , and RHC for the Los Angeles Region. Conflict often exists among the various data sources; this is an indication of the uncertainties in emission data. Presently, the most appropriate way to construct an emission inventory for implementation planning is to use many sources of data, picking the most reliable sources for each inventory category.
- Data are not available for compiling an RHC inventory based on the aerosol forming potential of organic gases. For the purposes of this study, an RHC inventory based on oxidant reactivity seems more appropriate than a total hydrocarbon inventory.
- The size distribution of particulate emissions from various sources is not well documented. However, estimates of the fraction of particles below 10 microns for various sources are available so that suspended particulate emissions can be distinguished in an approximate way from total particulate emissions.
- Motor vehicles are the major source of RHC and  $\text{NO}_x$  emissions in the 1972 base year inventory for the Los Angeles Region. Motor vehicles and stationary source fuel combustion account for most of the suspended particulate emissions. Stationary fuel combustion, the chemical industry, petroleum refineries, and motor vehicles are respectively the most important sources of  $\text{SO}_2$ .
- The forecasted substitution of fuel oil for natural gas in many stationary combustion sources and the scheduled controls for motor vehicles are the two most significant factors affecting emission projections for 1977 and 1980 in the Los Angeles Region. Due to the increased use of fuel oil, total emissions of suspended particulates,  $\text{SO}_2$ , and  $\text{NO}_x$  will increase from 1972 to 1977 with present control policies. The motor vehicle control program will significantly reduce regional RHC emissions in 1977 and 1980; it will also reverse the upward trend in  $\text{NO}_x$  emissions, (leading to a decrease between 1977 and 1980). Stationary combustion will be the largest single source of suspended particulates and  $\text{SO}_2$  in 1980 and will nearly equal motor vehicles as an  $\text{NO}_x$  contributor.
- The EPA oxidant implementation plan results in significantly low RHC emissions than present control policy. The EPA oxidant plan also achieves very slight reductions in particulate and  $\text{SO}_2$  emissions. However, the catalytic converter retrofit called for by the EPA plan, (as well as the new car catalytic converters), will result in the emission of sulfuric acid mist from motor



vehicles. The latter can be controlled by desulfurization of motor fuels or by SO<sub>2</sub> scrubber/particulate trap retrofits.

- Large scale emission density maps reveal that RHC, NO<sub>x</sub>, and (to some extent) particulate emissions are distributed in a way similar to population and motor vehicle traffic within the Los Angeles Region. An emission density map for SO<sub>2</sub> indicates the importance of very localized sources for that pollutant.

#### Recommendations

- Efforts to update emission information for both mobile and stationary sources should be supported. Further documentation is needed to reduce uncertainties concerning both source growth rates and source emission factors.
- Of special importance to particulate air quality studies is the need for RHC emission inventories based on the aerosol forming reactivity of organic gases. Also of importance is information on the size distribution of particulates from various sources. Further effort should be made to generate data pertinent to these two issues.
- The severe air pollution problem in the Los Angeles Region will be significantly aggravated by the forecasted substitution of fuel oil for natural gas in many stationary combustion sources. It is recommended that national allocation of clean fuels, such as natural gas, be performed with strong consideration given to air quality impacts in various regions.

TABLE 1-3. 1977 EMISSION INVENTORY SUMMARY FOR THE  
ENTIRE AIR BASIN UNDER PRESENT CONTROLS

<u>Source Category</u>	<u>Total Particulates</u>	<u>Suspended Particulates</u>	<u>SO<sub>2</sub></u>	<u>NO<sub>x</sub></u>	<u>RHC</u>
Petroleum	1%	1%	10%	4%	10%
Organic Solvent	6	6	-	-	6
Chemical	-	-	2	-	-
Metallurgical	4	5	2	-	-
Mineral	11	11	1	-	-
Incineration	1	1	-	-	-
Fuel Combustion					
Domestic & Commercial	4	4	-	4	-
Industrial	14	16	17	33	-
Power Plants	13	15	56	9	-
Agriculture	3	3	-	-	1
Stationary Source Total	57%	62%	88%	50%	17%
Light Duty Vehicles	19%	16%	7%	34%	60%
Heavy Duty Vehicles	-	1	-	1	3
Diesel	1	1	2	8	2
Aircraft	10	11	1	2	5
Ships and Railroads	-	1	2	1	-
Miscellaneous (Motorcycles, offroad, etc.)	2	2	-	4	13
Motor Vehicle Tire Wear	11	6	-	-	-
Mobile Source Total	43%	38%	12%	50%	83%
Total Inventory	321 tons/day	277 tons/day	591 tons/ day	1742 tons/ day	798 tons/day

TABLE 1-4. 1977 EMISSION INVENTORY SUMMARY FOR THE  
ENTIRE AIR BASIN UNDER THE EPA OXIDANT PLAN

<u>Source Category</u>	<u>Total Particulates</u>	<u>Suspended Particulates</u>	<u>SO<sub>2</sub></u>	<u>NO<sub>x</sub></u>	<u>RHC</u>
Petroleum	1%	1%	10%	4%	3%
Organic Solvent	6	6	-	-	6
Chemical	-	-	2	-	-
Metallurgical	4	5	2	-	-
Mineral	12	12	1	-	-
Incineration	1	1	-	-	-
Fuel Combustion					
Domestic and Commercial	4	4	-	4	-
Industrial	15	16	17	33	-
Power Plants	14	15	56	9	-
Agriculture	3	4	-	-	1
Stationary Source Total	60%	64%	88%	50%	10%
Light Duty Vehicles	14%	14%	6%	34%	60%
Heavy Duty Vehicles	-	-	-	1	4
Diesel	2	2	2	8	2
Aircraft	-	-	3	1	-
Ships and Railroads	10	11	1	2	7
Miscellaneous (Motorcycles, offroad, etc.)	2	2	-	4	17
Motor Vehicle Tire Wear	12	7	-	-	-
Mobile Source Total	40%	36%	12%	50%	90%
Total Inventory	301 tons/ day	266 tons/ day	585 tons/ day	1742 tons/ day	591 tons/ day

TABLE 1-5. 1977 EMISSION INVENTORY SUMMARY FOR THE FOUR  
COUNTY SUB-AREA UNDER PRESENT CONTROLS

<u>Source Category</u>	<u>Total Particulates</u>	<u>Suspended Particulates</u>	<u>SO<sub>2</sub></u>	<u>NO<sub>x</sub></u>	<u>RHC</u>
Petroleum	1%	1%	11%	4%	10%
Organic Solvent	6	7	-	-	6
Chemical	-	-	2	-	-
Metallurgical	5	6	3	-	-
Mineral	4	5	-	-	-
Incineration	1	1	-	-	-
Fuel Combustion					
Domestic and Commercial	4	5	-	4	-
Industrial	16	18	18	32	-
Power Plants	13	15	53	8	-
Agricultural	1	1	-	-	-
Stationary Source Total	51%	59%	87%	48%	16%
Light Duty Vehicles	21%	19%	8%	35%	62%
Heavy Duty Vehicles	1	-	-	2	3
Diesel	2	2	2	8	2
Aircraft	10	11	1	2	4
Ships and Railroads	-	-	2	1	-
Miscellaneous (Motorcycles, offroad, etc.)	2	2	-	4	13
Motor Vehicle Tire Wear	13	7	-	-	-
Mobile Source Total	49%	41%	13%	52%	84%
Total Inventory	273 tons/ day	233 tons/ day	530 tons/ day	1614 tons/ day	741 tons/ day

TABLE 1-6. 1977 EMISSION INVENTORY SUMMARY FOR THE FOUR  
COUNTY SUB-AREA UNDER THE EPA OXIDANT PLAN

<u>Source Category</u>	<u>Total Particulates</u>	<u>Suspended Particulates</u>	<u>SO<sub>2</sub></u>	<u>NO<sub>x</sub></u>	<u>RHC</u>
Petroleum	1%	1%	11%	4%	3%
Organic Solvent	7	7	-	-	6
Chemical	-	-	2	-	-
Metallurgical	5	5	3	-	-
Mineral	5	5	-	-	-
Incineration	1	1	-	-	-
Fuel Combustion					
Domestic and Commercial	4	5	-	4	-
Industrial	17	19	19	32	-
Power Plants	14	15	53	8	-
Agricultural	1	1	-	-	-
Stationary Source Total	55%	59%	88%	48%	9%
Light Duty Vehicles	15%	15%	7%	36%	62%
Heavy Duty Vehicles	1	1	-	1	5
Diesel	2	2	2	8	3
Aircraft	10	11	1	2	2
Ships and Railroads	-	-	2	1	-
Miscellaneous (Motorcycles, offroad, etc.)	3	3	-	4	18
Motor Vehicle Tire Wear	14	9	-	-	-
Mobile Source Total	45%	41%	12%	52%	91%
Total Inventory	254 tons/ day	223 tons/ day	524 tons/ day	1614 tons/ day	547 tons/ day

TABLE 1-7. 1980 EMISSION INVENTORY SUMMARY FOR THE  
ENTIRE AIR BASIN UNDER PRESENT CONTROLS

<u>Source Category</u>	<u>Total Particulates</u>	<u>Suspended Particulates</u>	<u>SO<sub>2</sub></u>	<u>NO<sub>x</sub></u>	<u>RHC</u>
Petroleum	1%	1%	9%	4%	14%
Organic Solvent	6	6	-	-	8
Chemical	-	-	2	-	-
Metallurgical	4	5	3	-	-
Mineral	11	12	1	-	-
Incineration	1	1	-	-	-
Fuel Combustion					
Domestic and Commercial	4	4	-	4	-
Industrial	12	14	15	34	-
Power Plants	13	14	57	10	-
Agricultural	3	3	-	-	1
Stationary Source Total	55%	60%	87%	52%	23%
Light Duty Vehicles	15%	14%	7%	28%	48%
Heavy Duty Vehicles	1	1	-	1	3
Diesel	1	1	2	9	2
Aircraft	13	15	2	3	9
Ships and Railroads	1	1	2	2	-
Miscellaneous (Motorcycles, offroad, etc.)	2	2	-	5	17
Motor Vehicle Tire Wear	12	6	-	-	-
Mobile Source Total	45%	40%	13%	48%	77%
Total Inventory	330 tons/ day	289 tons/ day	605 tons/ day	1552 tons/ day	634 tons/ day

TABLE 1-8 1980 EMISSION INVENTORY SUMMARY FOR THE ENTIRE  
AIR BASIN UNDER THE EPA OXIDANT PLAN

<u>Source Category</u>	<u>Total Particulates</u>	<u>Suspended Particulates</u>	<u>SO<sub>2</sub></u>	<u>NO<sub>x</sub></u>	<u>RHC</u>
Petroleum	1%	1%	10%	4%	5%
Organic Solvent	6	6	-	-	8
Chemical	-	-	2	-	-
Metallurgical	4	5	2	-	-
Mineral	12	12	2	-	-
Incineration	1	1	-	-	-
Fuel Combustion					
Domestic and Commercial	4	4	-	4	-
Industrial	13	14	15	33	-
Power Plants	13	15	57	10	-
Agricultural	3	3	-	-	1
Stationary Source Total	57%	61%	88%	51%	14%
Light Duty Vehicles	12%	12%	6%	28%	43%
Heavy Duty Vehicles	1	1	-	1	4
Diesel	2	2	2	9	3
Aircraft	14	15	2	4	12
Ships and Railroads	-	-	2	2	-
Miscellaneous (Motorcycles, offroad, etc.)	3	2	-	2	24
Motor Vehicle Tire Wear	11	7	-	5	-
Mobile Source Total	43%	39%	12%	49%	86%
Total Inventory	316 tons/ day	283 tons/ day	601 tons/ day	1552 tons/ day	458 tons/ day

TABLE 1-9. 1980 EMISSION INVENTORY SUMMARY FOR THE FOUR  
COUNTY SUB-AREA UNDER PRESENT CONTROLS

<u>Source Category</u>	<u>Total Particulates</u>	<u>Suspended Particulates</u>	<u>SO<sub>2</sub></u>	<u>NO<sub>x</sub></u>	<u>RHC</u>
Petroleum	1%	1%	11%	5%	13%
Organic Solvent	7	7	-	-	8
Chemical	-	-	2	-	-
Metallurgical	5	6	3	-	-
Mineral	4	5	-	-	-
Incineration	-	1	-	-	-
Fuel Combustion					
Domestic and Commercial	4	5	-	4	-
Industrial	14	16	17	32	-
Power Plants	13	14	54	10	-
Agricultural	1	1	-	-	-
Stationary Source Total	49%	56%	87%	51%	21%
Light Duty Vehicles	17%	16%	7%	29%	49%
Heavy Duty Vehicles	1	1	-	1	3
Diesel	2	2	2	10	3
Aircraft	14	15	2	3	6
Ships and Railroads	1	1	2	1	-
Miscellaneous (Motorcycles, offroad, etc.)	3	2	-	5	18
Motor Vehicle Tire Wear	13	7	-	-	-
Mobile Source Total	51%	44%	13%	49%	79%
Total Inventory	278 tons/ day	240 tons/ day	540 tons/ day	1434 tons/ day	567 tons/ day



TABLE 1-10. 1980 EMISSION INVENTORY SUMMARY FOR THE FOUR  
COUNTY SUB-AREA UNDER THE EPA OXIDANT PLAN

<u>Source Category</u>	<u>Total Particulates</u>	<u>Suspended Particulates</u>	<u>SO<sub>2</sub></u>	<u>NO<sub>x</sub></u>	<u>RHC</u>
Petroleum	1%	1%	11%	5%	4%
Organic Solvent	7	7	-	-	8
Chemical	-	-	2	-	-
Metallurgical	5	6	3	-	-
Mineral	4	5	-	-	-
Incineration	1	1	-	-	-
Fuel Combustion					
Domestic and Commercial	5	5	-	4	-
Industrial	15	17	17	32	-
Power Plants	13	15	55	10	-
Agricultural	1	1	-	-	-
Stationary Source Total	52%	58%	88%	51%	12%
Light Duty Vehicles	13%	14%	6%	28%	46%
Heavy Duty Vehicles	1	1	-	1	4
Diesel	2	2	2	10	4
Aircraft	14	15	2	3	9
Ships and Railroads	1	-	2	2	25
Miscellaneous (Motorcycles, offroad, etc.)	3	3	-	5	-
Motor Vehicle Tire Wear	14	7	-	-	-
Mobile Source Total	48%	42%	12%	49%	88%
Total Inventory	265 tons/ day	233 tons/ day	535 tons/ day	1434 tons/ day	410 tons/ day

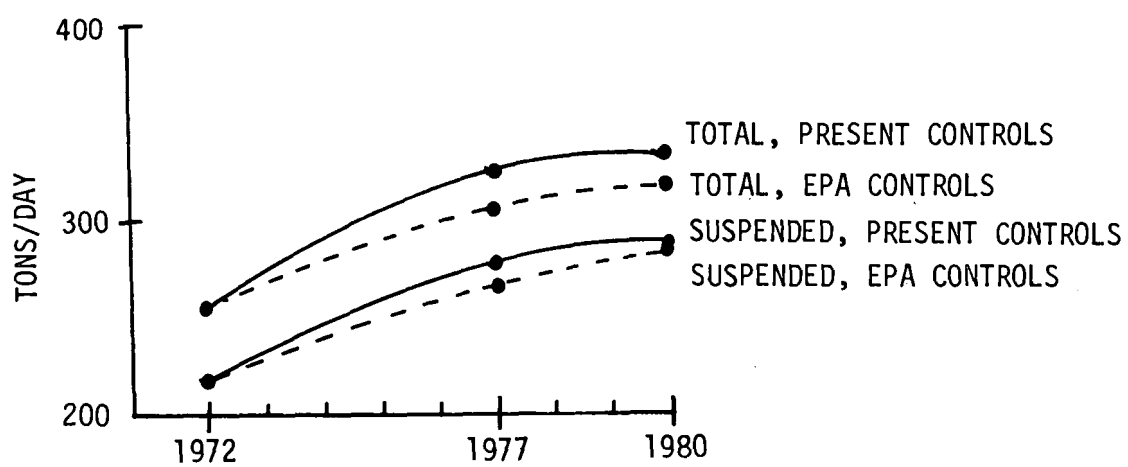


Figure 1.1 Particulate Emissions in the Entire Los Angeles Basin

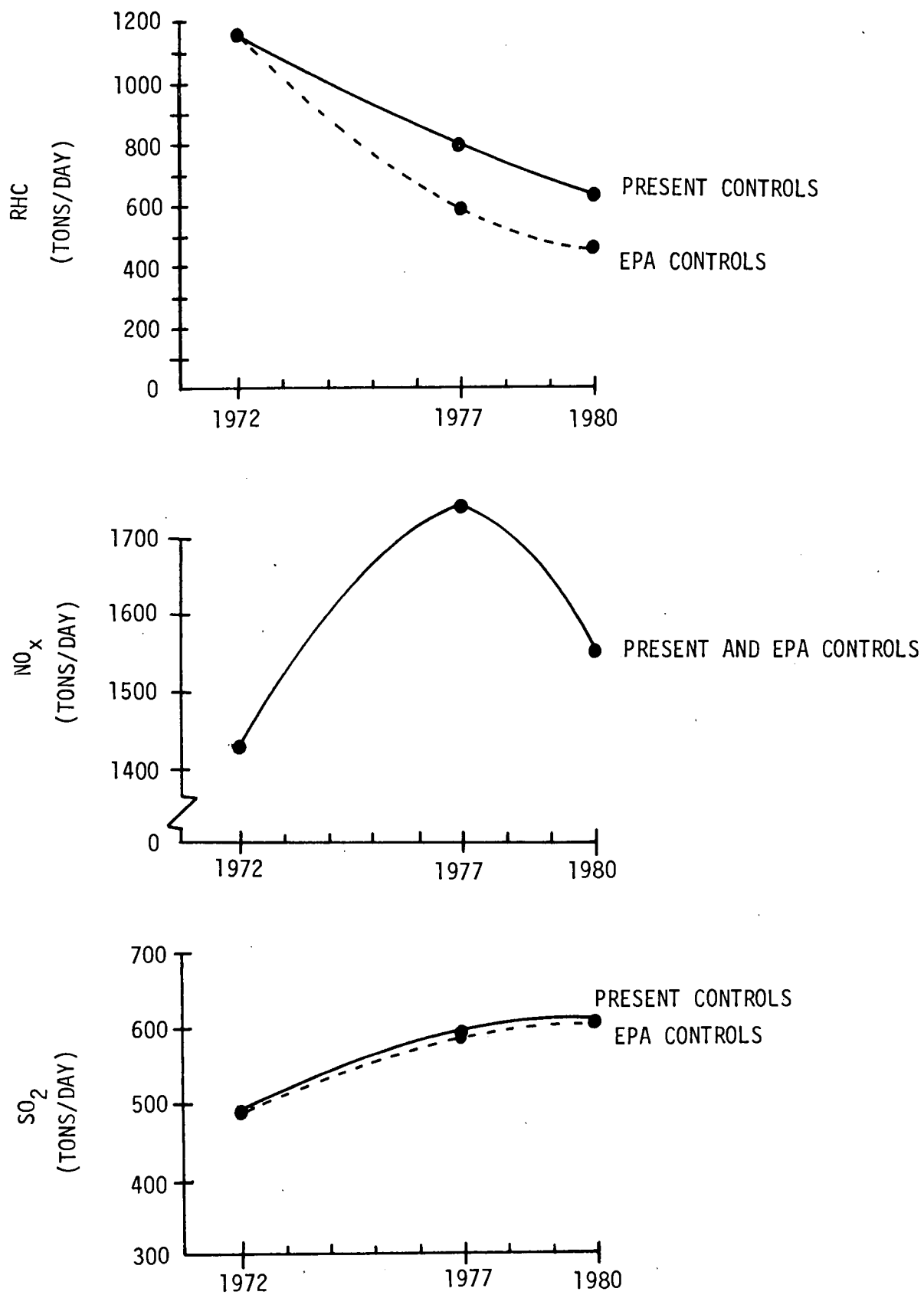


Figure 1.2 Gaseous Precursor Emissions  
in the Entire Los Angeles  
Air Basin

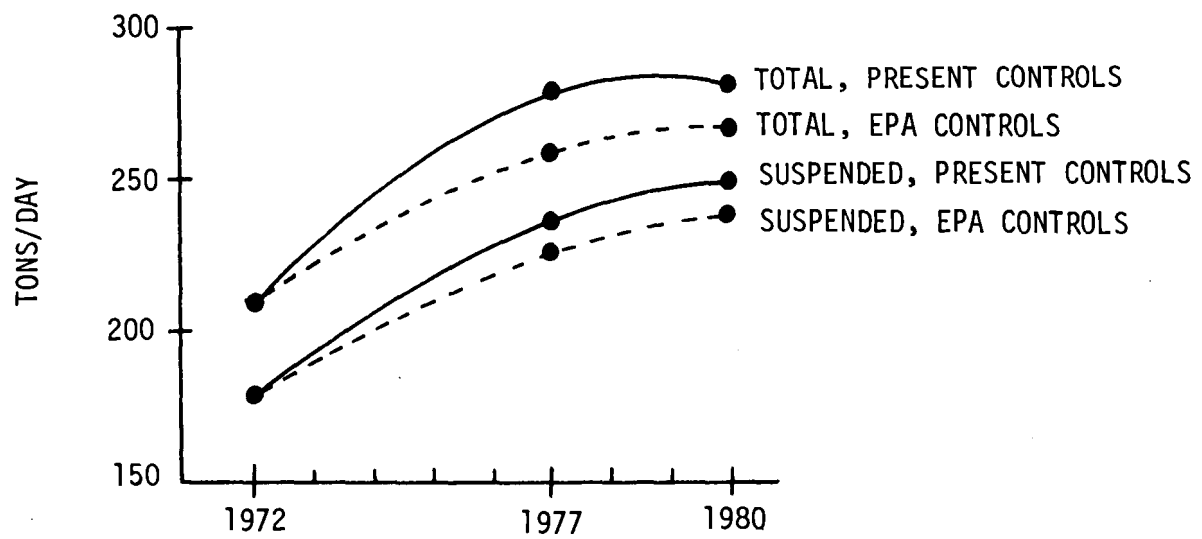


Figure 1.3 Particulate Emissions in the Four-County Sub Area

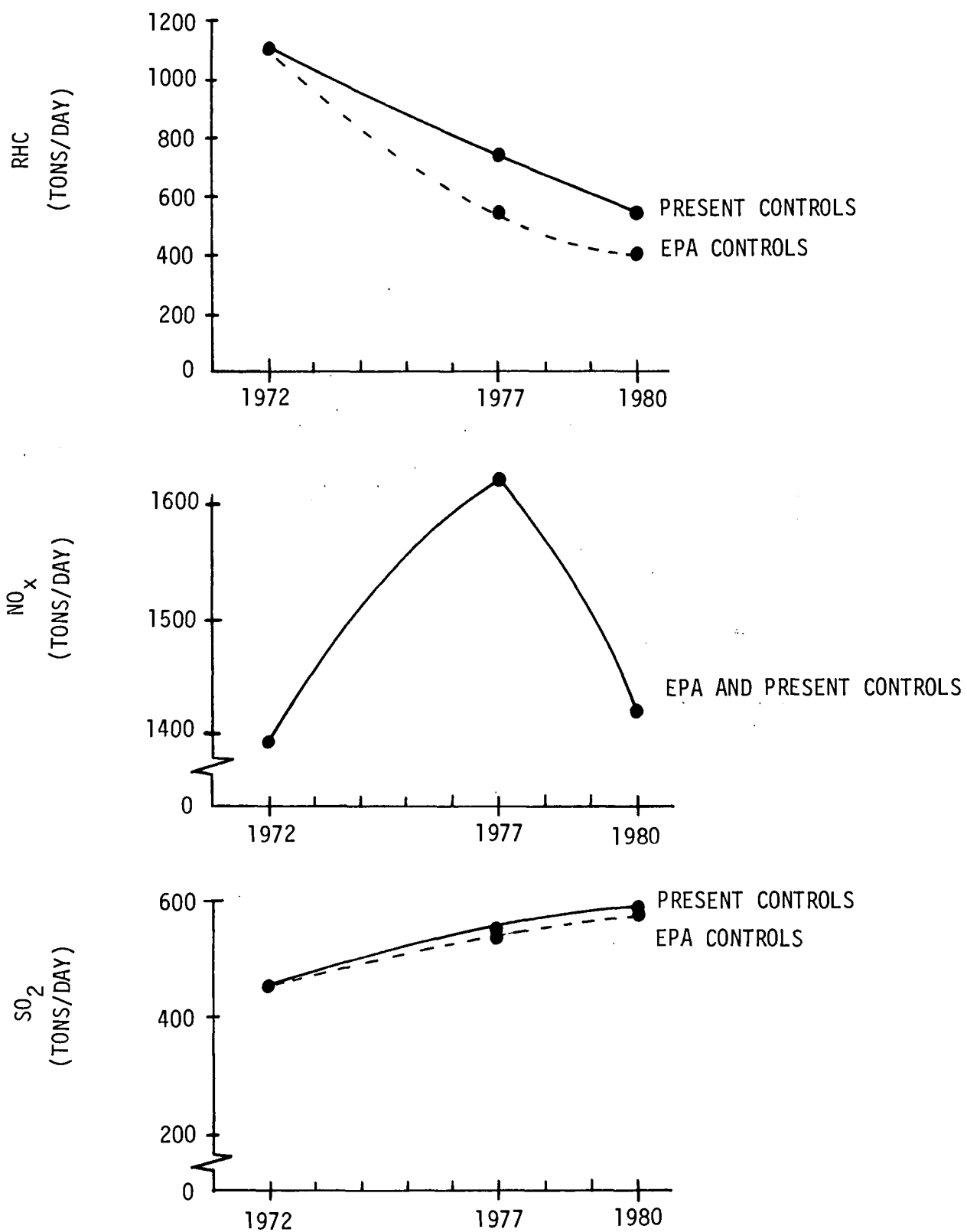


Figure 1.4 Gaseous Precursor Emissions in the Four-County Sub Area

## 2.0 1972 EMISSION INVENTORY FOR THE METROPOLITAN LOS ANGELES AIR QUALITY CONTROL REGION

Previously compiled inventories of pollutant emissions for the Metropolitan Los Angeles AQCR are contained in the 1970 California Air Resources Board Emission Inventory<sup>1</sup>; the technical support document for the Los Angeles transportation control plan<sup>2</sup>, and the Los Angeles episode contingency plan report.<sup>3</sup> These inventories were examined and found to be inappropriate for direct application to the present task. Stationary source information is required on a much more detailed level than has been reported in the previous documents. Further, a common reporting basis must be developed for the base year inventory, the projected inventory, and the controlled inventory indicating effectiveness of the specific control techniques under consideration. The more detailed inventory reported here incorporates the results of a variety of studies performed in this area.

### 2.1 SOURCES OF DATA

Aggregated data concerning stationary source emissions were obtained from the six County Air Pollution Control Districts having jurisdiction in the Los Angeles Region. Data concerning plant-by-plant emissions from point sources emitting greater than 100 tons/year of any or all pollutants were obtained through the EPA's National Emissions Data System (NEDS), as well as from the authors of that data, Pacific Environmental Services, Inc. of Santa Monica, California. In addition to the "100 ton" NEDS inventory, a similar inventory of smaller emitters in the 25 to 100 ton per year category was obtained from Pacific Environmental Services; this latter inventory covered the Los Angeles County area only.

A third source of data concerning present stationary source emissions was a special preliminary inventory of nitrogen oxides emissions from stationary sources in the entire air basin, prepared by KVB Engineering, Inc. for the California Air Resources Board. Finally, both present and projected emission of  $\text{SO}_2$ ,  $\text{NO}_x$ , and particulate matter are available from Southern California Edison for its power plants.

Several sources of information were consulted during the preparation of the mobile source inventory. The County APCD's routinely prepare

inventories for mobile sources in addition to stationary sources. Unfortunately, the techniques used by the various districts are not uniform, and, in the case of gasoline powered motor vehicles, emission factors used by the APCD's are in direct conflict with officially published EPA emission factors.<sup>4</sup>

Thus, while the APCD's are the primary source of information in the stationary source area, alternative sources of information do exist in the area of mobile source emissions. Here, calculations are performed for emissions of  $\text{SO}_2$ ,  $\text{NO}_x$ , and reactive hydrocarbons from light and heavy duty motor vehicles using published EPA emission factors.

In the case of particulate emissions from motor vehicles, alternative emission factors were developed specifically for use in the present study. Finally, estimates of emissions of hydrocarbons and  $\text{NO}_x$  from motorcycles and off-road engines (tractors, lawn mowers, chain saws, etc.) were obtained from a study performed for EPA by Automotive Environmental Systems, Inc (AESi).<sup>6</sup>

## 2.2 POLICIES AND ASSUMPTIONS

Inherent in any attempt to compile and reconcile data from a multitude of sources using a multitude of different estimation techniques is the necessity of establishing both generalized policies as well as specific assumptions in order to reduce the task to manageable proportions. This section is devoted to the documentation of these key points in order that the resulting inventory may be properly interpreted.

### 2.2.1 Air Pollution Control District Inventories

The principal function of the County APCD's is the control of stationary source emissions. To this end, the Los Angeles APCD maintains a separate full-time staff responsible for the inventory and control of each source sub-category. Since no other agency is presently in a position to acquire and maintain such information, the L.A. APCD in most cases remains the ultimate source of information regarding stationary source emissions in Los Angeles County. APCD's in the neighboring counties of Orange, San Bernardino, Ventura, Riverside, and Santa Barbara are likewise in the best position to assess the emissions from stationary sources within their jurisdictions.

Thus, a general guideline established early in the development of this inventory was that the stationary source inventories developed by the APCD's would be accepted unless a better alternative could be demonstrated.

#### 2.2.2 National Emissions Data System (NEDS) Inventory

The use of NEDS inventory data was rejected for the present study due to its presently incomplete nature. An inventory of sources emitting more than 100 tons per year of pollutants was obtained from EPA, while an inventory of sources emitting between 25 and 100 tons per year of pollutants in Los Angeles County only was obtained from Pacific Environmental Services, Inc. Unfortunately, only 40% of the total stationary source emissions of particulate matter was accounted for by the 100 ton per year inventory. Thus, it was apparent that a large fraction of the particulate emissions came from small sources. Since the 25 to 100 ton per year inventory for Los Angeles County was based essentially on L.A. APCD data,<sup>7</sup> little value was seen in using this data in lieu of an inventory obtained directly from the APCD.

#### 2.2.3 Stationary Source NO<sub>x</sub> Emissions

A special preliminary inventory of NO<sub>x</sub> emissions from stationary sources in the Metropolitan Los Angeles AQCR was obtained from KVB Engineering Inc.<sup>8</sup> KVB conducted recent tests of NO<sub>x</sub> emissions from various types of sources and applied the results of these tests toward the compilation of an NO<sub>x</sub> inventory. The resulting inventory of industrial NO<sub>x</sub> emissions was used in lieu of APCD data in this category.

Although NO<sub>x</sub> emissions due to power plant and domestic fuel combustion were also estimated by KVB, here this portion of the inventory was estimated from utility data.<sup>9,10</sup> The reason for using utility data is that the best estimates of projected fuel combustion and emissions due to utility operations were obtained from Southern California Edison and Southern California Gas Company. For the sake of consistency, the utility data was used to estimate base year as well as projected emissions for this source category.



#### 2.2.4 Motor Vehicle Emission Factors for Exhaust Particulates

The Los Angeles APCD estimates exhaust particulate emissions by applying certain simple assumptions to the total gasoline consumed within the County. The published EPA emission factor (AP-42) for exhaust particulates is based on only a single series of tests. Since motor vehicles constituted a very significant source of particulate emissions in the Los Angeles Region a new emission factor for exhaust particulates was developed here based on the results of several studies. A detailed description of the development of this factor is contained in Section 2.3.2.

#### 2.2.5 Motor Vehicle Emission Factors for Gaseous Precursors

Since assuming responsibility for the control of motor vehicle emissions, EPA has published emission factors based on its ongoing testing program and the federal motor vehicle control program for new cars. The Los Angeles County APCD disputes the use of the published factors at the present time, due to confusion involving the change from the 7-mode cycle to the constant volume sampling (CVS) technique.<sup>11</sup> As described in Section 2.4.2, conversations with key EPA personnel in this area have resulted in the use of the published EPA emission factors for hydrocarbons and NO<sub>x</sub> in this study.

#### 2.2.6 Aircraft Emissions

Aircraft emission estimates were obtained from both the local APCD's and EPA. The Los Angeles APCD has been a pioneer in the area of aircraft testing and landing/takeoff (LTO) cycle development, and has recently performed a detailed study of aircraft emissions at Los Angeles International Airport under contract to EPA.<sup>12</sup> EPA, on the other hand, has subsequently published baseline and projected emissions from Los Angeles International Airport which are substantially lower than APCD estimates.<sup>13</sup> The reason for the discrepancy is not clear at this time. For the purposes of the present study, the L.A. APCD estimate has been used.

#### 2.2.7 Suspended Particulate Inventory

Previously compiled inventories of particulate emissions have been based on total particulate emissions. Yet it may well be argued that it is

suspended particulates which are measured at sampling stations, and then ultimately compared with ambient air quality standards. Hence, it is desirable to express the particulate inventory in terms of the suspended fraction. Although such a disaggregation leads to the incorporation of yet another level of uncertainty in the final inventory, it is believed that by developing such an inventory, the relative contribution of various source categories to the total problem may be more accurately assessed. For the purposes of the present study it has been assumed that only particles smaller than 10 microns remain suspended in the atmosphere.<sup>14</sup>

#### 2.2.8 The 4-County Sub-Area

Preliminary examination of air sampling data from the six counties in the air basin revealed that both Santa Barbara and Ventura Counties consistently experience particulate levels at or below the primary National Ambient Air Quality Standard.<sup>15</sup> On the basis of this information, it was proposed that the principal control strategy be formulated for the remaining four counties only (Los Angeles, Orange, San Bernardino, and Riverside), with Santa Barbara and Ventura treated as special cases with less stringent controls. Thus, the inventory reported here is presented for both the entire air basin and the Four-County sub-area. In addition, a Los Angeles County Inventory is presented for comparison to the L.A. County APCD inventory given in Appendix A.

#### 2.2.9 Hydrocarbon Reactivity Factors

The reactivity factors used in this study are based on the latest EPA analysis of smog chamber data, and are identical to the factors used in a recent oxidant contingency plan study.<sup>3</sup> The differences between this set of reactivities and the set used by the APCD's may be seen from Table 2.1.

Unfortunately, neither set of reactivities is appropriate from the standpoint of photochemical aerosol, since both sets are based on oxidant formation, not aerosol formation. Studies performed by Battelle Columbus Laboratories<sup>16, 17</sup> and the California Air Resources Board<sup>18</sup> indicate that olefins and/or aromatics play a much more singular role in the formation of aerosols than in the formation of oxidant. As might be expected, these

TABLE 2-1. ALTERNATIVE HYDROCARBON REACTIVITY ASSUMPTIONS

<u>Source Type</u>	<u>ARB-APCD Reactivity</u>	<u>Reactivity Used Here (EPA)</u>
<u>Stationary Sources</u>		
Petroleum Production and Refining	10%	10%
Petroleum Marketing	55%	93%
Organic Solvents	20%	20%
Others	0-20%	0-20%
<u>Motor Vehicles</u>		
LDMV Exhaust	75%	77%
HDMV Exhaust	75%	79%
LDMV & HDMV Evaporative	55%	93%
Motorcycles	-	96% (2-stroke) 86% (4-stroke)
Diesels	10%	99%
<u>Other Mobile Sources</u>		
Jet Aircraft	30%	90%
Piston Aircraft	75% Exhaust 55% Evaporative	77% Exhaust 93% Evaporative

studies indicate that the use of a single reactivity factor is not really appropriate for the variety of ambient conditions normally encountered.

### 2.3 1972 INVENTORY OF PARTICULATE MATTER EMISSIONS

The 1972 inventory of particulate matter emissions in the Metropolitan Los Angeles AQCR is presented in Table 2-2. The following discussion describes the procedures employed in the development of this inventory.

TABLE 2-2. 1972 PARTICULATE MATTER INVENTORY (TONS/DAY)

Source Category	Los Angeles County		Entire Air Basin		4-County Sub-Area	
	Total	Suspended	Total	Suspended	Total	Suspended
<u>Stationary Sources</u>						
Petroleum Refining (catalyst regeneration)	3	3	3	3	3	3
Organic Solvent Operations						
Chemical Manufacturing	9	8.1	9.5	8.1	9.2	8.1
Industrial Spray Booths	8	7.2	8	7.2	8	7.2
Metallurgical Operations						
Sand Handling	0.4	0.4	0.7	0.7	0.7	0.7
Melting & Pouring	6.9	6.9	11.6	11.6	11.6	11.6
Mineral Processing						
Glass & Frit Mfg.	2	1.8	2.4	2.2	2.4	2.2
Asphalt Roofing Mfg. (batching)	3	2.7	3	2.7	3	2.7
Asphalt Pavement Mfg. (batching)	1	0.9	2.9	2.4	1.9	1.7
Rock, gravel, cement ops	1	0.9	15.1	13.5	2.8	2.5
Other			8.3	7.5	1.2	1.1
Incineration Operations						
Industrial & Commercial	0.5	0.4	1.1	1.0	1.1	1.0
Domestic	0.5	0.4	1.1	1.0	1.1	1.0
Fuel Combustion						
Power Plants	17.7	17.5	26.9	26.6	22.3	22.1
Petroleum Refining Ops	4	4	4	4	4	4
Other Industrial (interrupt)	6	6	8	8	8	8
Domestic (non-interrupt)	7.7	7.7	11.1	11.1	10.6	10.6
Agricultural						
Debris Burning	-		0.5	0.5		
Orchard Heaters	-		4.2	4.2	2.2	2.2
Processing Plants	-		0.7	0.7		
Wild Fires			3.2	3.1		
Stationary Source Total	71	70	126	119	93	90

TABLE 2-2.  
1972 PARTICULATE MATTER INVENTORY (TONS/DAY) (continued)

<u>Source Category</u>	<u>Los Angeles County</u>		<u>Entire Air Basin</u>		<u>4-County Sub-Area</u>	
	<u>Total</u>	<u>Suspended</u>	<u>Total</u>	<u>Suspended</u>	<u>Total</u>	<u>Suspended</u>
<u>Mobile Sources</u>						
Motor Vehicles						
Light-Duty	42.7	34.7	60.9	49.3	58.6	47.5
Heavy Duty	1.4	1.1	1.8	1.5	1.7	1.4
Diesels	3.0	2.4	4.3	3.5	4.1	3.3
Miscellaneous (motor- cycles, off-road, etc)	4.2	3.4	6	4.9	5.8	4.7
Motor vehicle tire wear	22.7	11.1	32.3	15.8	31.1	15.2
Aircraft						
Jet	9	8.9	13.5	13.4	11.5	11.4
Piston			4.2	3.4	3.5	2.8
Ships & Railroads	1	0.8	1.9	1.5	1.5	1.2
Mobile Source Total	84	70	124	94	118	87
Total Inventory	155	140	250	213	211	178

### 2.3.1 Stationary Sources

Particulate matter originates from a wide variety of processes, as evidenced by the fact that Table 2-2 lists emissions under every major source category. Petroleum refining results in emissions of fine grain particles escaping during the regeneration of the "fluidized" catalyst. Emissions listed under organic solvent operations consist mainly of emissions from industrial spray booths. Metallurgical particulate emissions are due mainly to the melting and pouring of metals, resulting in the emission of metallic fumes which escape from conventional control equipment. Mineral operations resulting in emissions are glass and frit manufacturing, asphalt batching, and cement batching.

The largest single source category for particulates is the fuel combustion category, consisting of power plants as well as industrial and domestic combustion of fuel oil and natural gas.

Power plant emissions are estimated by Southern California Edison for their power plants.<sup>9</sup> These emission estimates were scaled up to include Los Angeles Department of Water and Power (DWP) power plants by assuming that emissions are proportional to installed electric generating capacity. The same methodology was used to disaggregate the total emissions estimates for the Los Angeles County and Four-County inventories. Table 2-3 contains a summary of this information.

TABLE 2-3 POWER PLANT EMISSIONS

<u>Area</u>	<u>Installed Capacity</u>	<u>Estimated Particulate Emissions*</u>
Los Angeles County	7,810 MWe	17.7 tons/day
4-County Area	9,864 MWe	22.3 tons/day
South Coast Air Basin	11,894 MWe	26.9 tons/day

\*Based on Southern California Edison estimate of 19.4 tons/day from their plants within the Los Angeles Region, with a total installed capacity of 8,584 MWe.

The local air pollution control districts (the Los Angeles County APCD in particular) are justly proud of their efforts to control emissions from stationary sources. The regulations summarized in Section 2.6 have been used as models for much of the nation. As mentioned previously, the inventories provided by each of the six local air pollution control districts were used in the compilation of the inventory presented here. The suspension factors listed in Table 2-4 along with the inventories were derived subjectively, based mainly on conversations with Los Angeles APCD engineers, and a limited knowledge of the control efficiency as a function of particle size for various control devices in current use.<sup>19</sup> Considering that conventional control equipment (filters, baghouses, electrostatic precipitators) are least efficient in the smaller particle size ranges (0.1 to  $1\mu$ ) and that due to ongoing control programs most sources are controlled in some fashion, it is to be expected that the bulk of emissions from stationary sources should be in the suspended particle size range.

### 2.3.2 Gasoline-Powered Motor Vehicles - Exhaust Particulates

Preliminary analyses indicated that motor vehicles would comprise a very significant portion of the total particulate inventory regardless of the estimation procedure employed. It was therefore decided to inquire as to the basis of the procedures being used and, if possible, improve upon them.

The Los Angeles County APCD computes automotive particulate emissions based on gasoline consumption. Assuming an average lead content of 2.5 grams per gallon, this gives a lead factor of 3.1 tons per million gallons. 75% of the lead "burned" is assumed to be exhausted, while the exhausted lead is assumed to comprise 60% of the total exhaust particulate emissions. The resulting emissions factor for exhaust particulates is 5.28 tons per million gallons of gasoline consumed, which in turn results in motor vehicle exhaust particulate emissions of 42 tons per day in 1972.<sup>11</sup>

The EPA emission factor for exhaust particulates, based on tests conducted by Ethyl Corporation, is 0.34 grams per mile.<sup>21</sup> An examination

TABLE 2-4. SUSPENSION FACTORS FOR PARTICULATE EMISSIONS

<u>Source Category</u>	<u>Suspension Factor (%)</u>	<u>Source*</u>
Petroleum Refining	99	1
Organic Solvent Operations	90	1
Chemical Manufacturing	90	1
Metallurgical Operations	100	1
Mineral Processing	90	5
Incineration	90	2
Fuel Combustion	99	2
Agriculture	99	3
Gasoline Powered Motor Vehicles	81	4
Diesels	81	5
Misc. Internal Combustion Engines	81	5
Motor Vehicle Tire Wear	49	6
Jet Aircraft	99	1
Piston Aircraft	81	5
Ships and Railroads	81	5

- \*1. Estimate based on conversations with L.A. APCD engineers
- 2. Estimate based on data presented in AP-68, "Control Techniques for Particulate Matter."
- 3. California Air Environment<sup>20</sup>
- 4. Based on data presented in this report
- 5. Assumed
- 6. Personal communication with Dr. J.P. Subrameni, EPA Region 4, Atlanta, Georgia.



of the documentation for this particular series of tests revealed the following:

- The factor was derived assuming a seven-mode cycle rather than the CVS method.
- The factor represented suspended particulate matter as opposed to total particulate matter.
- The factor applied to older vehicles having 30,000 to 50,000 miles accumulated.

A review of studies of exhaust particulate emissions<sup>22</sup> was subsequently obtained. Table 2-5 summarizes the information extracted from this review.

The available data indicate the following:

- The characteristics of exhaust particulate matter vary as a function of the age of the exhaust system of the vehicle, apparently leveling off after 3-5 years.
- Older vehicles emit more than younger vehicles.
- The average particle size is smaller for younger vehicles than for older vehicles.
- Exhaust particulate emissions are sensitive to driving mode, and hence to the test cycle used.

TABLE 2-5. AUTOMOTIVE EXHAUST PARTICULATE EMISSIONS FACTORS (grams/mile)

	Ter Harr, 1972 <sup>21</sup>		Habibi, 1973 <sup>22</sup>		1966 <sup>22</sup>	Larsen <sup>22</sup>	Factors Used In This Study	
	New Cars	Old Cars	New Cars	Old Cars	Filters Study	Tunnel Study	New Cars	Old Cars
Total Particulates					0.31		0.22 <sup>2</sup>	0.48 <sup>2</sup>
Suspended "	0.15	0.34	0.18			0.35	0.18	0.35
Total Lead (Pb)			0.10 <sup>1</sup>	0.22 <sup>1</sup>			0.10	0.22
Suspended Lead (Pb)	0.02	0.06	0.06	0.09			0.06	0.09

Notes:

- 1) Total lead (Pb) emissions are estimated from Habibi's factors of 0.15 gm/mile and 0.34 gm/mile for lead salt emissions from new and old cars, assuming roughly a 2/3 molecular weight ratio between lead and lead salt compounds.
- 2) The adopted values for the total particulate emission factor are derived from the other adopted emission factor assuming that non-lead particulates emitted which are larger than 10 microns are an insignificant fraction of total emissions. Hence,

$$\text{total particulates} = \text{suspended particulates} + (\text{total lead} - \text{suspended lead})$$

For the purposes of the present study, it has been assumed that young vehicles may be defined as being 0-2 years old, while "mature" vehicles may be defined as being greater than 3 years old. Thus, from a knowledge of the vehicle age distribution, a weighted average emission factor for exhaust particulates may be computed. For the Metropolitan Los Angeles AQCR, the 1972 vehicle age distribution is shown in Table 2-6.

TABLE 2-6. VEHICLE POPULATION AND VMT DISTRIBUTION AS OF JUNE, 1972

<u>Model Year</u>	<u>Population Distribution (%)</u> *	<u>Annual VMT</u>	<u>VMT Distribution (%)</u>
1972	8.0	11,000	8.4
1971	9.4	14,000	12.5
1970	9.2	13,000	11.4
1969	9.9	12,500	11.8
1968	8.9	11,500	9.7
1967	7.8	10,500	7.8
1966	8.2	10,500	8.2
1965	8.4	10,000	8.0
1964	7.2	9,500	6.5
1963	5.9	8,500	4.8
1962	4.6	7,500	3.3
1961	3.0	6,500	1.8
1960	2.5	6,500	1.5
1959	1.7	6,500	1.0
1958	5.3	6,500	3.3

\*Source: R. L. Polk and Company

The weighting factors are therefore 0.209 for young vehicles and 0.791 for mature vehicles. Using the emission factors shown in Table 2.5, we obtain the following weighted average emission factors for light-duty motor vehicles:

total exhaust particulates =  $0.209 \times 0.22 + 0.791 \times 0.48 = 0.43$  gms/mile  
suspended particulates =  $0.209 \times 0.18 + 0.791 \times 0.35 = 0.31$  gms/mile  
total Pb emissions =  $0.209 \times 0.10 + 0.791 \times 0.22 = 0.19$  gms/mile  
suspended Pb emissions =  $0.209 \times 0.06 + 0.791 \times 0.09 = 0.08$  gms/mile

VMT for the six county area approximately equivalent to the Metropolitan Los Angeles AQCR has been established from Los Angeles Regional Transportation Study (LARTS) data to be 147 million vehicle miles per day in 1972.<sup>2</sup> Assuming

that VMT within the six counties of the basin is distributed proportionate to carbon monoxide emissions (as estimated by the County APCD's), the inventory of exhaust particulate emissions have been disaggregated as follows:

Los Angeles County - 70.3% of air basin total  
4-County Sub-Area - 96.3% of air basin total

### 2.3.3 Other Mobile Source Particulate Emissions

In addition to particulates from vehicular exhaust, tire wear makes a significant contribution to the particulate inventory. The EPA emission factor for tire wear of 0.20 grams per mile is based on a Ph.D. thesis by Dr. J. P. Subramani. Conversations with Dr. Subramani revealed that according to the same work, only 49% of the particles (by weight) were less than 10 microns in diameter. Hence, only 49% of the total particulates from tire wear are assumed to be suspended. This factor yields suspended particulate ratios of tire wear to exhaust which are consistent with recent studies.<sup>23</sup>

Particulate emissions from motorcycles were calculated from the emission factors presented in AP-42, population data from the California Department of Motor Vehicles, and an assumed annual VMT of 4,000 miles from the AESi report. Aircraft, ship and railroad particulate emissions were taken from the Supplement to the Implementation Plan - South Coast Air Basin, submitted to the ARB by the local APCD's.

Emissions from heavy-duty diesel vehicles were estimated from diesel fuel consumption data as reported on NEDS. In 1970, diesel fuel consumption in the Metropolitan Los Angeles AQCR was 543,556 gallons/day. This consumption figure was projected to 1972 by applying the diesel truck registration growth rate between 1970 and 1971 (9.7%/year) to the diesel fuel consumption resulting in an estimated 653,700 gal/day in 1972. EPA emission factors (13 lb/1000 gal for particulates, 27 lbs/1000 gal for SO<sub>2</sub>, 37 lbs/1000 gal for total hydrocarbons, and 370 lbs/1000 gal for NO<sub>x</sub>) were then applied to the consumption figure to yield emissions. These emissions were then disaggregated in the same fashion as LDMV and HDMV emissions.

## 2.4 INVENTORY OF GASEOUS PRECURSOR EMISSIONS

### 2.4.1 Stationary Sources

The base year inventory of reactive hydrocarbons, sulfur oxides, and nitrogen oxides was developed using the inventories reported by the local APCD's as a starting point. From these, the hydrocarbon inventory was adjusted to reflect the latest set of EPA reactivities, and the stationary source  $\text{NO}_x$  inventory was replaced by the inventory provided by KVB Engineering. Power plant emissions were adjusted to reflect Southern California Edison emissions estimates, since the projected emissions in this category are based on Edison projections.

### 2.4.2 Motor Vehicle Emissions

Emissions from light and heavy duty gasoline powered motor vehicles were calculated using the latest EPA emission factors and deterioration factors, combined with vehicle population data from R. L. Polk and Company, and VMT data from the Los Angeles Regional Transportation Study (LARTS). The procedure for combining this data to produce the final emissions is described in Appendix C. Since the LARTS VMT data was disaggregated into freeway and non-freeway categories, computations were made assuming a 52.5 mph average freeway speed and a 21.9 mph average non-freeway speed.<sup>2</sup> The freeway speed is a "best guess" estimate. A sensitivity analysis was performed to estimate the effect of a 5 mph change in the freeway speed. Since the speed correction curves (AP-42) are relatively flat at the high speed end, the resulting sensitivity was found to be insignificant (2% for hydrocarbons, and 4% for  $\text{NO}_x$ ).

There is at the present time a controversy between EPA and the California Air Resources Board concerning the emission factors for gasoline-powered light duty vehicles. EPA contends that their CVS-II (constant volume sampling with both cold and hot start cycles) sampling technique yields emission factors which are more representative of actual emissions than the ARB's seven-mode cycle. The ARB on the other hand, contends that there is no cycle which is most representative of actual driving and that a change in sampling technique would not be a good idea from the standpoint of comparing new emissions testing data with historical

data obtained using the 7-mode cycle. This situation is further confused by a change in the position taken by EPA regarding the conversion of 7-mode cycle emission factors to CVS-II emission factors.

In 1971, EPA was directing state and local agencies to apply the following correction factors to their 7-mode cycle test data to obtain CVS-II emission factors:<sup>24</sup>

HC:	1.38
CO:	1.58
NO <sub>x</sub> :	1.03

Then, in 1973 EPA published as part of AP-42 (Compilation of Air Pollutant Emission Factors) motor vehicle emission factors which were presumably obtained using the CVS-II cycle. These factors, however, resembled the 7-mode cycle factors more closely than the 7-mode cycle adjusted according to the conversion factors. Thus, the difference between the two sets of CVS-II emission factors is quite significant and will lead to different control strategies, since one set of emission factors will represent motor vehicles as a much larger percentage of the total inventory than the other set.

Conversations with key EPA personnel<sup>25</sup> indicated that the emission factors published by EPA in AP-42 are indeed representative of the test data from EPA's ongoing mobile source testing program. Therefore, at the direction of the project officer, the factors as published in AP-42 were used in calculating the inventory presented here.

The inventory of gaseous precursor emissions is summarized in Table 2-7. As may be seen from this table the major sources of sulfur oxides are power plants and other stationary fuel combustion sources, chemical plants consisting mainly of sulfur recovery and sulfuric acid plants, and gasoline powered motor vehicles. (The emissions of SO<sub>2</sub> from gasoline-powered motor vehicles is higher than what would be computed from the EPA emission factor for this category. This is due to the 0.067% S content of gasoline sold in Southern California, which is about twice that assumed in AP-42.)<sup>26</sup> Likewise, the major sources of nitrogen oxides are

TABLE 2-7.  
1972 INVENTORY OF GASEOUS PRECURSORS (TONS/DAY)

<u>Source Category</u>	<u>Los Angeles County</u>			<u>Entire Air Basin</u>			<u>4-County Sub-Area</u>		
	<u>SO<sub>2</sub></u>	<u>NO<sub>x</sub></u>	<u>RHC</u>	<u>SO<sub>2</sub></u>	<u>NO<sub>x</sub></u>	<u>RHC</u>	<u>SO<sub>2</sub></u>	<u>NO<sub>x</sub></u>	<u>RHC</u>
<u>Stationary Sources</u>									
Petroleum									
Refining-Production	56	67.5	7	60	67.5	7	60	67.5	7
Service Stations			41			71.5			67.1
Org. Solvent Users									
Surface Coating			9			11			10
Dry Cleaning			1			2			1
Degreasing			8			11			10
Other			21			22			22
Chemical Processing									
Petrochemical						0.7			
Sulfur Recovery	95			95			95		
Pulp and Paper						0.4			
Other	2			2	0.4		2	0.4	
Metallurgical Proc.	5.7			13	0.5		13	0.5	
Mineral Processing				6.4			1.4		
Incineration		1.0			1.6	0.3		1.6	0.3
Fuel Combustion									
Power Plants	142.8	74.1	-	217.5	112.8	-	180.3	93.5	-
Industrial	10	80.4	-	27.6	129.7*	-	27.6	114.8*	-
Domestic (space heaters + comm'l)	0.2	53.9	-	0.3	77.7	-	0.3	74.1	-
Agricultural				1.1	0.7	6.6	1.1		
Stationary Source Total	312	279	87	423	391	133	381	352	117

\* KVB used emission factors from AP42 for the source category. The factors have since been updated by EPA. The emission shown here have been adjusted to include this latest update.

TABLE 2-7. 1972 INVENTORY OF GASEOUS PRECURSORS  
(TONS/DAY) (CONTINUED)

Source Category	Los Angeles County			Entire Air Basin			4-County Sub-Area		
	SO <sub>2</sub>	NO <sub>x</sub>	RHC	SO <sub>2</sub>	NO <sub>x</sub>	RHC	SO <sub>2</sub>	NO <sub>x</sub>	RHC
<u>Mobile Sources</u>									
Light Duty Motor Vehicles	29.2	546	604	41.4	776	859	39.8	747	827
Heavy Duty Motor Vehicles	0.4	20	22	0.6	28	32	0.6	27	31
Diesel	6.2	85	8	8.8	121	12	8.5	117	12
Misc. (motorcycles, off-road, etc.)	-	43	67	-	61	95	-	59	91
<u>Aircraft</u>									
Jet	3.0	10	9	3.7	13.4	15.9	3.4	12.4	9.9
Piston	-	3	2.4	0.2	6.3	8.1	0.2	6.2	5.8
Ships and Railroads	10	22	-	14.5	26	-	10.8	24	-
Mobile Source Totals	49	729	712.4	69	1032	1022	63	993	977
Total Inventory	361	1008	799	492	1423	1155	444	1345	1094

fuel combustion and motor vehicles. Finally, as mentioned previously, the reactive hydrocarbon inventory has been adjusted to reflect the latest EPA reactivity factors. The major source of emissions for this pollutant is gasoline powered motor vehicles.

## 2.5 LOCATIONAL CONSIDERATIONS

A significant feature of the inventory presented here is the preparation of maps indicating the geographical distribution of sources as well as emissions. The most common procedure in the past has been to report emissions on an aggregated basin-wide basis with no indication of spatial distribution. The source and emission maps will aid in evaluating locational aspects of control strategies.

Figure 2-1 gives a topographical reference map of the Metropolitan Los Angeles Region to aid in interpreting the subsequent figures. Figures 2-2 through 2-6 present the geographical distribution of the following source types: power plants, refineries, industrial activity, automotive mileage, and aircraft activity. Where possible, units have been chosen to be representative of emission potential, e.g. power capacity (power plants), barrels throughput (refineries), and vehicle miles travelled (autos).

Figures 2-7 through 2-10 give approximate 1972 emission maps for particulates, reactive hydrocarbons, sulfur dioxide, and nitrogen oxides. These maps have been derived by aggregating the individual source maps (Figures 2-2 - 2-6) according to the emissions from those sources as given in Tables 2-2 and 2-7. In this aggregation process, it was assumed that service station and residential emissions were distributed approximately the same as vehicle miles travelled (Figure 2-5).

Although the maps presented were not designed for a precise quantitative application, certain qualitative conclusions are immediately apparent:

- The distribution of RHC and  $\text{NO}_x$  approximately parallels the distribution of vehicular activity, the source of these emissions.



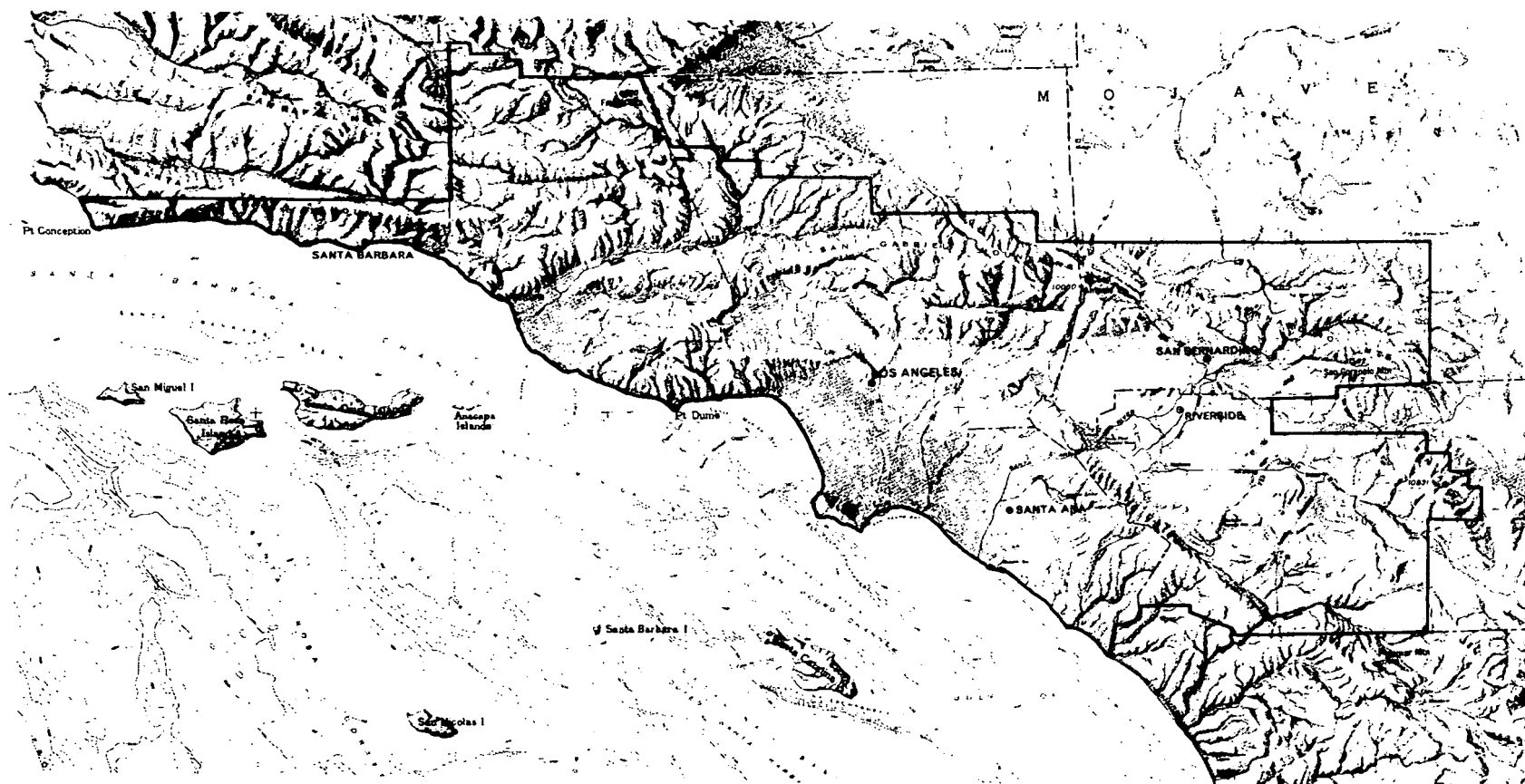
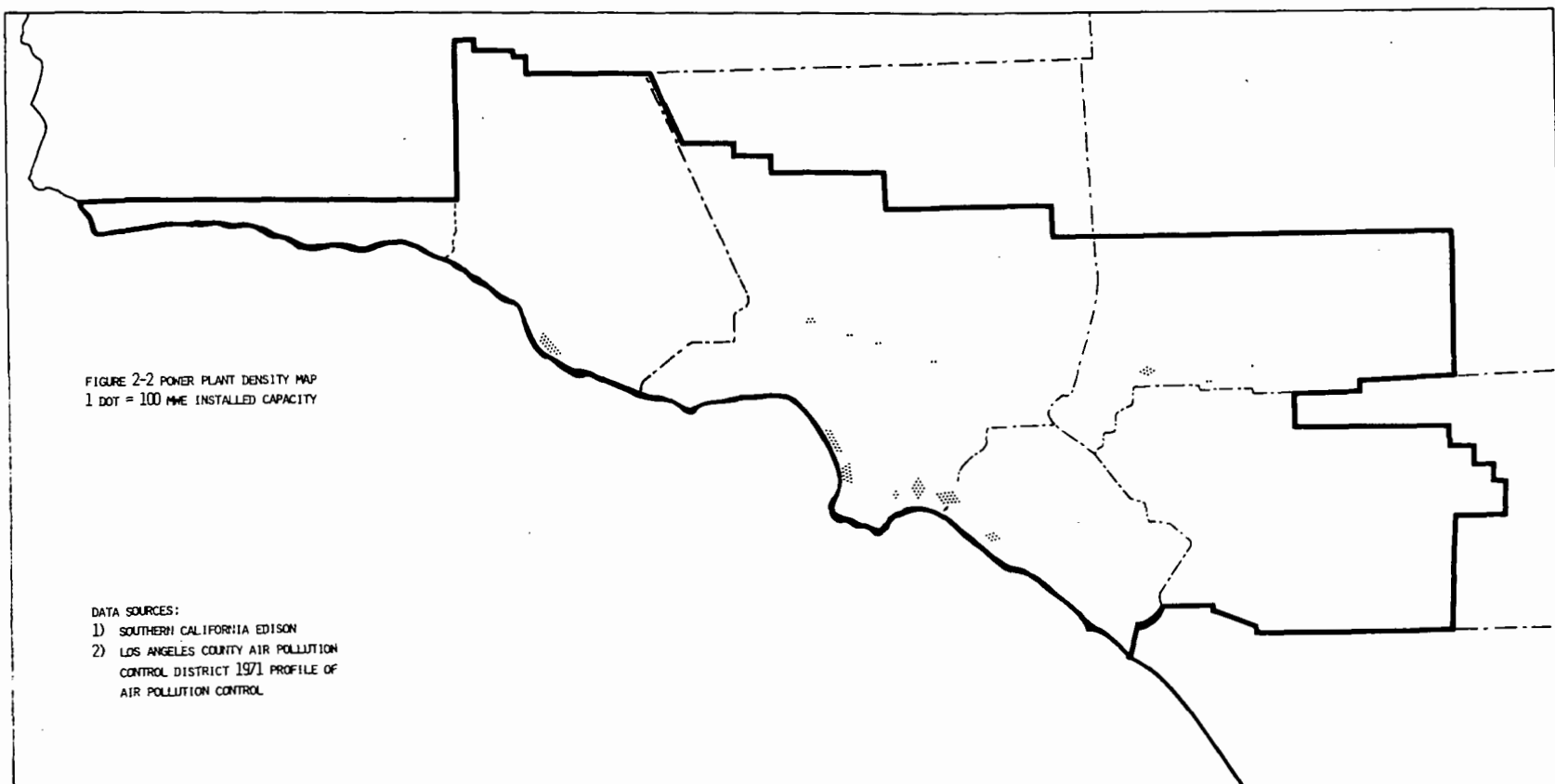
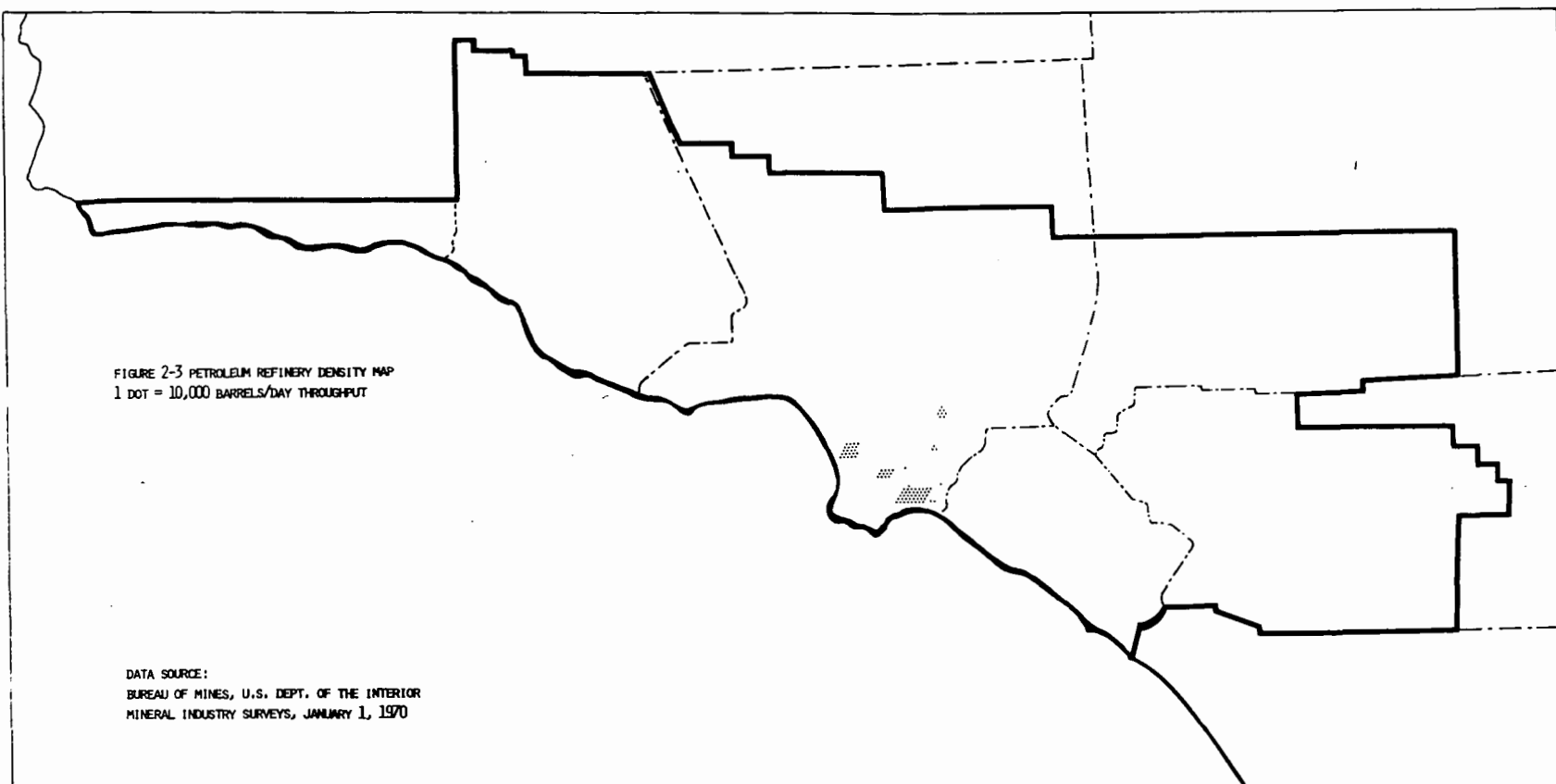
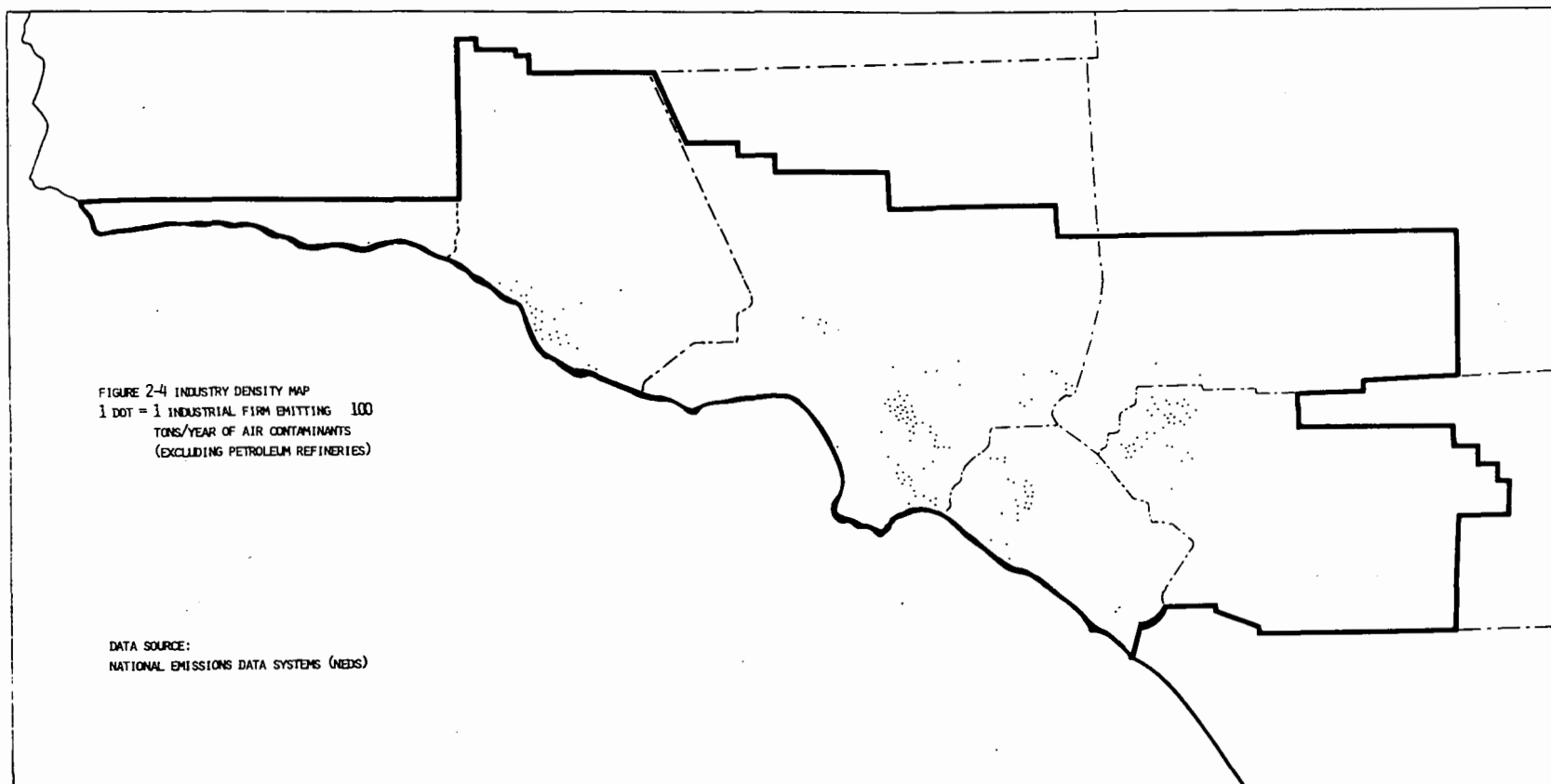
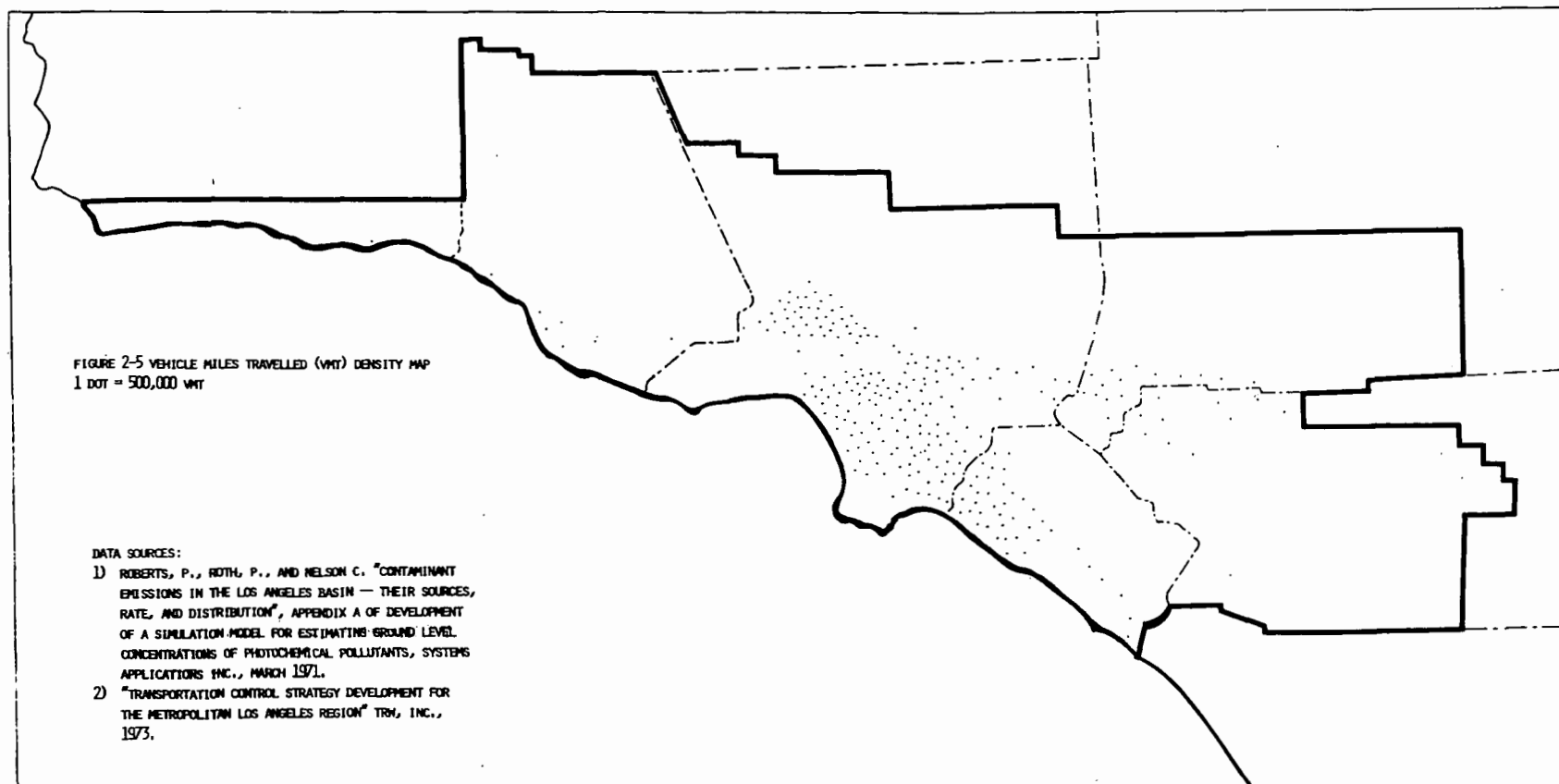


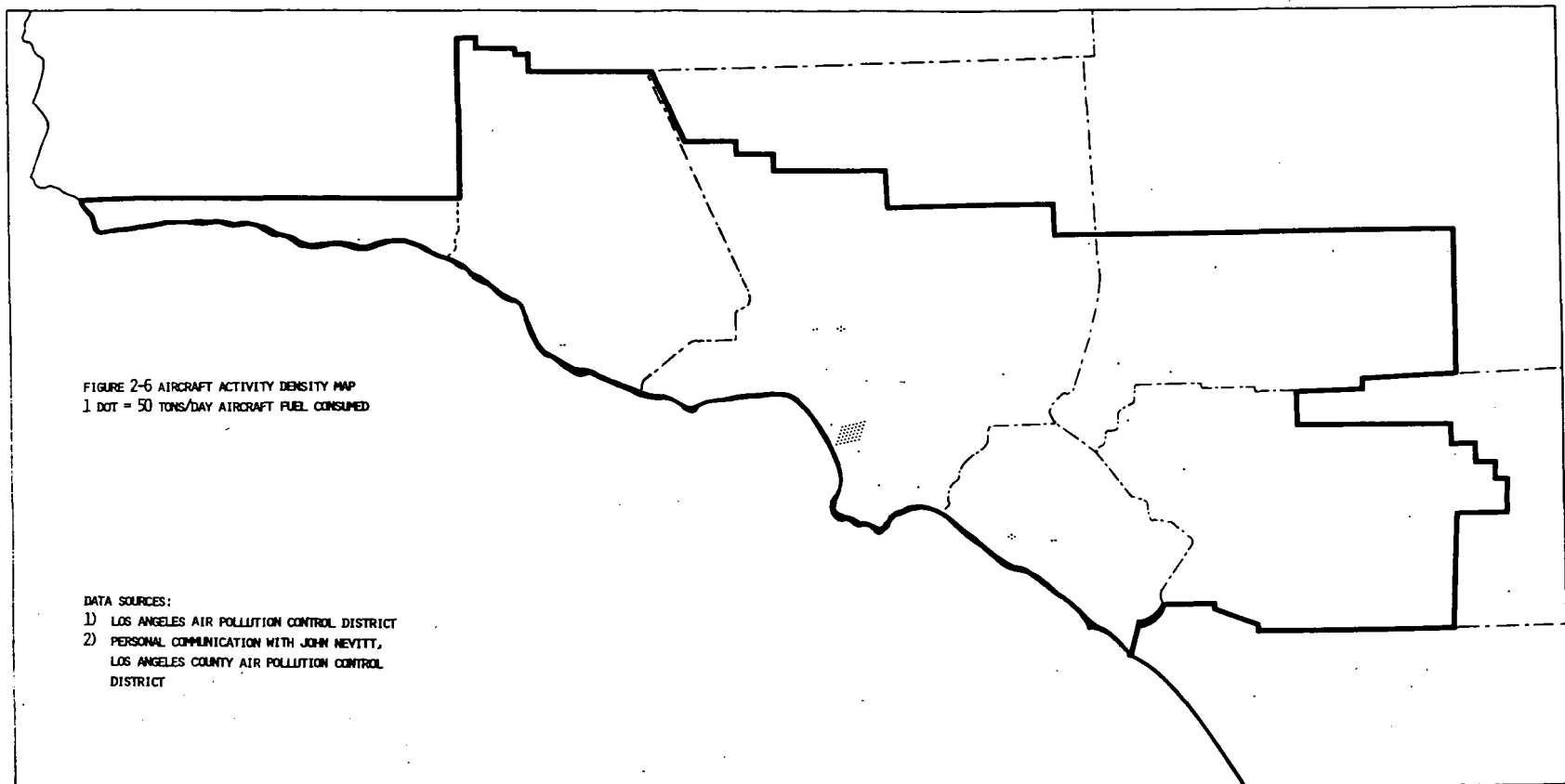
Figure 2-1  
 Topographical Reference Map for the Metropolitan Los Angeles AQCR;  
 including county boundaries











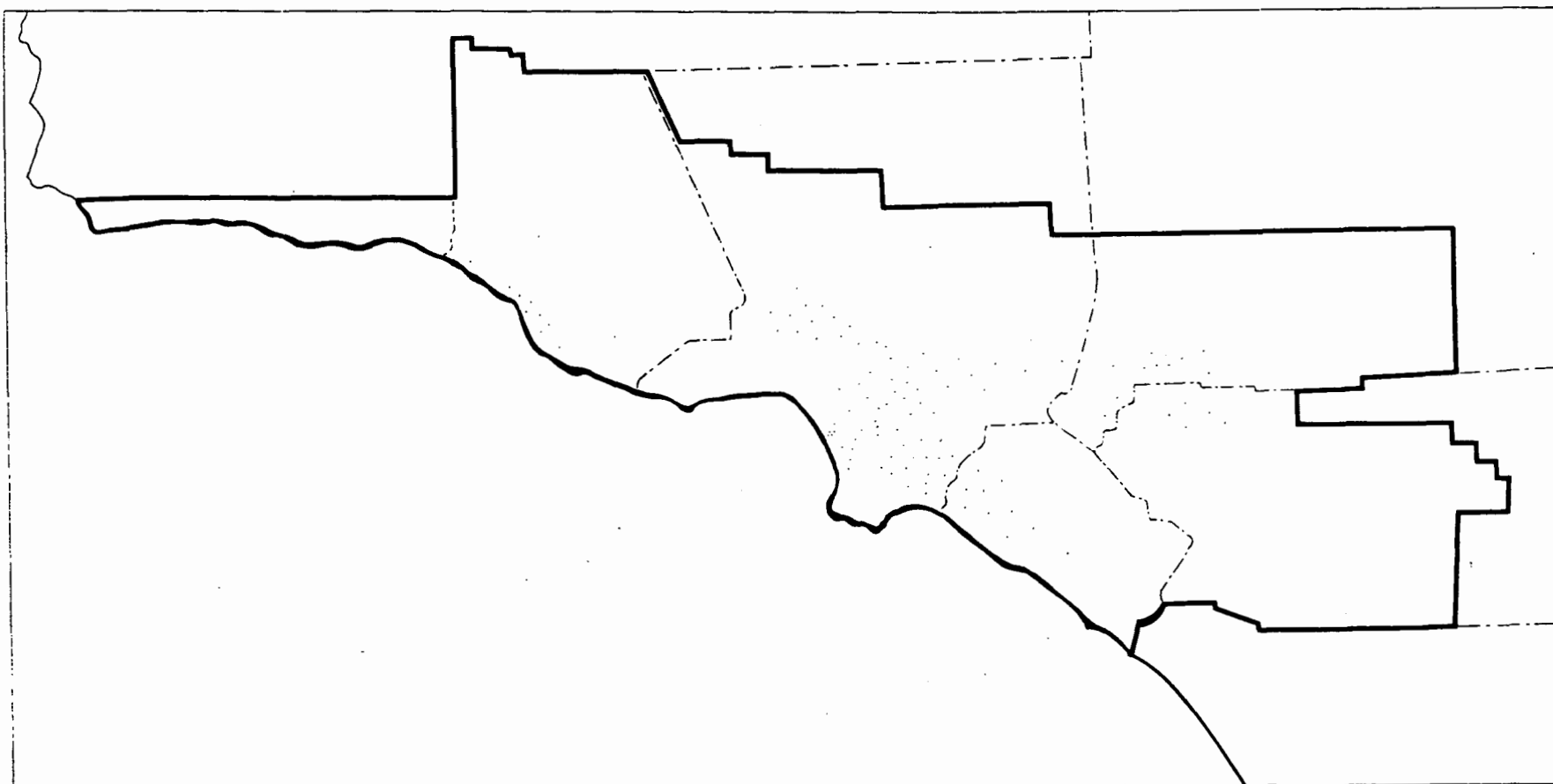


Figure 2-7. Particulate Emission Density Map.  
1 Dot = 2 Tons/Day Total Particulate Emissions

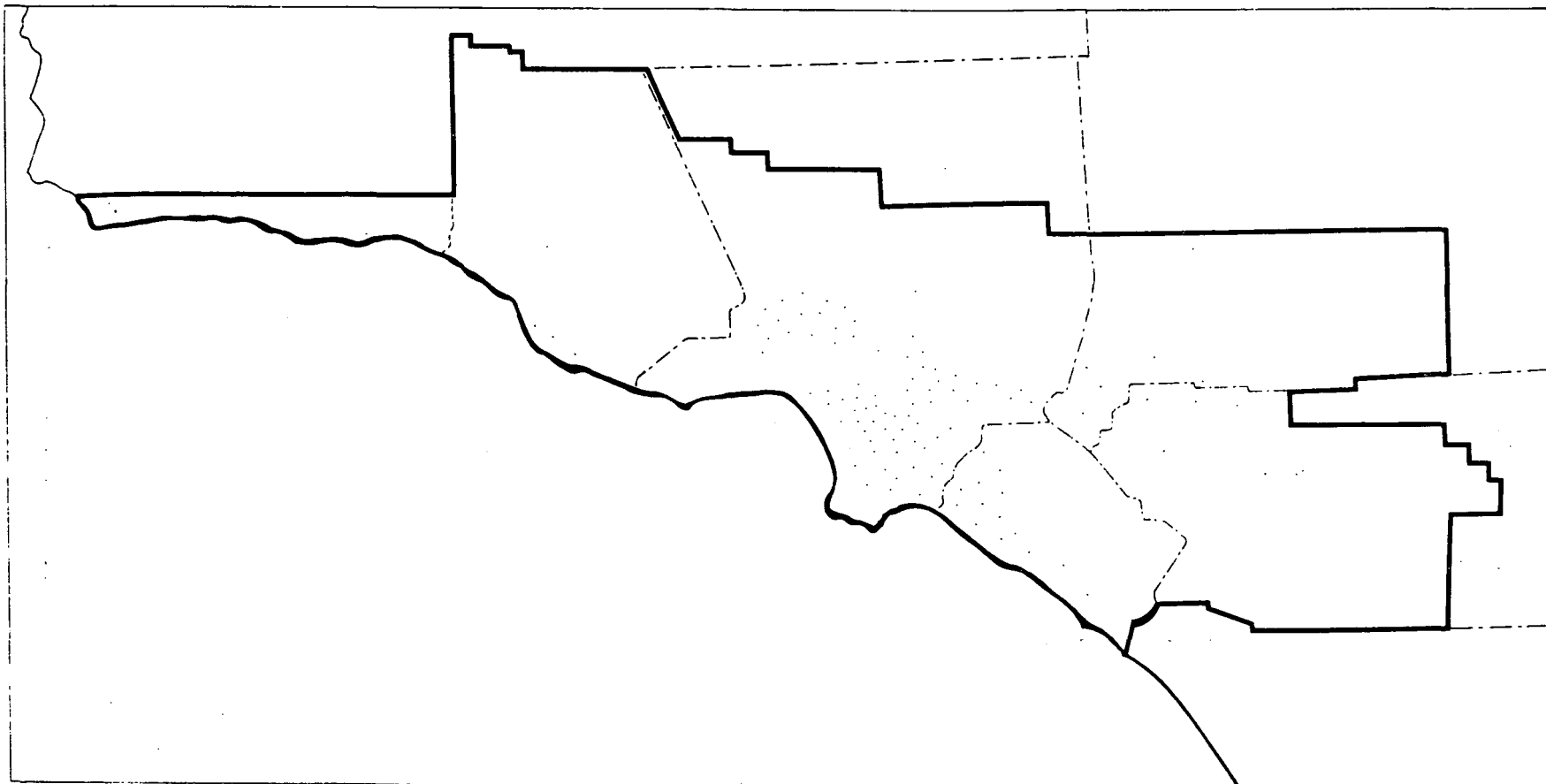


Figure 2-8. Reactive Hydrocarbon Emission Density Map.  
1 Dot = 10 Tons/Day of Reactive Hydrocarbon Emissions



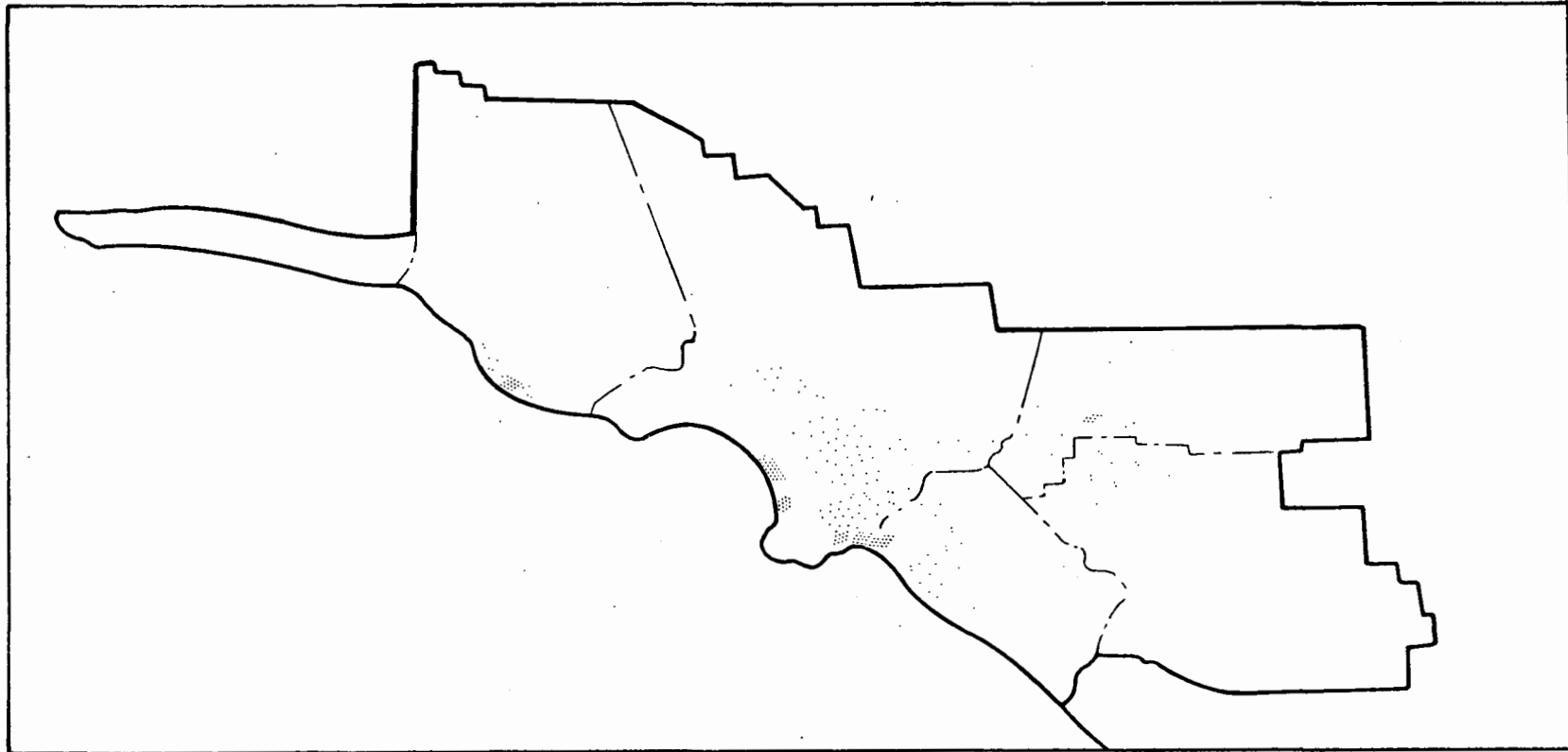


Figure 2-9 Sulfur Oxides Emissions Density Map for the Los Angeles Region  
1 Dot = 2 Tons/Day  $\text{SO}_x$  Emissions

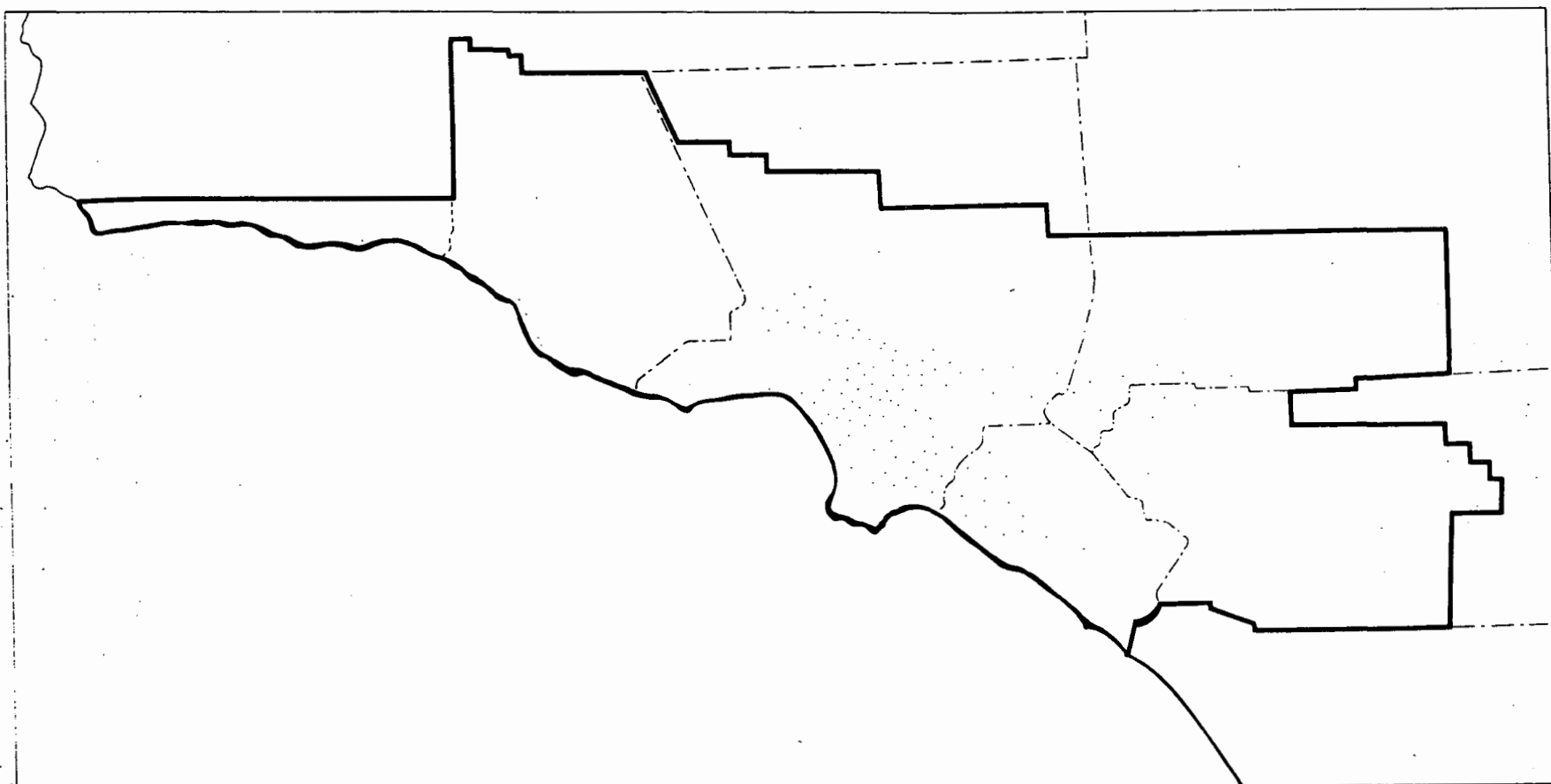


Figure 2-10. Nitrogen Oxides Emission Density Map.  
1 Dot = 11 Tons/Day NO<sub>x</sub> Emissions

- Major point sources of particulates have, on the whole been controlled to the point that emissions in this category are highly dispersed and indistinguishable from the distribution of vehicle miles travelled, despite the heavy concentration of industry near the coast. The concentration shown at the location of Los Angeles International Airport is not quite representative of the emissions occurring at that location since emissions are computed for complete landing and take-off cycles (LTO), which occur over a much larger geographical area.
- Only sulfur dioxide emissions are significantly concentrated in large stationary sources; motor vehicles do not dominate the inventory for this pollutant. These large stationary sources (power plants and petroleum refineries) are located near the coast, normally upwind from the bulk of the populace within the basin.

## 2.6 PRESENT CONTROL PROGRAM FOR STATIONARY SOURCE EMISSIONS

The Los Angeles County Air Pollution Control District has been a pioneer in the field of stationary source emission control and has established itself as a leader in this area. The remaining districts comprising the Metropolitan Los Angeles AQCR have followed the example set by the Los Angeles APCD, and in some cases have established rules which are even more stringent. Table 2-8 is a summary comparison of the rules currently in force in the various counties. A brief summary of the more significant rules enacted within the past two years is presented in Appendix B. The Rules and Regulations published by the individual agencies should be consulted if additional information is required.

The overall effectiveness of the present control program for stationary sources is summarized in Table 2-9. From this table, it is evident that significant reductions in stationary source emissions of both primary particulates and the gaseous precursors of secondary particulates have been made. The total percentage control listed at the bottom may create a false impression, however, with regard to the control efficiency on presently existing sources. These figures include sources that have been regulated out of existence, such that they do not contribute to the present levels of particulate matter in the ambient atmosphere (e.g., backyard incinerators). Thus, the overall percentage control of sources now operating within the basin is expected to be less than that shown.

The relatively low control level for particulate matter in the organic solvent category is due mainly to the highly dispersed nature of the sources which reduces the socio-economic "attractiveness" of applying controls in this source category. The percentage control of SO<sub>2</sub> emissions in the chemical industry category is expected to rise dramatically within the next year in response to the implementation of Rules 53.2 and 53.3 of the Los Angeles County APCD.<sup>27</sup> (These rules are described briefly in Appendix A). Finally, Los Angeles County's Rule 65 requires 90% organic vapor recovery during the loading of stationary storage tanks (such as at gasoline service stations) by 1976.<sup>28</sup> This rule should provide significant reductions in hydrocarbon emissions by 1977.

TABLE 2-8. SOUTH COAST BASIN RULES SUMMARY

Rules	L.A.	Orange	Riverside	San Bernardino	Ventura	Santa Barbara
Definitions	x	x	x	x	x	x
Authority to Arrest	x	x	x	x	-	-
Availability of Emission Data	-	-	-	x	x	-
Authority to Construct	x	x	x	x	x	x
Denial of A/C	x	x	x	x	x	x
Permit to Operate	x	x	x	x	x	x
Permit Fees	x	x	x	x	x	x
Annual Renewal	-	-	x	x	-	-
Ringelmann & Opacity	x	x	x	x	x	x
Nuisance	x	x	x	x	x	x
Fugitive Dust	-	-	-	x	-	-
Particulate Matter:						
Concentration	x	x	x	x	x	x
Weight	x	x	x(1)	x	x	x
Specific Contaminants:						
Sulfur	x	x*	x*	x*	x*	x
Combustion	x**	x	x	x	x	x
Fluorine	-	-	x	x	-	-
Scavenger Plants	x	-	x	x	-	x
Sulfur Recovery Units	x	x	x	x	-	x
Sulfuric Acid Units	x	x	x	x	-	x
Exceptions to Opacity Rule	x	x	x	x	x	x
Storage of Petro Products	x	x	x	x	x	x
Open Fires	x*	x*	x	x	x	x*
Disposal of Solid and Liquid Wastes	x	x	x(2)	x	x(3)	x
Oil-Water Separators	x	x	x	x	x	x
Circumvention	x	x	x	x	x	x
Organic Liquid Loading	x	x*	x(4)	x	x	x(4)
Sulfur in Fuels	x**	x	x	x	x	x
Gasoline Specifications	x	x	x	x	x	x
Reduc. of Animal Matter	x	x	x	x	x*	x
Gasoline Loading into Tanks	x*	x	x	x	x	x
Organic Solvents	x*	x*	x	x*	x*	x
New Fuel Burn. Equip.	x	x*	x	x	x	x
Existing Fuel Burn. Equip.:						
Oxides of Nitrogen	x	x(5)	x*	x*	x(6)	x
Combustion Contaminants	x**	x	x	x	x	x
Vacuum Producing Systems	x	x	x	x	x	x
Asphalt Air Blowing	x	x	x	x	x	x
Carbon Monoxide	x	x	x	x	x	x
Pumps & Compressors	x	-	-	-	-	-
Pressure Relief Valves	x	-	-	-	-	-

TABLE 2-8 SOUTH COAST BASIN RULES SUMMARY (continued)

<u>Rules</u>	<u>L.A.</u>	<u>Orange</u>	<u>Riverside</u>	<u>San Bernardino</u>	<u>Ventura</u>	<u>Santa Barbara</u>
Hearing Board	x	x	x	x	x	x
Orchard Heaters	x	x	x	x	x	-
Emergencies	x	-	x*	x*	x*	x**
Abatement	x	-	x	x	-	-

Notes:

- \* More stringent
- \*\* Less stringent
- No Rule
- (1) More stringent for process weights of 60,000 lb/hr or less.  
Less stringent for process weights of 70,000 lb/hr or more.
- (2) More stringent for incinerators burning 100 lbs/hr or less.
- (3) More stringent for incinerators burning 100 lbs/hr or less.  
Less stringent for incinerators burning more than 100 lbs/hr.
- (4) Less stringent than Los Angeles and Orange Counties.
- (5) More stringent for plants with heat inputs between 500 million and 1775 million BTU/hr. Less stringent for those having inputs of 1775 million BTU/hr to 2150 million BTU/hr.
- (6) More stringent for plants having heat input rates between 250 million and 1775 million BTU/hr. More stringent for existing sources having heat inputs between 1775 million and 2150 million BTU/hr when burning gas, but less stringent when burning oil.

TABLE 2-9. PERCENTAGE CONTROL OF STATIONARY SOURCES IN THE SOUTH COAST AIR BASIN

<u>Source Category</u>	<u>Reactive Organic Gases</u>	<u>Particulate Matter</u>	<u>NO<sub>x</sub></u>	<u>SO<sub>x</sub></u>	<u>CO</u>
Petroleum	71.3%	76.9%	58.1%	96.2%	99.8%
Organic Solvent Users	90.1	22.7			
Chemical	0	34		30.7	0
Metallurgical		95.6		22.9	98.8
Mineral	0	97.9		0	0
Incineration	99.7	97.9	96.6	0	94.4
Fuel Combustion	0	56.1	55.0	84.5	0
Agriculture	0	68.4	32.8	31.3	67.1
	<hr/>	<hr/>	<hr/>	<hr/>	<hr/>
Total	86.1%	94.9%	58.6%	88.2%	97.5%

Source: Los Angeles Air Pollution Control District, "Supplement to the Implementation Plan - South Coast Air Basin," August 1973, revised December 11, 1973.

### 3.0 EMISSION PROJECTIONS

This section of the report details the assumptions and methods used in projecting emissions in the Air Basin. Two alternatives are considered: First, projections are made assuming that only controls presently scheduled to go into effect by the local APCD's and the federal new car control program are implemented; second, projections are made assuming that the EPA-promulgated implementation plan for achieving the oxidant standard in the Air Basin is indeed implemented.

#### 3.1 SOURCES OF DATA

##### 3.1.1 Stationary Sources and Aircraft

The availability of data required to compile an emission projection can best be described as limited in quantity and diverse in quality. Ideally, projections by the individual categories of sources (such as petroleum refineries and utility companies) would be available, but this was true in only one case. The most reasonable alternative was to review the literature and to contact public agencies and private utilities possessing the information necessary to the formation of the projections. The following list summarizes these various sources.

##### Stationary Sources

- A. Literature - "Population and Economic Activity in the United States and Standard Metropolitan Statistical Areas"; EPA, 1972.<sup>29</sup>
  - "1973 California Gas Report."<sup>30</sup>
  - "Transportation Control Strategy Development for the Metropolitan Los Angeles Region," TRW, Inc., 1973.<sup>2</sup>
- B. Public Agencies - Los Angeles City Department of Water and Power.
  - Los Angeles, San Bernardino and Ventura County Air Pollution Control Districts.
  - Los Angeles County Chamber of Commerce.
  - University of California, Los Angeles (UCLA)



- C. Private Organizations - Southern California Edison Company
  - Southern California Gas Company
  - Security Pacific National Bank
  - Wells Fargo Bank

#### Aircraft

- A. Literature - "Aircraft Emissions: Impact on Air Quality and Feasibility of Control"; EPA, 1973.<sup>31</sup>
- B. Public Agencies - Los Angeles International Airport
- C. Private Organizations - Southern California Association of Governments (SCAG).

#### 3.1.2 Motor Vehicles

Emissions from motor vehicles have been previously projected for the purposes of oxidant control strategy development.<sup>2</sup> However, these projections were made prior to the granting of delays to the auto manufacturers in meeting the Clean Air Act Standards, and the establishment of interim standards for new car emissions. Hence, new projections were developed for light-duty vehicles which incorporated this change. Heavy duty vehicle emissions were projected in a similar fashion to light duty vehicles. The local APCDs report current emissions for gasoline-powered motor vehicles where light and heavy duty vehicles are unfortunately lumped together. Further, no projections have been made by these agencies. Therefore, the procedure outlined in Appendix C was used to project emissions in these source categories.

### 3.1.3 Uncontrolled Vehicles

The most comprehensive study located concerning projected emissions from uncontrolled vehicles is one done for the California Air Resources Board by Automotive Environmental Systems, Inc., (AESi) of Westminster California.<sup>6</sup> Uncontrolled vehicles are defined by AESi to include:

- (1) Exempted automobiles - pre 1955 model year vehicles, vehicles with engines of less than 50 CID, vehicles of limited production and foreign origin.
- (2) Competition vehicles - vehicles used in road, drag, oval or flat track, record car or off road racing.
- (3) Motorcycles.
- (4) Snowmobiles, ATV's and dune buggies.
- (5) Lawn and garden equipment, chainsaws and home utilities.
- (6) Farm equipment.
- (7) Off road heavy duty equipment - construction and earth moving, mining and quarrying, lumber equipment.

AESi's work included extensive literature searches, surveys of knowledgeable personnel and emission tests to arrive at emission factors. For example, in the case of motorcycles, some aspects examined by AESi were (1) on and off road motorcycles (2) two and four stroke engines (3) number and annual mileage travelled (from California State Department of Motor Vehicles, U.S. Department of Interior, U.S. Bureau of Land Management and sales statistics) (4) emissions for off road motorcycles (by testing) and (5) growth rates of sales.

Emissions were projected by AESi from 1970 to 1980 for each air quality control region in the State of California.

### 3.2 POLICIES AND ASSUMPTIONS

To arrive at an emission projection with information obtained from the sources available, the decision was made not to rely on any one specific source, but rather to use different ones in different categories of sources. As a consequence, the following policies were adopted:

- (1) Petroleum industry emissions - Dr. Richard L. Perrine of UCLA was consulted regarding trends in petroleum production and refining operations. TRW's report<sup>2</sup> was used for trends in gasoline marketing.
- (2) Organic solvent users; chemical, metallurgical and mineral industries; incineration and agricultural emissions - For all these categories, the growth rate of emissions was considered equal to the growth rate of the individual type of emitter (i.e. chemical, metallurgical industries). The EPA's population and economic activity study<sup>29</sup> contained growth rates for certain select industries but was not used because of its assumption of a Bureau of Census "C" series birthrate, a figure considerably higher than the actual birthrate. Other organizations contacted (banks and chamber of commerces) did not have long term industrial growth rate projections. Thus, the decision was made to use instead a total employment growth rate forecasted by the Wells Fargo Bank.<sup>32</sup>
- (3) Steam electric power plant fuel combustion emissions - The Southern California Edison Company has made projections of its emissions in the South Coast Air Basin. However, none of the other utilities contacted has made any projections, so estimates based on Edison's figures were used for them.<sup>9</sup>
- (4) Industrial (excluding steam electric) fuel combustion emissions - Because industrial facilities in the air basin burn natural gas (when available), Southern California Gas Company and the "1973 California Gas Report" projections of natural gas supplies were used along with emission factors to calculate emissions. Adjustment for combustion of fuel other than natural gas was made.
- (5) Domestic and commercial fuel combustion emissions - All domestic and commercial fuel combustion is assumed to result from the use of natural gas. Southern California Gas Company and the "1973 California Gas Report" projections were used.
- (6) Aircraft emissions - Although Los Angeles International is in the process of projecting its future air traffic activity, personnel contacted at the facility were unwilling to release any information. The EPA aircraft emissions report contained emission projections at Los Angeles International and Van Nuys Airport for 1975 and 1980. However, these figures were not acceptable because (a) the baseline data (1970) disagreed with Los Angeles County APCD figures (which were assumed to be more accurate) and (b) the report included only two airports out of a total of 42 in the air basin. As a result of these difficulties, a SCAG report "Southern California Regional Aviation System Study"<sup>33</sup> was used instead.

The preceding policies and assumptions regarding the projection of the emission inventory are summarized in Table 3-1.

TABLE 3-1 SUMMARY OF ASSUMPTIONS USED FOR BASELINE DATA (1972)  
PROJECTIONS TO 1977 AND 1980

	Los Angeles	Orange	Riverside	San Bernardino	Santa Barbara	Ventura
Petroleum						
(1) Production	1	1	2	2	2	1
(2) Refining	9	2	2	2	2	2
(3) Marketing	3	3	3	3	2	3
Organic Solvent						
(1) Surface Coating	4	2	4	4	4	4
(2) Dry Cleaning	4	2	4	4	4	4
(3) Degreasing	4	4	4	4	4	4
(4) Other	4	4	4	4	4	4
Chemical						
(1) Petrochemical	4	2	4	2	2	4
(2) Sulfur Plants	4	2	4	2	2	4
(3) Sulfuric Acid Plants	4	2	4	2	2	4
(4) Pulp and Paper	4	2	4	2	2	4
(5) Other	4	4	4	2	2	4
Metallurgical						
(1) Ferrous	4	4	4	4	2	2
(2) Non Ferrous	4	4	4	4	2	2
Mineral						
(1) Glass and Frit	4	4	4	4	4	4
(2) Asphalt Batching	4	4	4	4	4	4
(3) Asphalt Roofing	4	4	4	4	4	4
(4) Cement Production	4	4	4	4	4	4
(5) Concrete Patching	4	4	4	4	4	4
(6) Other	4	4	4	4	4	4

TABLE 3-1. SUMMARY OF ASSUMPTIONS USED FOR BASELINE DATA  
(1972) PROJECTIONS TO 1977 AND 1980 (CONTINUED)

	Los Angeles	Orange	Riverside	San Bernardino	Santa Barbara	Ventura
Incineration						
(1) Open Burning (Dumps)	2	2	2	2	2	2
(2) Open Burning (Backyard)	2	2	2	2	2	2
(3) Incinerators	8	8	8	2	2	2
(4) Other	2	2	2	5	2	5
Combustion of Fuel						
(1) Steam and Power Plants	6	6	6	6	6	6
(2) Other Industrial	7	7	7	7	7	7
(3) Domestic and Commercial	7	7	7	7	7	7
Agricultural						
(1) Debris Burning	2	5	5	2	5	5
(2) Orchard Heaters	2	2	5	5	2	5
(3) Agricultural Production Pro- cessing Plants	2	2	5	2	2	5

Assumption #1: There will be no change of emission levels from 1972 because no new oil fields or increased production from existing fields and refineries is expected.

Assumption #2: There were no emissions from these sources in 1972 and none is expected in the future.

Assumption #3: The historical 4% per year growth rate in gasoline sales is expected to hold true in the future. No attempts have been made to assess the impact of possible fuel shortages on gasoline sales.

TABLE 3-1. SUMMARY OF ASSUMPTIONS USED FOR BASELINE DATA  
(1972) PROJECTIONS TO 1977 AND 1980 (CONTINUED)

Assumption #4: The rate of increase in emissions is equal to the rate of increase in the total employment of each county, which is given below:

Los Angeles	1.5% per year
Orange	3.5% per year
Riverside	2.5% per year
San Bernardino	2.3% per year
Santa Barbara	2.3% per year
Ventura	2.9% per year

Source: "Moving Ahead - Wells Fargo Looks at California," Wells Fargo Bank, 1973.

Assumption #5: The emissions from these sources are assumed to remain constant through 1980.

Assumption #6: Emission projections were obtained from Southern California Edison.

Assumption #7: Emission projections were obtained from the 1973 California Gas Report.

Assumption #8: Emissions are assumed to increase at the same rate as population in each county, which is shown in Section 3.3.4.

Assumption #9: Emission projections reflecting anticipated expansions from local refineries (Atlantic Richfield and Standard) were based on figures extracted from the environmental impact statement associated with the proposed Standard Oil expansion project, as conveyed to TRW by EPA in private communication. 42

### 3.3 EMISSION INVENTORY PROJECTION UNDER PRESENT CONTROLS

#### 3.3.1 Petroleum Industry Emissions

Only three counties in the entire air basin report emissions due to petroleum production in 1972 (Los Angeles, Orange and Ventura). For these three counties, emissions are assumed to hold constant through the year 1980. This assumption may overestimate emissions since production has historically declined since the mid-1960's.<sup>34</sup> No attempt has been made to account for possible new techniques of increasing oil production from existing fields (such as steam injection). Counties reporting no emissions are not expected to have any changes through 1980.

Except for Los Angeles County, all counties reporting emissions due to refining process operations are expected to have the same quantity of emissions through 1980. In Los Angeles County, Standard Oil of California and the Atlantic Richfield Company (ARCO) plan to construct facilities to desulfurize high sulfur fuel oil. Changes in refining processes resulting from these new facilities are projected to cause a decrease in RHC emissions of 0.5 tons/day beginning in 1976.<sup>42</sup> For counties having no refineries, none are assumed to be constructed prior to 1980.

In the case of petroleum marketing, the historical 4% per year increase in gasoline sales<sup>2</sup> is assumed to hold true until 1980. Possible declines in gasoline sales due to shortages and for conservation measures by the public have not been assessed. The Los Angeles County APCD vapor recovery rule (Rule #65) will reduce reactive hydrocarbon emissions from the filling of service station storage tanks by 90% starting in 1975. (The transfer of gasoline to vehicular tanks remains uncontrolled.)

#### 3.3.2 Organic Solvent Users

For counties reporting no emissions in 1972, no emissions are assumed through 1980. Otherwise the following yearly growth rates in emissions are assumed:

<u>COUNTY</u>	<u>PERCENT YEARLY GROWTH</u>
Los Angeles	1.5
Orange	3.5
Riverside	2.5
San Bernardino	2.3
Santa Barbara	2.3
Ventura	2.9

These figures are actually the projected yearly increase in total employment from 1972 through 1980. Thus the rate of increase in emissions is assumed equal to the rate of increase in total employment. By doing so, the projections may result in higher emissions than would actually occur, since much of the increase in employment can undoubtedly be attributed to light industry and service-oriented occupations.

### 3.3.3 Chemical, Metallurgical and Mineral

The methodology used for these industries is the same as that employed in the case of Organic Solvent Users. One exception is sulfur dioxide emissions from Los Angeles County sulfur recovery plants which are held constant (after 1974) at 10 tons/day. This is because of the Los Angeles County APCD Rule 53.2 which limits SO<sub>2</sub> emissions from sulfur recovery plants to

- 500 ppm by volume of sulfur compounds calculated as sulfur dioxide.
- 10 ppm by volume of hydrogen sulfide.
- 200 pounds per hour of sulfur compounds calculated as sulfur dioxide.

Emissions from metallurgical industries in San Bernardino County may not actually increase as rapidly as the projections indicate. This is because the following information concerning the Kaiser Steel Plant in Fontana was revealed in conversations with personnel at the San Bernardino County APCD:<sup>35</sup>

- (1) The plant is the largest stationary point source (excluding power plants) in the county.
- (2) A proposed coke oven desulfurization plant (scheduled to go into operation in the late 1970's) will probably reduce SO<sub>x</sub> emission levels to 1 ton/day.
- (3) An on-going dust level reduction program should reduce particulate emissions by 5 tons/day (scheduled to be completed by 1977).

The reductions in emissions indicated above were not included in the projections because of the uncertain nature of the effectiveness of control and because the projected changes are not required by law.



### 3.3.4 Agriculture and Incineration

For counties reporting emissions from agriculture related industries, no change in emission rates is expected through 1980. There may actually be declines in this category of emissions in the future because the present trend of development in the air basin has been towards increased urbanization.

Emissions due to incineration are assumed to increase at the same rate as population in each county, assuming that the series D-100 projections of the State's Population Research Unit apply. The projections are summarized below:

<u>County</u>	<u>Population</u>			<u>Annual Growth Rate (%)</u>
	<u>1970</u>	<u>1975</u>	<u>1980</u>	
Los Angeles	7,045,200	6,924,500	6,963,200	- .1
Orange	1,432,900	1,712,000	1,970,000	+3.8
San Bernardino	685,500	711,000	765,100	+1.2
Riverside	461,200	527,100	596,900	+2.9
Ventura	381,200	446,200	523,300	+3.7
Santa Barbara	264,700	283,300	305,800	+1.6

### 3.3.5 Steam Electric Power Plant Fuel Combustion Emissions

The Southern California Edison Company (SCE) has made projections of emissions of particulates,  $\text{NO}_x$  and  $\text{SO}_2$  from its steam plants in the Los Angeles Basin<sup>36</sup> (Table 3-2). These projections include the expectancy of fuels available from the proposed ARCO and Standard Oil refineries, and are based in part on:

- The operation of a new combined cycle unit of 563 MWe at Edison's Long Beach plant by 1976.
- The operation of a new combined cycle unit of 1416 MWe at Edison's Huntington Beach plant by 1978.
- The availability of electrical power brought into the South Coast Air Basin from sources such as Pacific Northwest hydroelectric, the Four Corners (New Mexico) coal fired plant and the San Onofre nuclear plant.
- The expected customer demand.
- The expected availability of fuel oil, distillate and natural gas.

TABLE 3-2. PROJECTED EMISSIONS OF PARTICULATES, NO<sub>x</sub> AND SO<sub>2</sub> FROM SCE STEAM ELECTRIC PLANTS IN THE BASIN

<u>Year</u>	<u>Particulates</u>	<u>NO<sub>x</sub></u>	<u>SO<sub>2</sub></u>
1977	31.4	112.8	255.1
1980	32.5	122.0	268.3

Source: S. Moody, SCE, private communication, April 1974.

TABLE 3-3. GENERATING CAPACITIES OF SCE (IN THE AIR BASIN), DWP AND GPB

<u>Utility Company</u>	<u>County</u>	<u>Generating Capacity (MWe)</u>		
		<u>1972</u>	<u>1977</u>	<u>1980</u>
SCE	Los Angeles	4788	5351	5351
	Orange	880	2296	2296
	San Bernardino	1186	1186	1186
	Ventura	2010	2010	2010
DWP	Los Angeles	3363	3363	3363
GPB	Los Angeles	580	580	580

Note: There are no steam electric plants in Riverside and the Air Basin portion of Santa Barbara County

Source: M. Ziol and S. Moody, SCE, Private Communication, 1974

TABLE 3-4. ELECTRIC GENERATING CAPACITY RATIOS

<u>Year</u>				
1972	$\frac{\text{DWP Generating Capacity}}{\text{SCE Generating Capacity}}$	=	$\frac{3363 \text{ MWe}}{8864 \text{ MWe}}$	= 0.379
1977, 1980	$\frac{\text{GPB Generating Capacity}}{\text{SCE Generating Capacity}}$	=	$\frac{580 \text{ MWe}}{10843 \text{ MWe}}$	= .05

- The fact that if the fuel oil supplied by ARCO is less than the Los Angeles County APCD requirement of 0.5% (by weight) sulfur content, Edison will not blend higher percentage sulfur fuel oil (such as Venezulean) with the lower percentage grade to just meet the APCD requirement.

The allocation of fuel oil from the new refineries will go to existing conventional boiler Edison plants, while the 0.1% (by weight) sulfur distillate will go to the new combined cycle plants at Long Beach and Huntington Beach. Edison predicts that only 2-3% of the fuel it will use in the future will be natural gas. The Los Angeles City Department of Water and Power (DWP) has made no emission projections because they expect to meet future demand by obtaining electricity from sources outside the air basin.<sup>37</sup> Due to the relatively minor contributions of pollutants from the municipalities of Glendale, Pasadena and Burbank (GPB), no attempt was made to contact them concerning the availability of emission projections.

Based on information received, the following methodology for predicting emissions was adopted:

- (1) Calculate the generating capacities (excluding gas turbine units) of SCE in the Los Angeles Basin, DWP and GPB. (These municipalities are considered as a unit.) (Table 3-3).
- (2) Calculate the ratio of the DWP and GPB generating capacities to that of SCE. (Table 3-4).
- (3) Assume that the emissions from GPB is proportional to the ratio obtained in Step (2). For example, since  $(\text{GPB generating capacity} / \text{SCE operating capacity}) = .05$ , GPB's emissions for all projection years equals .05 times those of SCE.
- (4) Because of the DWP's proposed policy of bringing power into the basin, their emissions are assumed to remain constant through 1980. Since in 1972  $(\text{DWP generating capacity} / \text{SCE generating capacity}) = 0.379$ , DWP baseline emissions are assumed to be equal to 0.379 times SCE's emissions in 1972.

The results of Steps (3) and (4) are shown in Table 3-5.

The methodology outlined above does not account for possible energy conservation measures adopted by consumers and the fact that emissions are not directly proportional to generating capacities (since the emission characteristics of individual plants differ).

TABLE 3-5. PROJECTED EMISSIONS FROM STEAM ELECTRIC PLANTS  
IN THE AIR BASIN (TONS/DAY)

<u>Year</u>	<u>County</u>	<u>Particulates</u>	<u>NO<sub>x</sub></u>	<u>SO<sub>2</sub></u>
1977	Los Angeles	25.9	98.5	210.2
	Orange	6.6	23.7	53.6
	Riverside	-	-	-
	San Bernardino	3.5	12.4	28.1
	Santa Barbara	-	-	-
	Ventura	5.9	21.4	48.5
1980	Los Angeles	26.4	103.5	218.2
	Orange	6.8	25.6	56.3
	Riverside	-	-	-
	San Bernardino	3.6	13.4	29.5
	Santa Barbara	-	-	-
	Ventura	6.2	23.2	51.0

### 3.3.6 Domestic and Commercial Fuel Combustion

Emissions from domestic and commercial fuel combustion in the air basin result from the use of natural gas supplied by the Southern California Gas Company (SC Gas) and the city of Long Beach (LB). Both SC Gas' parent company, the Pacific Lighting Companies (PLC) and LB have made projections of deliveries to domestic and commercial customers<sup>30</sup> (also known as firm customers) (Tables 3-6 and 3-7). With these projections and EPA emission factors (Table 3-16), the average daily emissions of particulates, NO<sub>x</sub> and SO<sub>2</sub> can be calculated. It is desirable, however, to calculate a county by county emission projection. The methodology for accomplishing this is detailed in the following paragraph.

Since PLC sells natural gas to customers other than SC Gas and SC Gas' service area extends from San Luis Obispo to San Bernardino Counties and from Fresno to Imperial County (excluding the city of Long Beach), the initial step was to determine SC Gas' firm deliveries to the air basin counties. This was done by assuming that the fraction of SC Gas' total firm deliveries which went to the air basin counties in 1973 would remain

constant until 1980 (Table 3-9). Once these fractions were known, a county by county projection could be made (LB firm sales were attributed to Los Angeles County) (Tables 3-11, 13 and 14).

The procedure explained above assumes average temperature years, and does not account for possible conservation measures by consumers and the possible switching by interruptible customers to a firm delivery schedule.

### 3.3.7 Other Industrial Fuel Combustion

#### Los Angeles County

All emissions are due either to petroleum refining operations or other industries" (i.e. chemical, metallurgical). The new desulfurization facilities at Standard Oil and ARCO are projected to contribute the following quantities of combustion emissions:<sup>42</sup>

- Standard Oil (starting in 1976):

Particulate	+0.3 tons/day
NO <sub>x</sub>	+4.9 tons/day
SO <sub>2</sub>	+5.3 tons/day
- ARCO (starting in 1977):

Particulate	+0.7 tons/day
NO <sub>x</sub>	+7.2 tons/day
SO <sub>2</sub>	+7.3 tons/day

Otherwise fuel combustion emissions from all other refineries are expected to remain constant through 1980. In the "other industries" category, emissions result from the combustion of either natural gas or alternate fuels (propane, fuel oil, etc.). This is because most industrial facilities are on an interruptible natural gas supply basis and have alternate fuel supplies. The projection of natural gas supplies to these interruptible customers has been made by the PLC and LB.<sup>30</sup> This information, along with emission factors (Table 3-16), allow for the calculation of emissions due to natural gas combustion. However, the problem remains in attempting to project emissions from the combustion of alternate fuels.

In 1972, the total emissions from fuel combustion by "other industries" was:

Particulates:	6.0 tons/day (total particulates minus petroleum refining operations particulates).
NO <sub>x</sub> :	80.6 tons/day (KVB Engineering, Inc.).
SO <sub>2</sub> :	10 tons/day.

Also, in 1972, natural gas supplied to these "other industries" was 70,849 MMcf.<sup>2</sup> Using EPA emission factors (Table 3-16), the daily tonnage of pollutants generated by burning this quantity of natural gas was:

Particulates:	1.7 tons/day
NO <sub>x</sub> :	17.0 tons/day
SO <sub>2</sub> :	0.06 tons/day

Thus,

6.0 - 1.7 = 4.3 tons of particulate emissions in 1972 were due to the combustion of alternate fuels.

80.4 - 17 = 63.4 tons of NO<sub>x</sub> emissions in 1972 were due to the combustion of alternate fuels.

10.0 - .06 = 9.94 tons of SO<sub>2</sub> emissions in 1972 were due to the combustion of alternate fuels.

In 1972, 1977 and 1980 the curtailment (difference between demand and supply) of natural gas to industrial customers is 8502 MMcf, 37,423 MMcf and 32,268 MMcf respectively (Table 3-13). Then,

$$\frac{1977 \text{ curtailment}}{1972 \text{ curtailment}} = \frac{37,423 \text{ MMcf}}{8,502 \text{ MMcf}} = 4.4$$

$$\frac{1980 \text{ curtailment}}{1972 \text{ curtailment}} = \frac{32,268 \text{ MMcf}}{8,502 \text{ MMcf}} = 3.8$$

The above ratios reflect the increase in usage of alternate fuels in 1977 and 1980 as compared to 1972. By multiplying 4.4 times the 1972 emissions of particulates, NO<sub>x</sub> and SO<sub>2</sub> due to alternate fuels, the resulting figures yield the 1977 emissions of these pollutants due to the combustion of alternate fuels. For 1980, the factor of 3.8 is used instead.

#### Orange, San Bernardino, Santa Barbara, and Ventura Counties

All emissions are from "other industries" (no petroleum refineries) burning either natural gas or alternate fuels. The procedure outlined for "other industries" in Los Angeles County was also used here, except for San Bernardino County SO<sub>2</sub> emissions which are assumed to hold constant from 1972 through 1980, since SO<sub>2</sub> emissions in this category are due mainly to the Kaiser Steel Plant operation which is not projected to increase its throughput.

The baseline data is obtained by multiplying the quantity of interruptible natural gas supplied to the county times emission factors (Table 3-16), except for NO<sub>x</sub> where KVB Engineering, Inc.<sup>8</sup> data is used.

Table 3-6. PACIFIC LIGHTING COMPANIES NATURAL GAS USAGE  
PREDICTIONS (in MMcf)

<u>Year</u>	Firm Sales (Retail & Wholesale)		Interruptible Sales (Industrial & Wholesale)	
	<u>Demand</u>	<u>Supply</u>	<u>Demand</u>	<u>Supply</u>
1977	550,834	550,834	426,824	277,436
1980	585,345	585,345	460,038	331,227

Note: Above figures do not include sales to steam electric plants and oil companies (payback and exchange)

Source: 1973 California Gas Report.

Table 3-7. LONG BEACH NATURAL GAS USAGE PREDICTION  
(in MMcf)

<u>Year</u>	Firm Sales (Retail & Wholesale)		Interruptible Sales (Industrial & Wholesale)	
	<u>Demand</u>	<u>Supply</u>	<u>Demand</u>	<u>Supply</u>
1977	15,194	15,194	5,498	5,498
1980	15,194	15,194	5,537	5,537

Note: Above figures do not include sales to steam electric plants and oil companies (exchange and payback)

Source: 1973 California Gas Report.

TABLE 3-8 BREAKDOWN OF 1973 SC GAS COMPANY SALES IN AIR BASIN  
(Not including sales to steam electric plants  
and oil companies) (MMcf)

<u>County</u>	<u>Firm Sales</u>	<u>% of Firm Sales</u>	<u>Interruptible Sales</u>	<u>% of Interruptible Sales</u>
Los Angeles	285,910.48	69.2	82,412.93	61.1
Orange	65,914.05	15.9	17,935.16	13.3
Riverside	15,572.63	3.8	10,185.26	7.5
San Bernardino	26,010.02	6.4	20,383.04	15.1
Santa Barbara	3,511.76	0.8	182.26	0.1
Ventura	16,414.96	3.9	3,971.29	2.9

Source: E. Harris, Southern California Gas Company

TABLE 3-9. BREAKDOWN OF 1973 PACIFIC LIGHTING COMPANIES SALES  
TO AIR BASIN PORTION OF SC GAS (Not including  
sales to steam electric plants and oil companies)

<u>SC Gas Company Firm Sales</u>	=	<u>413,333.9 MMcf</u>	=	0.82
Pacific Lighting Companies Firm Sales		504,013 MMcf		
<u>SC Gas Company Interruptible Sales</u>	=	<u>135,069.4 MMcf</u>	=	0.41
Pacific Lighting Co's Interruptible Sales		328,911 MMcf		



Table 3-10

Summary of Pacific Lighting Companies Breakdown  
of Sales to Southern California Gas Company (By County)

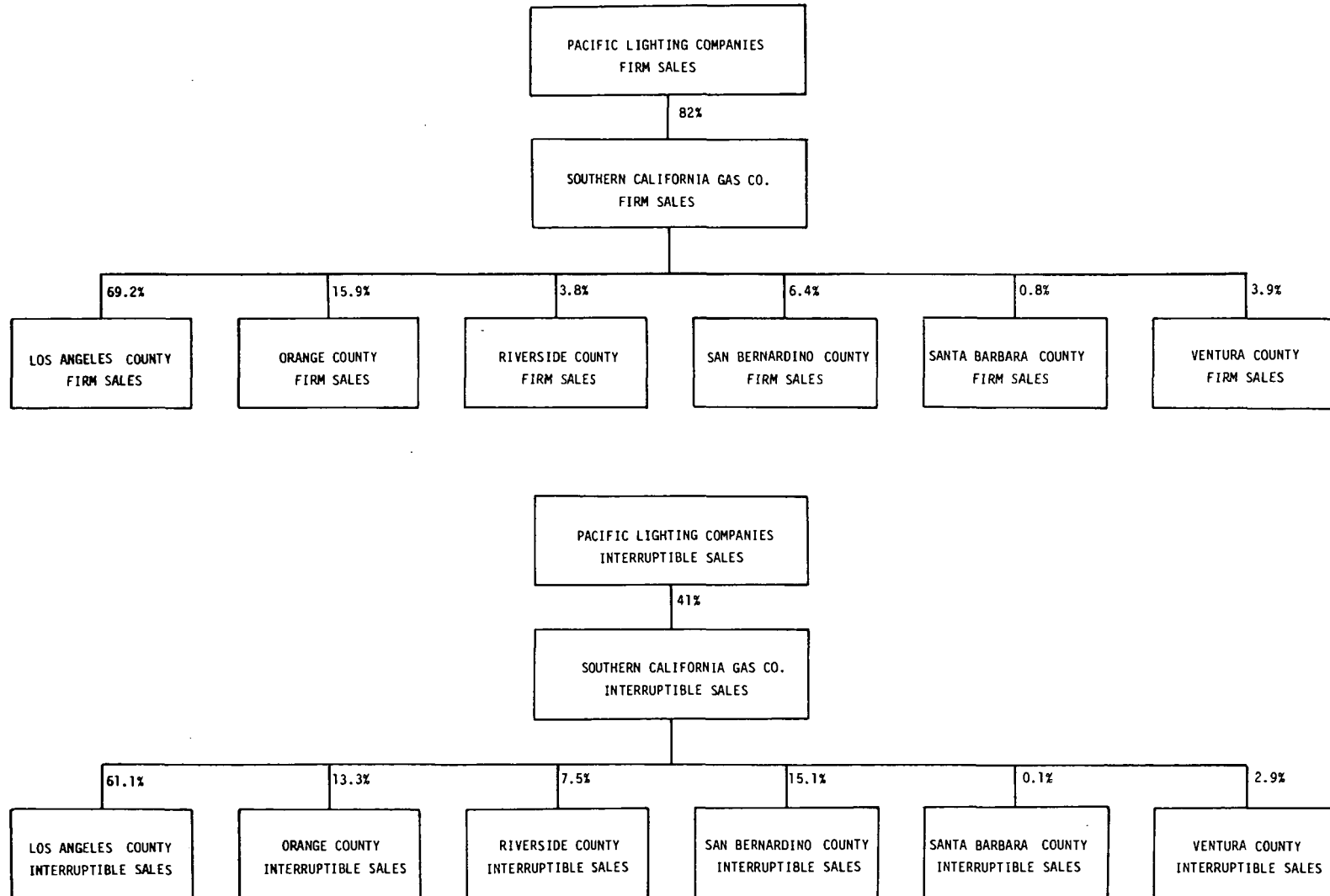


TABLE 3-11. PROJECTION OF FIRM SALES IN THE AIR BASIN FROM SC GAS AND LONG BEACH (in MMcf)

<u>Year</u>	<u>Pacific Lighting Companies Firm Sales</u>	<u>Percent of PLC Firm Sales to Air Basin SC Gas</u>	<u>SC Gas Firm Sales in the Air Basin</u>	<u>LB Firm Sales</u>	<u>Total Firm Sales</u>
1973	504,013	82%	413,290.7	14,327	427,617.7
1977	550,834	82%	451,683.9	15,194	466,877.9
1980	585,345	82%	479,982.9	15,194	495,176.9

TABLE 3-12. PROJECTION OF INTERRUPTIBLE SALES IN THE AIR BASIN FROM SC GAS AND LONG BEACH (MMcf)

<u>Year</u>	<u>Pacific Lighting Companies</u>		<u>Percent of PLC to SC Gas Portion of Air Basin</u>	<u>SC Gas in Air Basin</u>		<u>Long Beach</u>		<u>Total</u>	
	<u>Demand</u>	<u>Supply</u>		<u>Demand</u>	<u>Supply</u>	<u>Demand</u>	<u>Supply</u>	<u>Demand</u>	<u>Supply</u>
1977	426,824	277,436	41%	174,998	113,749	5,498	5,498	180,496	119,247
1980	460,038	331,227	41%	188,616	135,803	5,537	5,537	194,153	140,340

TABLE 3-13. FIRM AND INTERRUPTIBLE GAS SALES PROJECTION IN THE  
AIR BASIN (MMcf)

<u>Year</u>	<u>County</u>	<u>Firm</u>		<u>Inturruptible</u>		
		<u>Demand</u>	<u>Supply</u>	<u>Demand</u>	<u>Supply</u>	<u>Curtailment</u>
1972	Los Angeles	-	-	79,351	70,849	8,502
	Orange	-	-	15,961	14,251	1,710
	Riverside	-	-	9,000	8,036	964
	San Bernardino	-	-	18,122	16,180	1,942
	Santa Barbara	-	-	120	107	13
	Ventura	-	-	3,480	3,107	373
1977	Los Angeles	327,759	327,759	112,421	74,999	37,423
	Orange	71,818	71,818	23,274	15,129	8,146
	Riverside	17,164	17,164	13,124	8,531	4,594
	San Bernardino	28,908	28,908	26,425	17,176	9,249
	Santa Barbara	3,614	3,614	175	114	61
	Ventura	17,616	17,616	5,075	3,299	1,776
1980	Los Angeles	347,342	347,342	120,781	88,513	32,268
	Orange	76,317	76,317	25,086	18,062	7,024
	Riverside	18,239	18,239	14,146	10,185	3,961
	San Bernardino	30,719	30,719	28,481	20,506	7,965
	Santa Barbara	3,840	3,840	189	136	53
	Ventura	18,719	18,719	5,470	3,938	1,532

TABLE 3-14. PROJECTED EMISSIONS FROM DOMESTIC AND COMMERCIAL FUEL COMBUSTION (tons/day) \*

<u>Year</u>	<u>County</u>	<u>Particulates</u>	<u>NO<sub>x</sub></u>	<u>SO<sub>2</sub></u>
1977	Los Angeles	8.5	44.9	0.3
	Orange	1.9	9.8	0.1
	Riverside	0.4	2.4	negl.
	San Bernardino	0.8	4.0	negl.
	Santa Barbara	0.1	0.5	negl.
	Ventura	0.5	2.4	negl.
1980	Los Angeles	9.0	47.6	0.3
	Orange	2.0	10.5	0.1
	Riverside	0.5	2.5	negl.
	San Bernardino	0.8	4.2	negl.
	Santa Barbara	0.1	0.5	negl.
	Ventura	0.5	2.6	negl.

\*Figures obtained by multiplying natural gas usage (Table 3-13) times EPA emission factors (Table 3-16).

negl. = negligible

TABLE 3-15. PROJECTED EMISSIONS FROM INDUSTRIAL FUEL COMBUSTION (tons/day)

<u>Year</u>	<u>County</u>	<u>Particulates</u>	<u>NO<sub>x</sub></u>	<u>SO<sub>2</sub></u>
1977	Los Angeles	29.0	346.1	63.6
	Orange	2.0	26.0	negl.
	Riverside	0.2	4.0	negl.
	San Bernardino	4.7	100.0	17.6
	Santa Barbara	negl.	8.0	negl.
	Ventura	1.3	61.0	0.4
1980	Los Angeles	26.0	311.1	57.6
	Orange	2.0	23.3	negl.
	Riverside	0.3	4.0	negl.
	San Bernardino	4.2	87.0	17.6
	Santa Barbara	negl.	6.9	negl.
	Ventura	1.0	54.0	0.3

negl. = negligible

TABLE 3-16. EMISSION FACTORS FOR NATURAL GAS COMBUSTION

Pollutant	Industrial		Domestic and Commercial	
	(Lbs/10 <sup>6</sup> Ft <sup>3</sup> )	(Tons/10 <sup>6</sup> Ft <sup>3</sup> -Day)	(Lbs/10 <sup>6</sup> Ft <sup>3</sup> )	(Tons/10 <sup>6</sup> Ft <sup>3</sup> -Day)
Particulate	18.0	24.7 x 10 <sup>-6</sup>	19.0	26.0 x 10 <sup>-6</sup>
SO <sub>2</sub>	0.6	0.8 x 10 <sup>-6</sup>	0.6	0.6 x 10 <sup>-6</sup>
CO	17.0	23.3 x 10 <sup>-6</sup>	20.0	27.4 x 10 <sup>-6</sup>
CH <sub>4</sub>	3.0	4.1 x 10 <sup>-6</sup>	8.0	11.0 x 10 <sup>-6</sup>
NO <sub>2</sub>	175.0*	239.7 x 10 <sup>-6</sup> *	100.0*	137.0 x 10 <sup>-6</sup> *

\*Average

Source: Compilation of Air Pollutant Emission Factors, EPA, April 1973.

### 3.3.8 Aircraft Emissions

Note: Air carrier airports are defined as ones which primarily handle commercial passenger and air cargo traffic. The aircraft at these airports are assumed to be mainly jet driven, with a small fraction being piston driven. General aviation airports are defined to be ones which primarily serve small private aircraft, with the majority being piston driven.

#### Los Angeles County

There are three air carrier, ten general aviation, and no military airfields in the county (Table 3-17). It is assumed that the air carrier airports contribute an overwhelming percentage of the countywide jet aircraft emissions (in 1970, the Los Angeles County APCD reported that 75% of the total jet aircraft emissions in the county emanated from Los Angeles International alone) and that these emissions will increase at the rate of 14% per year, the historical (1960-1970) growth rate of the number of passengers carried.<sup>33</sup> This rate may tend to overestimate emissions because of the introduction of cleaner jet engines and the increased use of "jumbo jets." As for piston aircraft emissions, the general aviation airports are presumed to contribute the majority of these emissions which are assumed to increase at the rate of 6% per year. This 6% figure is the estimated growth rate of piston aircraft based at general aviation airports.<sup>33</sup>

#### Orange County

Following the procedure outlined for Los Angeles County, jet aircraft emissions are assumed to increase at the rate of 14% per year (from Orange County Airport) and piston aircraft emissions at 6% per year (from the general aviation airports). No information was available to assess the present and future impact of the lone military airbase, El Toro Marine Corps Air Station.

#### Riverside County

Conversations with personnel familiar with March AFB revealed that only a minor fraction of the county's aircraft emissions could be attributed to this facility. Consequently, all emissions were assigned

to the eight general aviation airports and were assumed to increase at the rate of 6% per year.

#### San Bernardino County

The two military airbases account for a very minor portion of the total aircraft emissions. All emissions were assigned to Ontario International (the general aviation airports contribute a negligible quantity of emissions<sup>38</sup>) and assumed to increase at 14% per year.

#### Santa Barbara County

There is only one airport in the county (Table 3-17). Since it is an air carrier airport, emission rates for both jet and piston driven aircraft are assumed to increase at the rate of 14% per year.

#### Ventura County

While there are a total of five airports (Table 3-17), only the three general aviation airports contribute to the emission inventory, since Oxnard AFB is inactive and Pt. Mugu NAS is used only for periodic training flights. Emissions are therefore assumed to increase at 6% per year.

The procedure outlined above does not account for the 1979 federal standards for new jet engines. However, since the average lifetime of a jet engine is 15 years<sup>39</sup>, only 1/15 of the total aircraft in service would be replaced between 1979 and 1980. It is assumed that all retrofitting of JT3D jet engines was completed by 1972 and of JT8D jet engines by 1973. The growth rates for general aviation and air carrier airports are historical trends and thus may not be correct because of possible future changes in the economy.

TABLE 3-17. AIRPORTS IN THE AIR BASIN

<u>County</u>	<u>Air Carrier</u>	<u>General Aviation</u>	<u>Military</u>
Los Angeles	Los Angeles International Hollywood - Burbank Long Beach	San Fernando Whiteman Van Nuys Santa Monica Hawthorne Compton Torrance Shepherd El Monte Brackett	
Orange	Orange County	Fullerton Meadowlark Capistrano	Los Alamitos NAS* El Toro MCAS
Riverside		Fla-Bob Riverside Corona Stony Bridge Ranch Perris Valley Hemet - Ryan Skylark Rancho California	March AFB
San Bernardino	Ontario	Cable Chino Fontana Rialto Colton Tri-City Redlands Big Bear City	Norton AFB George AFB
Santa Barbara		Santa Barbara	
Ventura		Ventura County Santa Paula Santa Susana	Oxnard AFB* Pt. Mugu NAS

\*Inactive

Source: Southern California Regional Aviation System Study, System Development Corporation/William L. Pereira Associates, 1972, (Done for the Southern California Association of Governments).



TABLE 3-18. LOS ANGELES COUNTY AIRCRAFT EMISSIONS  
(tons/day)

<u>Year</u>	<u>Source</u>	<u>RHC</u>	<u>Particulates</u>	<u>NO<sub>x</sub></u>	<u>SO<sub>2</sub></u>
1977	Jet Driven	17.3	17.3	19.3	5.7
	Piston Driven	3.3	-	4.0	-
1980	Jet Driven	25.6	25.5	28.6	8.4
	Piston Driven	3.9	-	4.8	-

TABLE 3-19. ORANGE COUNTY AIRCRAFT EMISSIONS  
(tons/day)

<u>Year</u>	<u>Source</u>	<u>RHC</u>	<u>Particulates</u>	<u>NO<sub>x</sub></u>	<u>SO<sub>2</sub></u>
1977	Jet Driven	-	2.4	1.7	0.2
	Piston Driven	2.3	0.3	0.2	
1980	Jet Driven	-	3.5	2.5	0.3
	Piston Driven	2.7	0.3	0.3	

TABLE 3-20. RIVERSIDE COUNTY AIRCRAFT EMISSIONS  
(tons/day)

<u>Year</u>	<u>Source</u>	<u>RHC</u>	<u>Particulates</u>	<u>NO<sub>x</sub></u>	<u>SO<sub>2</sub></u>
1977	Total (Piston)	2.1	4.3	4.1	-
1980	Total (Piston)	2.4	5.2	4.9	-

TABLE 3-21. SAN BERNARDINO COUNTY AIRCRAFT EMISSIONS (tons/day)

<u>Year</u>	<u>Source</u>	<u>RHC</u>	<u>Particulates</u>	<u>NO<sub>x</sub></u>	<u>SO<sub>2</sub></u>
1977	Jet Driven	1.7	2.5	2.9	0.6
	Piston Driven	-	-	-	-
1980	Jet Driven	2.5	3.8	4.3	0.9
	Piston Driven	-	-	-	-

TABLE 3-22. SANTA BARBARA COUNTY AIRCRAFT EMISSIONS (tons/day)

<u>Year</u>	<u>Source</u>	<u>RHC</u>	<u>Particulates</u>	<u>NO<sub>x</sub></u>	<u>SO<sub>2</sub></u>
1977	Jet Driven	-	0.2	0.2	-
	Piston Driven	-	0.2	-	-
1980	Jet Driven	-	0.3	0.3	-
	Piston Driven	-	0.2	-	-

TABLE 3-23. VENTURA COUNTY AIRCRAFT EMISSIONS (tons/day)

<u>Year</u>	<u>Source</u>	<u>RHC</u>	<u>Particulates</u>	<u>NO<sub>x</sub></u>	<u>SO<sub>2</sub></u>
1977	Jet Driven	11.5	3.8	1.6	0.6
	Piston Driven	3.1	0.8	0.2	-
1980	Jet Driven	16.9	5.6	2.4	0.8
	Piston Driven	3.7	1.0	0.2	-

### 3.3.9 Mobile Source Projection (other than aircraft)

Light and heavy duty motor vehicle emissions were projected using the procedure outlined in Appendix C. The present control program for light-duty vehicles includes the Federal new car control program and the California Air Resources Board retrofit program requiring VSAD on all 1966-1970 vehicles. The effect of the latter program by 1977 and 1980 is of course, minimal, since cars of those model years become a relatively small fraction of the total population.

Diesel emissions were projected by assuming that the growth in diesel VMT is identical to the growth in VMT as projected by LARTS for the Los Angeles Metropolitan area. The 9.7% growth rate used to obtain 1972 diesel emissions was not used because it was felt that such a high rate could not be sustained through 1977 and 1980.

Emissions from miscellaneous uncontrolled vehicles were projected on the basis of the statewide projection to 1980 made by AESi as part of that study. The projection to 1977 was made assuming a linear interpolation between base year and 1980 figures.

Emissions from ships and railroads were assumed to be constant through 1980. Since this category accounts for such a small part of the total inventory for each pollutant, little value was seen in pursuing this subject further.

## 3.4 PROJECTED EMISSION INVENTORY UNDER EPA-PROMULGATED CONTROLS

By 1977, federal regulations for stationary sources in the South Coast Air Basin include the installation of vapor recovery systems at gasoline stations, additional controls on dry cleaning emissions, elimination of certain industrial solvent compounds, improved control on painting operation solvent loss and additional restrictions on the loss of organic solvents in general industrial use.<sup>40</sup> These controls will reduce reactive hydrocarbon emissions at gasoline stations by 81% and reactive hydrocarbon emissions from organic solvent users by 33.6%.<sup>4,41</sup>

The projection of light and heavy duty vehicle emissions to 1977 and 1980 is described in Appendix C. Under the promulgated EPA plan for oxidant control, inspection/maintenance, catalytic converter retrofit and VMT reduction measures are required for light-duty vehicles. Data published in the EPA promulgation (Federal Register, vol. 38, no. 217, Nov. 12, 1973) indicate a 15% reduction in hydrocarbon emissions is anticipated from the inspection/maintenance program, and a 50% reduction in hydrocarbons is anticipated from cars retrofitted with catalysts. VMT reduction measures have not been assessed due to the current uncertainty with regard to their effectiveness as well as their socio-economic acceptability. Instead, any VMT reduction required for the purpose of a particulate matter control strategy will be identified and compared to VMT reduction requirements for oxidant control in a subsequent volume.

### 3.5 PROJECTED EMISSION INVENTORY SUMMARY TABLES

Eight tables summarizing the emission inventory projections are contained in this section, covering the following:

- 1977 Inventory of Particulate Matter Under Present Controls
- 1977 Inventory of Gaseous Precursors Under Present Controls
- 1977 Inventory of Particulate Matter Under the EPA Oxidant Control Plan
- 1977 Inventory of Gaseous Precursors Under the EPA Control Plan
- 1980 Inventory of Particulate Matter Under Present Controls
- 1980 Inventory of Gaseous Precursors Under Present Controls
- 1980 Inventory of Particulate Matter Under the EPA Oxidant Control Plan
- 1980 Inventory of Gaseous Precursors Under the EPA Oxidant Control Plan

These tables indicate the contribution to the total inventory by each major source category, as well as the total inventory in tons per day.

TABLE 3-24. 1977 INVENTORY OF PARTICULATE EMISSIONS UNDER  
PRESENT CONTROLS (tons/day)

<u>Source Category</u>	<u>Entire Air Basin</u>		<u>Four County Area</u>	
	<u>Total</u>	<u>Suspended</u>	<u>Total</u>	<u>Suspended</u>
Petroleum	3.0	3.0	3.0	3.0
Organic Solvent	18.5	16.7	18.2	16.4
Metallurgical	13.4	13.4	13.4	13.4
Mineral	35.6	32.0	12.5	11.0
Incineration	2.4	2.2	2.5	2.3
Fuel Combustion				
Domestic and Commercial	12.2	12.1	11.6	11.5
Industrial	37.2	36.8	35.9	35.5
Power Plants	41.9	41.5	36.0	35.6
Agricultural	10.0	9.9	2.9	2.9
Stationary Sources Total	174.0	168.0	136.0	132.0
Light Duty Vehicles	61.9	47.0	59.7	45.3
Heavy Duty Vehicles	2.0	1.7	1.9	1.6
Diesels	4.9	4.0	4.7	3.9
Aircraft				
Jet	26.2	25.9	22.2	22.0
Piston	5.6	4.5	4.6	3.7
Miscellaneous (Motorcycles, offroad, etc.)	7.2	5.9	7.0	5.6
Ships and Railroads	1.9	1.5	1.5	1.2
Motor Vehicle Tire Wear	36.9	18.1	35.6	17.4
Mobile Sources Total	147.0	109.0	137.0	101.0
Total Inventory	321.0	277.0	273.0	233.0

TABLE 3-25. 1977 INVENTORY OF GASEOUS PRECURSOR EMISSIONS  
UNDER PRESENT CONTROLS (tons/day)

<u>Source Category</u>	<u>Entire Air Basin</u>			<u>Four County Area</u>		
	<u>SO<sub>2</sub></u>	<u>NO<sub>x</sub></u>	<u>RHC</u>	<u>SO<sub>2</sub></u>	<u>NO<sub>x</sub></u>	<u>RHC</u>
Petroleum	60.0	67.5	79.0	60.0	67.5	71.1
Organic Solvent	-	-	50.6	-	-	45.9
Chemical	10.0	0.6	-	10.0	0.5	-
Metallurgical	15.0	0.6	-	15.0	0.6	-
Mineral	7.5	-	-	1.7	-	-
Incineration	-	1.9	0.4	-	1.8	0.4
Fuel Combustion						
Domestic and Commercial	0.4	64.0	-	0.4	61.1	-
Industrial	81.6	545.0	-	81.2	476.0	-
Power Plants	340.4	156.0	-	291.9	134.6	-
Agricultural	1.1	1.1	6.6	1.1	0.3	10.4
Stationary Sources Total	516.0	837	136.7	465.0	743.0	117.8
Light Duty Vehicles	42.7	607.8	476.9	41.2	585.9	459.7
Heavy Duty Vehicles	0.8	25.6	25.0	0.8	24.7	24.1
Diesels	10.1	138.3	13.7	9.7	133.7	13.7
Aircraft						
Jet	7.1	25.7	30.5	6.5	23.9	19.0
Piston	-	8.5	10.8	-	8.3	7.7
Miscellaneous (motorcycles, offroad, etc.)	-	72.6	103.6	-	70.2	99.2
Ships and Railroads	14.5	26 .0	-	10.8	24.0	-
Mobile Sources Total	75.2	904.5	660.5	69.0	870.7	623.4
Total Inventory	591.0	1742.0	798.0	530.0	1614.0	741.0

TABLE 3-26. 1977 INVENTORY OF PARTICULATE EMISSIONS UNDER  
THE EPA OXIDANT CONTROL PLAN (tons/day)

<u>Source Category</u>	<u>Entire Air Basin</u>		<u>Entire Air Basin</u>	
	<u>Total</u>	<u>Suspended</u>	<u>Total</u>	<u>Suspended</u>
Petroleum	3.0	3.0	3.0	3.0
Organic Solvent	18.5	16.7	18.2	16.4
Metallurgical	13.4	13.4	13.4	13.4
Mineral	35.6	32.0	12.5	11.0
Incineration	2.4	2.2	2.5	2.3
Fuel Combustion				
Domestic and Commercial	12.2	12.1	11.6	11.5
Industrial	37.2	36.8	35.9	35.5
Power Plants	41.9	41.5	36.0	35.6
Agricultural	10.0	9.9	2.9	2.9
Stationary Sources Total	174.0	168.0	136.0	132.0
Light Duty Vehicles	41.9	36.4	40.4	35.1
Heavy Duty Vehicles	2.0	1.7	1.9	1.6
Diesels	4.9	4.0	4.7	3.9
Aircraft				
Jet	26.2	25.9	22.2	22.0
Piston	5.6	4.5	4.6	3.7
Miscellaneous (Motorcycles, offroad, etc.)	7.2	5.9	7.0	5.6
Ships and Railroads	1.9	1.5	1.5	1.2
Motor Vehicle Tire Wear	36.9	18.1	35.6	17.4
Mobile Sources Total	127.0	98.0	118.0	91.0
Total Inventory	301.0	266.0	254.0	223.0

TABLE 3-27. 1977 INVENTORY OF GASEOUS PRECURSOR EMISSIONS  
UNDER THE EPA OXIDANT CONTROL PLAN (tons/day)

<u>Source Category</u>	<u>Entire Air Basin</u>			<u>Four County Area</u>		
	<u>SO<sub>2</sub></u>	<u>NO<sub>x</sub></u>	<u>RHC</u>	<u>SO<sub>2</sub></u>	<u>NO<sub>x</sub></u>	<u>RHC</u>
Petroleum	60.0	67.5	19.6	60.0	67.5	17.3
Organic Solvent	-	-	33.4	-	-	30.4
Chemical	10.0	0.6	-	10.0	0.5	-
Metallurgical	15.0	0.6	-	15.0	0.6	-
Mineral	7.5	-	-	1.7	-	-
Incineration	-	1.9	0.4	-	0.8	0.4
Fuel Combustion						
Domestic and Commercial	0.4	64.0	-	0.4	61.1	-
Industrial	81.6	545.0	-	81.2	476.0	-
Power Plants	340.4	156.0	-	291.9	134.6	-
Agricultural	1.1	1.1	6.6	1.1	0.3	0.4
Stationary Sources Total	516.0	837.0	60.0	461.0	743.0	48
Light Duty Vehicles	36.9	607.8	347.7	35.6	585.9	335.2
Heavy Duty Vehicles	0.8	25.6	25.0	0.8	24.7	24.1
Diesels	10.1	138.3	13.7	9.7	133.7	13.7
Aircraft						
Jet	7.1	25.7	30.5	6.5	23.9	19.0
Piston	-	8.5	10.8	-	8.3	7.7
Miscellaneous (Motorcycles, offroad, etc.)	-	72.6	103.6	-	70.2	99.2
Ships and Railroads	14.5	26.0	-	10.8	24.0	-
Mobile Sources Total	69.4	904.5	531.0	63.4	870.7	498.9
Total Inventory	585.0	1742.0	591.0	524.0	1614.0	547



TABLE 3-28. 1980 INVENTORY OF PARTICULATE EMISSIONS  
UNDER PRESENT CONTROLS (tons/day)

<u>Source Category</u>	<u>Entire Air Basin</u>		<u>Four County Area</u>	
	<u>Total</u>	<u>Suspended</u>	<u>Total</u>	<u>Suspended</u>
Petroleum	3.0	3.0	3.0	3.0
Organic Solvent	19.2	17.3	18.8	16.9
Metallurgical	14.0	14.0	14.0	14.0
Mineral	38.3	34.5	12.8	11.5
Incineration	2.5	2.3	2.6	2.3
Fuel Combustion				
Domestic and Commercial	12.9	12.8	12.3	12.2
Industrial	33.5	33.2	32.5	32.1
Power Plants	43.0	42.6	36.8	36.4
Agricultural	10.3	10.2	2.9	2.9
Stationary Sources Total	177.0	170.0	136.0	131
Light Duty Vehicles	50.8	41.7	49.0	40.2
Heavy Duty Vehicles	2.1	1.8	2.0	1.7
Diesels	5.3	4.3	5.1	4.1
Aircraft				
Jet	38.7	38.3	32.8	32.5
Piston	6.7	5.4	5.5	4.5
Miscellaneous (Motorcycles, offroad, etc.)	7.9	6.5	7.7	6.2
Ships and Railroads	1.9	1.5	1.5	1.2
Motor Vehicle Tire Wear	39.6	19.3	38.2	18.6
Mobile Sources Total	153.0	119.0	142.0	109.0
Total Inventory	330.0	289.0	278.0	240.0

TABLE 3-29. 1980 INVENTORY OF GASEOUS PRECURSOR EMISSIONS  
UNDER PRESENT CONTROLS (tons/day)

<u>Source Category</u>	<u>Entire Air Basin</u>			<u>Four County Area</u>		
	<u>SO<sub>2</sub></u>	<u>NO<sub>x</sub></u>	<u>RHC</u>	<u>SO<sub>2</sub></u>	<u>NO<sub>x</sub></u>	<u>RHC</u>
Petroleum	60.0	67.5	89.1	60.0	67.5	71.1
Organic Solvent	-	-	53.2	-	-	45.9
Chemical	10.0	0.6	-	10.0	0.5	-
Metallurgical	15.9	0.6	-	15.9	0.6	-
Mineral	9.1	-	-	1.8	-	-
Incineration	-	2.1	0.4	-	1.8	0.4
Fuel Combustion						
Domestic and Commercial	0.4	64.0	-	0.4	61.1	-
Industrial	75.5	486.3	-	75.2	425.4	-
Power Plants	355.0	165.7	-	304.0	142.5	-
Agricultural	1.1	1.1	6.6	1.1	0.3	0.4
Stationary Sources Total	527.0	788	149.0	468.0	700.0	118.0
Light Duty Vehicles	41.4	443.3	286.2	39.9	426.9	275.9
Heavy Duty Vehicles	0.9	20.0	18.5	0.9	19.3	17.8
Diesels	10.8	148.1	14.7	10.4	143.2	14.7
Aircraft						
Jet	10.4	38.1	45.0	9.6	35.4	28.1
Piston	-	10.2	12.7	-	10.0	9.0
Miscellaneous (Motorcycles, offroad, etc.)	-	78.1	108.3	-	75.5	103.7
Ships and Railroads	14.5	26.0	-	10.8	24.0	-
Mobile Sources Total	78.0	763.8	485.4	71.6	734.3	449.2
Total Inventory	605.0	1552.0	634.0	540.0	1434.0	567.0

TABLE 3-30. 1980 INVENTORY OF PARTICULATE EMISSIONS UNDER  
THE EPA OXIDANT CONTROL PLAN (tons/day)

<u>Source Category</u>	<u>Entire Air Basin</u>		<u>Four County Area</u>	
	<u>Total</u>	<u>Suspended</u>	<u>Total</u>	<u>Suspended</u>
Petroleum	3.0	3.0	3.0	3.0
Organic Solvent	19.2	17.3	18.8	16.9
Metallurgical	14.0	14.0	14.0	14.0
Mineral	38.3	34.5	12.8	11.5
Incineration	2.5	2.3	2.6	2.3
Fuel Combustion				
Domestic and Commercial	12.9	12.8	12.3	12.2
Industrial	33.5	33.2	32.5	32.1
Power Plants	43.0	42.6	36.8	36.4
Agricultural	10.3	10.2	2.9	2.9
Stationary Sources Total	177.0	170.0	136.0	131.0
Light Duty Vehicles	37.1	34.9	35.8	33.6
Heavy Duty Vehicles	2.1	1.8	2.0	1.7
Diesels	5.3	4.3	5.1	4.1
Aircraft				
Jet	38.7	38.3	32.8	32.5
Piston	6.7	5.4	5.5	4.5
Miscellaneous (Motorcycles, offroad, etc.)	7.9	6.5	7.7	6.2
Ships and Railroads	1.9	1.5	1.5	1.2
Motor Vehicle Tire Wear	36.9	19.3	38.2	18.6
Mobile Sources Total	139.0	113.0	129.0	102.0
Total Inventory	316.0	283.0	265.0	233.0

TABLE 3-31 1980 INVENTORY OF GASEOUS PRECURSOR EMISSIONS  
UNDER THE EPA OXIDANT CONTROL PLAN (tons/day)

<u>Source Category</u>	<u>Entire Air Basin</u>			<u>Four County Area</u>		
	<u>SO<sub>2</sub></u>	<u>NO<sub>x</sub></u>	<u>RHC</u>	<u>SO<sub>2</sub></u>	<u>NO<sub>x</sub></u>	<u>RHC</u>
Petroleum	60.0	67.5	21.5	60.0	67.5	18.2
Organic Solvent	-	-	35.0	-	-	30.0
Chemical	10.0	0.6	-	10.0	0.5	-
Metallurgical	15.9	0.6	-	15.9	0.5	-
Mineral	9.1	-	-	1.8	-	-
Incineration	-	2.1	0.4	-	1.9	0.4
Fuel Combustion						
Domestic and Commercial	0.4	64.0	-	0.4	61.1	-
Industrial	75.5	486.3	-	75.2	425.4	-
Power Plants	355.0	165.7	-	304.0	142.5	-
Agricultural	1.1	1.1	6.6	1.1	0.3	0.4
Stationary Sources Total	527.0	788.0	64.0	468.0	700.0	49.0
Light Duty Vehicles	37.0	443.3	194.9	35.7	426.9	187.9
Heavy Duty Vehicles	0.9	20.0	18.5	0.9	19.3	17.8
Diesels	10.8	148.1	14.7	10.4	143.2	14.7
Aircraft						
Jet	10.4	38.1	45.0	9.6	35.4	28.1
Piston	-	10.2	12.7	-	10.0	9.0
Miscellaneous (Motorcycles, offroad, etc.)	-	78.1	108.3	-	75.5	103.7
Ships and Railroads	14.5	26.0	-	10.8	24.0	-
Mobile Sources Total	73.6	763.8	394.1	67.4	734.3	361.2
Total Inventory	601.0	1552.0	458.0	535.0	1434.0	410.0

### 3.6 DISCUSSION

The baseline and projected inventories for each pollutant considered in the preceding analysis are presented in Tables 3-32 through 3-35. Both total and suspended particulate emissions are projected to increase through 1977 and 1980. The EPA oxidant control plan as well as the EPA new car control program will result in a reduction in particulate emissions from light duty vehicles due to the anticipated use of oxidizing catalysts. However, it must be noted that the character of the remaining particulates from those vehicles so equipped will change dramatically to a much more toxic form (sulfuric acid mist).

Sulfur dioxide emissions are projected to increase through 1980, due mainly to the growth in fuel demand and the current trend toward the use of low-sulfur fuel oil as a replacement for dwindling natural gas supplies.  $\text{SO}_2$  emissions are expected to be reduced slightly under the EPA oxidant control plan due to the oxidizing catalyst retrofit requirement for light duty vehicles.

Emissions of oxides of nitrogen are projected to increase substantially through 1977. This behavior is due to the fact that the EPA new car control program will produce only moderate reductions in  $\text{NO}_x$  emissions from 1975 and 1976 model year cars, while growth in the fuel combustion, aircraft, and uncontrolled vehicle categories is almost enough to offset the reductions projected for light duty vehicles. By 1980, the full force of the EPA new car control program should be realized with drastic reductions in  $\text{NO}_x$  emissions from 1977 and later model year vehicles. Hence, significant reductions in  $\text{NO}_x$  emissions are projected to occur by 1980.

Finally, reactive hydrocarbon emissions are projected to decrease dramatically as local, state, and federal control programs for oxidant progress. As stated previously, reductions due to VMT reduction measures contained in the EPA oxidant control plan have not been included in the preparation of the preceding projections. Whether such measures are necessary in full or in part to the success of a control program for particulate matter will be addressed in a subsequent volume.

TABLE 3-32. ENTIRE AIR BASIN SUMMARY INVENTORY UNDER PRESENT CONTROLS (tons/day)

<u>Pollutant</u>	<u>Year</u>		
	<u>1972 Inventory</u>	<u>1977 Inventory</u>	<u>1980 Inventory</u>
Total Particulates	250	321	330
Suspended Particulates	213	277	289
SO <sub>2</sub>	492	591	605
NO <sub>x</sub>	1423	1742	1552
RHC	1155	798	634

TABLE 3-33. ENTIRE AIR BASIN SUMMARY INVENTORY UNDER EPA OXIDANT CONTROL PLAN (tons/day)

<u>Pollutant</u>	<u>Year</u>		
	<u>1972 Inventory</u>	<u>1977 Inventory</u>	<u>1980 Inventory</u>
Total Particulates	250	301	316
Suspended Particulates	213	266	283
SO <sub>2</sub>	492	585	601
NO <sub>x</sub>	1423	1742	1552
RHC	1155	591	458

TABLE 3-34. FOUR COUNTY SUB-AREA SUMMARY INVENTORY UNDER PRESENT CONTROLS (tons/day)

<u>Pollutant</u>	<u>Year</u>		
	<u>1972 Inventory</u>	<u>1977 Inventory</u>	<u>1980 Inventory</u>
Total Particulates	211	273	278
Suspended Particulates	178	233	240
SO <sub>2</sub>	444	530	540
NO <sub>x</sub>	1345	1614	1434
RHC	1094	741	567

TABLE 3-35. FOUR COUNTY SUB-AREA SUMMARY INVENTORY UNDER EPA OXIDANT CONTROL PLAN (tons/day)

<u>Pollutant</u>	<u>Year</u>		
	<u>1972 Inventory</u>	<u>1977 Inventory</u>	<u>1980 Inventory</u>
Total Particulates	211	254	265
Suspended Particulates	178	223	233
SO <sub>2</sub>	444	524	535
NO <sub>x</sub>	1331	1614	1434
RHC	1094	547	410

## REFERENCES

1. State of California, The Resources Agency, Air Resources Board, "Air Pollution Control in California 1971", January 1971
2. "Transportation Control Strategy Development for the Metropolitan Los Angeles Region", TRW Inc., January 1973
3. Episode Contingency Plan Development for the Metropolitan Los Angeles Air Quality Control Region", TRW Inc., December 1973
4. "Compilation of Air Pollution Emission Factors", EPA, February 1973
5. Los Angeles Air Pollution Control District, "Supplement to the Implementation Plan-South Coast Air Basin", August 1973, revised December 11, 1973
6. Automotive Environmental Systems Inc., "Uncontrolled Vehicle Emission Study", Report to the California State Air Resources Board, October 30, 1973
7. Private communication, Murray Levy, Pacific Environmental Services
8. Private communication, KVB Engineering Inc.
9. Private communication, Skene Moody, Southern California Edison Company
10. "1973 California Gas Report"
11. Private communication, Bill McBeth, Los Angeles County APCD
12. Private communication, John Nevitt, Los Angeles County APCD
13. "Aircraft Emission Controls: Impact on Air Quality and Feasibility of Control", EPA, 1973
14. U.S. Department of Health, Education and Welfare, Public Health Service and Environmental Health Service, "Air Quality Criteria for Particulate Matter", NAPCA Publication No. AP-49, April 1970
15. "The Development of a Particulate Implementation Plan for the Los Angeles Region, Report #1, Analysis of Air Monitoring Data", TRW Inc., Preliminary Draft to the EPA, May 1974
16. Wilson, W.E., et. al., "A Literature Survey of Aerosol Formation and Visibility Reduction in Photochemical Smog", Battelle Memorial Institute, August 1, 1969
17. Miller, D.F., et. al., "A Study of Motor Fuel Composition Effects on Aerosol Formation, Part II, Aerosol Reactivity Study of Hydrocarbons", Battelle Columbus Laboratories, February 21, 1972



18. O'Brian, R.J., et. al., "Photochemical Aerosol Formation in the Atmosphere and in an Environmental Chamber", presented at the Symposium on Sources and Evolution of the Atmospheric Aerosol, American Chemical Society, Los Angeles, California, April 1-5. 1974
19. U.S. Environmental Protection Agency, "Control Techniques for Particulate Air Pollutants", AP-51. 1969
20. Miller, G.E., et. al., "Minimizing Visible Emissions from Agricultural Burning", California Air Environment, University of California, vol. 4, no. 1, Fall 1973
21. Ter Haar, G.L., et. al., "Composition, Size and Control of Automotive Exhaust Particulates, Journal of the Air Pollution Control Association, vol.22, no.1, January 1972
22. Habibi, K., "Characterization of Particulate Matter in Vehicle Exhaust", Environmental Science and Technology, vol.7, no.3, March 1973
23. Pierson, W.R. and Brachaczek, W.W., "Airborne Particulate Debris from Rubber Tires", preliminary draft, presented at the American Chemical Society Rubber Division Symposium on Ecology, May 7-10, Toronto, Ontario, Canada
24. Private communication from Eric Stork, Director, Mobile Source Pollution Control Program. EPA, to Robert Chass, Air Pollution Control Officer, Los Angeles County APCD, November 17, 1971
25. Private communication, Dr. Thomas Huls, EPA, Ann Arbor, Michigan
26. Campion, R.J., et. al., "Measurement of Vehicle Particulate Emissions", Society of Automotive Engineers, Automotive Engineering Congress, February 25 - March 1, 1974, Detroit, Michigan
27. Private communication, George Thomas, Los Angeles County APCD
28. County of Los Angeles, Air Pollution Control District Rules and Regulations
29. "Population and Economic Activity in the United States and Standard Metropolitan Statistical Areas", EPA, 1972
30. "1973 California Gas Report"
31. "Aircraft Emissions: Impact on Air Quality and Feasibility of Control", EPA, 1973
32. "Moving Ahead - Wells Fargo Looks at Southern California", Wells Fargo Bank, 1973

33. "Final Report - Southern California Regional Aviation Systems Study", prepared for the Southern California Association of Governments, Aviation Study Authority by System Development Corporation/William L. Pereira Associates
34. Private communication, R. L. Perrine, University of California, Los Angeles
35. Private communication with various personnel, San Bernardino County APCD
36. Private communication, Skene Moody, Southern California Edison Company
37. Private communication, Bart Sokolow, Los Angeles City Department of Water and Power
38. Private communication, W. Stobaugh, San Bernardino County APCD
39. "Air Quality Implementation Plan Development for Critical California Regions : Sacramento Valley AQCR", TRW Inc., June 1973
40. Federal Register, vol.38, no.217, part II, November 12, 1973
41. County of Los Angeles, Air Pollution Control District Rules and Regulations
42. Private communication, Morris Goldberg, EPA, Region IX

## APPENDIX A - LOCAL AGENCY EMISSION INVENTORIES

TABLE A-1 EMISSIONS

## LOS ANGELES COUNTY PORTION

of the

## SOUTH COAST BASIN

1972

EMISSION SOURCE	Reactive Organic Gases	Particu- late Matter	NO <sub>x</sub>	SO <sub>x</sub>	CO
STATIONARY SOURCES					
	TONS/DAY				
PETROLEUM					
Production			2		
Refining	7	3	19	56	2
Marketing	24		10		
SUBTOTAL	31	3	31	56	2
ORGANIC SOLVENT USERS					
Surface Coating	9	8			
Dry Cleaning	1				
Degreasing	8				
Other	21	9			
SUBTOTAL	39	17			
CHEMICAL					
Petrochemical					
Sulfur Plants					
Sulfuric Acid Plants					
Pulp and Paper					
Other					
SUBTOTAL				97	
METALLURGICAL					
Ferrous		1		6	2
Non Ferrous		6			
SUBTOTAL		7		6	2
MINERAL					
Glass and Frit		2			
Asphalt Batching		1			5
Asphalt Roofing		3			
Cement Production					
Concrete Batching		1			
Other					
SUBTOTAL		7			5
INCINERATION					
Open Burning (dumps)					
Open Burning (backyard)					
Incinerators		1	1		1
Other					
SUBTOTAL		1	1		1

Date 5-17-73

TABLE A-1 EMISSIONS

LOS ANGELES COUNTY PORTION  
of the

SOUTH COAST BASIN

1972 (continued)

EMISSION SOURCE	Reactive Organic Gases	Particu- late Matter	NO <sub>x</sub>	SO <sub>x</sub>	CO
STATIONARY SOURCES					
	TONS/DAY				
COMBUSTION OF FUELS					
Steam and Power Plants		9	91	75	
Other Industrial		10	65	10	1
Domestic and Commercial		8	47		
SUBTOTAL (Daily Av. Yr.)		27	203	85	1
AGRICULTURE					
Debris Burning					
Orchard Heaters					
Agr. Product Proc. Plts					
SUBTOTAL					
TOTAL STATIONARY SOURCES	70	62	235	244	11
MOBILE SOURCES					
MOTOR VEHICLES	1288	38	1088	33	16910
Gasoline Powered					
Exhaust					
Blowby					
Evaporation					
Diesel Powered		9	18	2	18
SUBTOTAL	1288	47	1106	35	16928
AIRCRAFT					
Jet Driven	3	9	10	3	33
Piston Driven	2		3		117
SUBTOTAL	5	9	13	3	150
SHIPS AND RAILROADS		1	22	10	20
TOTAL TRANSPORTATION	1293	57	1141	48	17098
GRAND TOTAL	1363	119	1376	292	17109

Date 5-17-73

TABLE A-2 EMISSIONS

ALL COUNTIES

of the

SOUTH COAST AIR BASIN

1972

EMISSION SOURCE	Reactive Organic Gases	Particu- late Matter	NO <sub>x</sub>	SO <sub>x</sub>	CO
STATIONARY SOURCES					
TONS/DAY					
PETROLEUM					
Production	1.5		2	4	
Refining	7	3	19	56	2
Marketing	42.1		10		
SUBTOTAL	50.6	3	31	60	2
ORGANIC SOLVENT USERS					
Surface Coating		8			
Dry Cleaning					
Degreasing					
Other		9			
SUBTOTAL	45.3	17			
CHEMICAL					
Petrochemical					
Sulfur Plants					
Sulfuric Acid Plants					
Pulp and Paper					
Other					
SUBTOTAL	1.1	0.5	0.5	97	1.3
METALLURGICAL					
Ferrous					
Non Ferrous		12	0.5	13.5	2
SUBTOTAL					
MINERAL					
Glass and Frit					
Asphalt Batching					
Asphalt Roofing					
Cement Production					
Concrete Batching					
Other					
SUBTOTAL	0.1	31.6	2.2	6.4	5
INCINERATION					
Open Burning (dumps)					
Open Burning (backyard)					
Incinerators					
Other					
SUBTOTAL	0.3	5.4	2.4		44.6

Date 7-30-73

Rev. 9-73

TABLE A-2 EMISSIONS

ALL COUNTIES  
of the  
SOUTH COAST AIR BASIN

1972 (continued)

EMISSION SOURCE	Reactive Organic Gases	Particu- late Matter	NO <sub>x</sub>	SO <sub>x</sub>	CO
STATIONARY SOURCES					
	TONS/DAY				
COMBUSTION OF FUELS Steam and Power Plants Other Industrial Domestic and Commercial SUBTOTAL (Daily Av. Yr.)	0.2	37.0	295.2	147.2	5.4
AGRICULTURE Debris Burning Orchard Heaters Agr. Product Proc. Plts SUBTOTAL	6.6	5.6	0.4	1.1	6.9
TOTAL STATIONARY SOURCES	104.2	112.1	332.2	325.2	67.2
MOBILE SOURCES					
MOTOR VEHICLES Gasoline Powered Exhaust Blowby Evaporation Diesel Powered SUBTOTAL	1854.6	67.8	1597.9	49.9	24098.5
AIRCRAFT Jet Driven Piston Driven SUBTOTAL	10.5	17.7	19.7	3.9	232.7
SHIPS AND RAILROADS		1.9	26.0	14.5	23.3
TOTAL TRANSPORTATION	1865.1	87.4	1643.6	68.3	24354.5
GRAND TOTAL	1969.3	199.5	1975.8	393.5	24421.7

Date Rev. 9-73

## APPENDIX B

### SUMMARY OF RECENT CHANGES IN LOCAL RULES AND REGULATIONS

Rather than describe each rule in detail, only the more significant changes to the rules which have occurred over the past two years will be mentioned here. The official Rules and Regulations published by each APCD may be consulted for more detailed information.

#### Los Angeles County

- (1) Rule 10g. Prohibits open outdoor fires unless a permit has been issued by the APCO.
- (2) Rule 20.1. Requires the denial of authority to construct any equipment which will emit 100 tons or more per year of any contaminant if the emissions will prevent the attainment or maintenance of any applicable ambient air quality standard.
- (3) Rule 50. Reduces the permissible limit of visible emissions from No. 2 to No. 1 Ringlemann.
- (4) Rule 52. Reduces the allowable discharge of particulates from 0.3 grain per cubic foot of gas to a value ranging from 0.2 grain per cubic foot for small sources to 0.01 grain per cubic foot for large sources.
- (5) Rule 53.2 and 3 provides for the extension of sulfur compound limitations to sulfur recovery plants and sulfuric acid units. These secondary sources had previously been granted variances if their emissions were less than that which would occur without them from primary sources.
- (6) Rule 54. Reduces the maximum permissible discharge of particulate matter from any source from 40 to 30 pounds per hour. Specifically includes lead and lead compounds.
- (7) Rule 57.1-4. Extends open-burning prohibitions to the Upper Santa Clara River Valley Basin, the Antelope Valley Basin, the Island Area and the Mountain Area of Los Angeles County.
- (8) Rule 58. Reduces the allowable discharge of particulate matter from large incinerators from 0.3 to 0.1 grain per standard cubic foot of gas.
- (9) Rule 65. Requires collection of the vapors vented during the filling of stationary gasoline storage containers of more than 250 gallon capacity.



- (10) Rule 66. Induces large users of coating materials to change to water base or high-solid content materials in order to decrease emissions of organic solvents.
- (11) Rule 72. Requires mechanical seals on pumps and compressors handling organic materials having a Reid Vapor Pressure of 1.5 pounds or greater.
- (12) Rule 73. Specifies requirements for safety pressure relief valves handling organic materials at pressures above 15 psia in order to reduce emissions of contaminants into the air.

Orange County

- (1) Rule 4. Grants authority to arrest to APCO and employees designated by him.
- (2) Rule 10. Prohibits open outdoor fires unless a permit has been issued by the APCO.
- (3) Rule 50. Reduces the permissible limit of visible emissions from No. 2 to No. 1 Ringelmann.
- (4) Rule 52. Particulate Matter Concentration. Same as Los Angeles County.
- (5) Rule 53. Reduces the allowable discharge of sulfur compounds from 2000 to 500 parts per million by volume.
- (6) Rule 53.2 Sulfur Recovery Units. Same as Los Angeles County.
- (7) Rule 53.3. Sulfuric Acid Units. Same as Los Angeles Co.
- (8) Rule 54. Particulate Matter - Weight. Same As Los Angeles Co.
- (9) Rule 58. Disposal of Solid and Liquid Wastes. Same as Los Angeles County.
- (10) Rule 59. Effluent Oil Water Separators. Same as Los Angeles County.
- (11) Rule 61. Requires vapor collection and disposal systems during the loading of volatile organic compounds into mobile or stationary tanks larger than 250 gallons.
- (12) Rule 62. Reduces the allowable sulfur content of natural gas from 50 to 15 grains of sulfur compounds per 100 cubic feet of gas.
- (13) Rule 66. Organic Solvents. Essentially the same as Los Angeles County.

- (14) Rule 67.1. Limits the oxides of nitrogen discharge from new fuel-burning equipment having a heat input rate of more than 250 million BTU per hour to 125 ppm for gaseous fuels and 225 ppm for liquid or solid fuel.
- (15) Rule 68. Limits the oxides of nitrogen discharge from existing fuel-burning equipment. Similar to Los Angeles Co.
- (16) Rule 68.1. Limits the discharge from fuel-burning equipment of combustion contaminants, derived from the fuel, to 0.1 grain per standard cubic foot of gas.
- (17) Rule 69. Vacuum Producing Devices or Systems. Same as Los Angeles County.
- (18) Rule 70. Asphalt Air Blowing. Same as Los Angeles Co.

#### Riverside County

- (1) Rule 4. Authority to Arrest. Similar to Los Angeles Co.
- (2) Rule 50. Ringelmann Chart. Similar to Los Angeles County.
- (3) Rule 52. Particulate Matter - Concentration. Same as Los Angeles County.
- (4) Rule 53. Specific Air Contaminants. Reduces the allowable discharge of sulfur compounds from 0.2 percent by volume, calculated as sulfur dioxide, to the following values:
  - a. 0.05 percent in the West-Central Area.
  - b. 0.15 percent in areas other than West-Central, effective 1-1-75.

Combustion contaminants are deleted from this rule. See Rule 72.2.

- (5) Rule 54. Solid Particulate Matter - Weight. Specifies that the maximum allowable discharge shall be 0.5 pounds per ton of process weight fed per hour.

#### San Bernardino County

- (1) Rule 5. Provides authority to obtain emission data from each stationary source operator. Specifies reporting procedures, compliance schedule requirements, and availability of emission data to the public.
- (2) Rule 6. Requires crankcase control devices to be installed on 1955 through 1962 motor vehicles.

- (3) Rule 20.1. Provides for denial of authority to construct any equipment which will emit more than 100 tons per year of air contaminants in an area where it would prevent the attainment of a National Air Quality Standard.
- (4) Rule 50A. Visible Emission. Similar to Rule 50 of Los Angeles County.
- (5) Rule 51.1. Provides authority to enforce controls on fugitive dust.
- (6) Rule 52A. Particulate Matter - Concentration. Same as Rule 52 of Los Angeles County.
- (7) Rule 53A. Specific Contaminants. Reduces the allowable discharge of sulfur compounds, calculated as sulfur dioxide, from 0.1 percent by volume to 500 ppm by volume. Reduces the allowable discharge of combustion contaminants from 0.3 to 0.1 grain per cubic foot of gas.
- (8) Rule 53.2. Sulfur Recovery Units. Similar to Los Angeles County.
- (9) Rule 53.3. Sulfuric Acid Units. Similar to Los Angeles County.
- (10) Rule 54A. Solid Particulate Matter - Weight. Similar to Los Angeles County.
- (11) Rule 58A. Disposal of Solid and Liquid Wastes. Same as Los Angeles County.
- (12) Rule 61. Organic Liquid Loading. Same as Los Angeles Co.
- (13) Rule 66. Organic Solvents. Same as Los Angeles County.
- (14) Rule 68. Fuel-Burning Equipment - Oxides of Nitrogen. Similar to the Los Angeles County Rule but applies also to steam-generating equipment having a heat input rate of 500 million to 1,775 million BTU per hour.
- (15) Rule 69. Vacuum Producing Devices or Systems. Same as Los Angeles County.
- (16) Rule 70. Asphalt Air Blowing. Similar to Los Angeles Co.

Santa Barbara County

- (1) Rule 4. Amended to include requirements for obtaining an authority to construct.
- (2) Rule 9.1. Provides for denial of authority to construct any equipment which will emit more than 100 tons per year of air contaminants in an area where it would cause to exceed or prevent the attainment of the national air quality standards.
- (3) Rule 18-A. Particulate Matter - Concentration. Same as Los Angeles County Rule 52, but effective only in the South Coast Basin portion of the County.
- (4) Rule 19-A. Specific Contaminants. Reduces allowable combustion contaminants from 0.3 to 0.1 grain per cubic foot of gas, in the South Coast Basin portion of the County.
- (5) Rule 21-A. Process Weight Rate. Same as Los Angeles County Rule 54, but effective only in the South Coast Air Basin portion of the County.
- (6) Rule 28-A. Disposal of Solid and Liquid Waste - South Coast Basin. Same as Los Angeles County Rule 58.
- (7) Rule 36.1. Vacuum Producing Devices or Systems - South Coast Air Basin. Similar to Rule 69 of Los Angeles Co.
- (8) Rule 36.2. Asphalt Air Blowing - South Coast Air Basin. Similar to Los Angeles County Rule 70.
- (9) Rule 39.1. Fuel-Burning Equipment - Oxides of Nitrogen - South Coast Air Basin. Similar to Rule 68 of Los Angeles County.
- (10) Rule 39.2. Carbon Monoxide - South Coast Air Basin. Similar to Rule 71 of Los Angeles County.
- (11) Rule 40. Agricultural Burning. Implements the Agricultural Burning Guidelines promulgated under Article I, Subchapter 2, Title 17, California Administrative Code, as amended on June 21, 1972.
- (12) Rule 41. Enforcement. Provides for enforcement of the agricultural burning regulation.

## Ventura County

- (1) Regulation II. Permits. Amended to include requirements for obtaining an authority to construct.
- (2) Rule 26. Denial of Permits. Requires denial of authority to construct any source which will emit 100 tons or more per year of any single air contaminant if the emissions will prevent attaining or maintaining a National Air Quality Standard.
- (3) Rule 31. Public Disclosure of Data. Specifies that source emission data shall be available to the public.
- (4) Rule 36. Circumvention. Same as Rule 60 of Los Angeles County.
- (5) Rule 50. Opacity. Similar to Rule 50 of Los Angeles County.
- (6) Rule 52. Particulate Matter - Concentration. Similar to Rule 52 of Los Angeles County.
- (7) Rule 53. Particulate Matter - Process Weight. Similar to Rule 54 of Los Angeles County.
- (8) Rule 54. Sulfur Compounds. Limits the maximum discharge of sulfur compounds, calculated as concentration of  $\text{SO}_2$ , to 300 ppm by volume from combustion operations and 500 ppm by volume from any other operations. Limits the maximum discharge of hydrogen sulfide to 10 ppm by volume. Average ground level concentrations at or beyond the property line must not exceed the following:

<u>Containment</u>	<u>Concentration (Volume)</u>	<u>Averaging Time</u>
$\text{SO}_2$	0.5 ppm	1 hour
$\text{SO}_2$	0.04 ppm	24 hours
$\text{H}_2\text{S}$	0.06 ppm	3 min
$\text{H}_2\text{S}$	0.03 ppm	1 hour
- (9) Rule 55. Storage of Organic Liquid Petroleum Products. Similar to Rule 56 of Los Angeles County.
- (10) Rule 56. Open Fires. Similar to Los Angeles Rule 57. Includes guidelines for open burning.
- (11) Rule 57. Combustion Contaminants - Specific. Limits the maximum discharge from any equipment used to dispose of or process combustible refuse to a two-hour average of 0.08 grains of particulate matter per cubic foot of gas. For

incinerators burning 200 pounds or less per hour, particulate matter discharged must not exceed 0.2 grain per cubic foot of gas. Hydrocarbon or carbonyl emitted from incinerators must not exceed a volume concentration of 25 ppm. Combustion contaminants from any fuel-burning equipment must not exceed a concentration of 0.1 grain per cubic foot of gas.

- (12) Rule 59. Oxides of Nitrogen Emissions. Maximum  $\text{NO}_x$  emissions from stationary sources are specified to be 250 ppm, except for sources having heat input rates less than 250 million BTU per hour and existing turbine power peaking units at Mandalay. Effective January 1, 1975, the maximum emissions become 125 ppm for gas fueled sources and 225 ppm for solid or liquid fueled sources. Excluded from the 1-1-75 limitations are existing sources rated at less than 2150 million BTU per hour and new sources of less than 250 million BTU per hour. The rule also limits the maximum allowable oxides of nitrogen emissions to 20 tons per day from any existing source and 140 pounds per hour from any new source. Owners or operators of sources subject to the 1-1-75 limitations are required to submit compliance schedules to the District for approval.
- (13) Rule 61. Effluent Oil Water Separators. Similar to Rule 59, Los Angeles County.
- (14) Rule 63. Organic Liquid - Petroleum Products Loadings. Similar to Rule 63 of Los Angeles County.
- (15) Rule 64. Sulfur Content of Fuels. Specifies that the sulfur content of fuels burned in the County shall not exceed the following:
  - a. 15 grains per 100 cubic feet of natural gas.
  - b. 50 grains per 100 cubic feet of other gaseous fuels.
  - c. 0.5 percent by weight of liquid or solid fuels.
- (16) Rule 65. Gasoline Specifications. Similar to Rule 63 of Los Angeles County.
- (17) Rule 66. Organic Solvents. Similar to Rule 66 of Los Angeles County.
- (18) Rule 67. Vacuum Producing Devices. Similar to Rule 69 of Los Angeles County.
- (19) Rule 69. Asphalt Air Blowing. Similar to Rule 70 of Los Angeles County.

### All Counties

In addition to the above Rules, each of the counties in this air basin now has a rule similar to Los Angeles County's Rule 20.1.

Rule 20.1 requires the denial of authority to construct any equipment which will emit 100 tons or more per year of any contaminant if the emissions will prevent the attainment or maintenance of any applicable ambient air quality standard.

## APPENDIX C. MOTOR VEHICLE EMISSIONS ESTIMATION PROCEDURE

The calculation of light and heavy duty vehicle exhaust emission factors for hydrocarbons and oxides of nitrogen can be expressed mathematically as:

$$e_{np} = \sum_{i=n-12}^{n+1} c_{ip} \cdot d_{ipn} \cdot m_{in} \cdot s_{ip}$$

where

$e_{np}$  = emission factor in grams per vehicle mile for calendar year  $n$  and pollutant  $p$ ,

$c_{ip}$  = the 1975 Federal test procedure(C-2)emission rate pollutant  $p$  (grams/mile) for the  $i$ th model year, at low mileage,

$d_{ipn}$  = the controlled vehicle pollutant  $p$  emission deterioration factor for the  $i$ th model year at calendar year  $n$ ,

$m_{in}$  = the weighted annual travel of the  $i$ th model year during calendar year  $n$ . (The determination of this variable involves the use of the vehicle model year distribution),

$s_{ip}$  = the weighted speed adjustment factor for exhaust emission for pollutant  $p$  for the  $i$ th model year vehicles.

In addition to exhaust emission factors, the calculation of hydrocarbon gasoline motor vehicle emissions involves evaporative and crankcase hydrocarbon emission rates. Evaporation and crankcase emissions can be determined using:



$$f_n = \sum_{i=n-12}^{n+1} h_i \cdot m_{in}$$

where,

$f_n$  = the combined evaporative and crankcase hydrocarbon emission factor for calendar year  $n$ ,

$h_i$  = the combined evaporative and crankcase emission rate for the  $i$ th model year,

$m_{in}$  = the weighted annual travel of the  $i$ th model year during calendar year  $n$ .

- A light-duty vehicle is defined as any motor vehicle either designated primarily for transportation of property and rated at 6,000 pounds GVW (gross vehicle weight) or less or designated primarily for transportation of persons and having a capacity of 12 persons or less. (C-1) A heavy-duty vehicle is any vehicle which exceeds the above specifications.
- The deterioration factor ( $D$ ) is the ratio of the pollutant  $p$  exhaust emission factor at  $x$  miles to the pollutant  $p$  exhaust emission factor at 4,000 miles. Factors used in this study were obtained from reference C-1, where the projected values for deterioration of exhaust emission controls for 1976 model year vehicles and beyond were extracted from reference C-3, and are presumed to represent conservative estimates.
- The weighted annual mileage factor ( $m$ ) is determined by the following formula:

$$m_{in} = \frac{V_i \times D_i}{\sum_{i=n-12}^n V_i \times D_i}$$

where

$V_i$  = fraction of total vehicles in use with age  $i$  (in years)  
(determined from vehicle registration date for the region in question).

$D_i$  = average miles driven by a vehicle of age  $i$   
(determined from references C4 and C-5).

- The weighted speed adjustment factor(s) enables the calculation of a region-wide emission factor that takes into account variation in average route speed. This variable is calculated using: (C-1)

$$s_{im} = \sum_{j=1}^n f_j \cdot v_j$$

where,

$s_{im}$  = the weighted speed adjustment factor for exhaust emission of pollutant  $p$  for the  $i$ th model year, during calendar year  $m$

$f_{jm}$  = the fraction of the total annual vehicle miles traveled at speed  $j$  during the calendar year  $m$

$v_j$  = the vehicular average speed correction factor for average speed  $j$ .

(The determination of the average speed  $j$  is discussed in Section 2.4.2 of this volume.)

Having computed the emission factors, the final step is to multiply the emission factor by the vehicle miles travelled (VMT) to derive total motor vehicle emissions.

It must be stated at this point that the data developed under this technique is subject to the following limitations:

- The annual mileage factors ( $D$ ) used in computing the weighted annual travel ( $m$ ), are average values based on a nationwide study of 1,000 automobiles (C-4). Whether such a sample is representative of a particular region is, of course, open to question.

- The emission factors for post-1974 model year automobiles were developed under the assumption that they would meet the federal emission standards (except for 1975 model year vehicles, which were assumed to meet the interim standards set by the EPA Administrator).
- The deterioration factors for "future" controlled vehicles, although considered conservative, represent nothing more than the best engineering estimate available at this time. Since such vehicles do not presently exist, no road tests could be performed to gauge deterioration under actual driving conditions.

TABLE C-1. LARTS VMT -  $10^6$  Miles/Day

<u>Year</u>	<u>Total</u> <sup>(a)</sup>	<u>LDV</u>		<u>HDV</u> <sup>(b)</sup>	
		<u>Fwy</u>	<u>Non-Fwy</u>	<u>Fwy.</u>	<u>Non-Fwy</u>
1972	147	69.6	74.9	1.1	1.2
1977	168	83.5	81.6	1.3	1.3
1980	180	91.8	85.6	1.4	1.3

(a) Total VMT and Fwy/Non-Fwy split from TRW, Inc., "Transportation Control Strategy Development for the Metropolitan Los Angeles Region," January 1973.

(b) HDV fraction from TRW, Inc., "Air Quality Implementation Plan Development for Critical California Regions," July 1973.

TABLE C-2. LOS ANGELES BASIN GASOLINE VEHICLE EMISSIONS PER  
MILLION (VMT) (tons/day)

		1972			1977			1980		
		<u>THC</u>	<u>RHC</u>	<u>NO<sub>x</sub></u>	<u>THC</u>	<u>RHC</u>	<u>NO<sub>x</sub></u>	<u>THC</u>	<u>RHC</u>	<u>NO<sub>x</sub></u>
Baseline										
Freeway	LDV	5.82	4.86	6.28	2.83	2.32	4.27	1.69	1.29	2.89
	HDV	12.88	10.64	14.47	9.04	7.44	11.47	6.51	5.36	8.59
Non-Freeway	LDV	8.53	6.95	4.52	4.31	3.47	3.08	2.45	1.96	2.08
	HDV	20.46	16.62	10.41	14.53	11.76	8.26	10.45	8.47	6.18
Control Strategy*										
Freeway	LDV	5.82	4.86	6.28	2.09	1.76	4.27	1.10	0.92	2.89
	HDV	12.88	10.64	14.47	9.04	7.44	11.47	6.51	5.36	8.59
Non-Freeway	LDV	8.53	6.95	4.52	2.99	2.46	3.08	1.58	1.29	2.08
	HDV	20.46	16.62	10.41	14.53	11.76	8.26	10.45	8.47	6.18

\*Inspection Maintenance, Catalytic Converter Retrofit Measures.

TABLE C-3. LOS ANGELES BASIN GASOLINE VEHICLE EMISSIONS (tons/day)

		1972			1977			1980		
		<u>THC</u>	<u>RHC</u>	<u>NO<sub>x</sub></u>	<u>THC</u>	<u>RHC</u>	<u>NO<sub>x</sub></u>	<u>THC</u>	<u>RHC</u>	<u>NO<sub>x</sub></u>
Baseline										
Freeway	LDV	405.1	338.3	437.1	236.3	193.7	356.5	146.0	118.4	265.3
	HDV	14.2	11.7	15.9	11.8	9.7	14.9	9.1	7.5	12.0
Non-Freeway	LDV	638.9	520.6	338.5	351.7	283.2	251.3	209.7	167.8	178.0
	HDV	24.6	19.9	12.5	18.9	15.3	10.7	13.6	11.0	8.0
Total		1082.8	890.5	804.0	618.7	501.9	633.4	378.4	304.7	463.3
Control Strategy										
Freeway	LDV				174.5	147.0	356.5	101.0	84.5	265.3
	HDV				11.8	9.7	14.9	9.1	7.5	12.0
Non-Freeway	LDV				244.0	200.7	251.3	135.2	110.4	178.0
	HDV				18.9	15.3	10.7	13.6	11.0	8.0
Total					449.2	372.7	633.4	258.9	213.4	463.3

The VMT data utilized in the emissions estimation is summarized in Table C-1. Emission factors for total hydrocarbons, reactive hydrocarbons and oxides of nitrogen are computed on a tons/day/million VMT basis, and are shown in Table C-2. This table summarizes the projected emissions under both present controls and under the EPA-promulgated transportation control plan for the South Coast Air Basin. The EPA plan for oxidant control consists of the following measures:

- Vapor recovery at gasoline stations
- Dry cleaning solvent controls and degreasing solvent controls
- VMT control strategies with an assumed 14% VMT reduction (bus/carpool lanes, regional carpooling system, parking facility review)
- Oxidizing catalyst retrofit
- Mandatory inspection/maintenance program
- "VMT reductions and evaporative emission reductions necessary from additional control strategies to be implemented in 1977."

The projected inventories for 1977 and 1980 do not include consideration of the VMT reductions anticipated in the EPA oxidant control plan. This is due to the uncertainty regarding whether such reductions will actually occur.

## References

- (C-1) Kirchner, David S. and Donald P. Armstrong, "An Interim Report on Motor Vehicle Emission Estimation", U.S. Environmental Protection Agency Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina, October 1972, Revised January 12, 1973.
- (C-2) The Federal Register, July 2, 1971.
- (C-3) National Academy of Science, "Semiannual Report by the Committee on Motor Vehicle Emissions of the National Academy of Sciences to the Environmental Protection Agency", January 1, 1972.
- (C-4) Strate, H. E., "Nationwide Personal Transportation Study - Annual Miles of Automobile Travel", Report No. 2, U.S. Department of Transportation, Federal Highway Administration, April, 1972.
- (C-5) U.S. Department of Transportation, Highway Statistics, Published Annual by the Highway Statistics Division, Office of Highway Planning, Federal Highway Administration, Washington, D.C.

#### APPENDIX D. LOW LEAD AND UNLEADED GASOLINE

A literature search<sup>(D-1,2,3,4)</sup> revealed that American automobile manufacturers designed over 90% of their 1971 model year light duty vehicles to perform adequately on a 91 RON gasoline. On the basis of the vehicle age distribution (Table D-1) over 60% (in 1977) and 90% (in 1980) of the vehicles registered in the air basin will be of model year 1971 or later. In addition, California state law requires all vehicles of model year 1972 and later sold in the state to be able to run on a gasoline of 91 RON or less<sup>(D-5)</sup>.

From conversations with key personnel in the petroleum industry<sup>(D-6)</sup> it was learned that there should be no difficulties in providing a low lead gasoline of 91 RON or greater to meet expected demand and also to provide sufficient supplies of non-leaded gasoline to meet any demands without increasing the aromatic content of the present clear stock by more than 10%. No information concerning the price of unleaded gasoline was available.

The following conclusions can thus be drawn:

- (a) By the year 1977, the vehicle age distribution (Table D-2) will be such that:
  - 26.6% of the vehicles registered will be of model year 1975 or newer and will have catalytic mufflers as standard equipment.
  - 26.6% will be of model years 1972-1974, all of which will have been retrofitted with catalytic mufflers.
  - 8.2% will be of model year 1971, of which 75%<sup>(D-7)</sup> will have been retrofitted.
  - 29.1% will be of model years 1966-1970, of which 20%<sup>(D-7)</sup> will have been retrofitted.
- (b) By the year 1980, the vehicle age distribution (Table D-3) will be such that:
  - 53.2% of the vehicles registered will be of model year 1975 or later and will have catalytic mufflers as standard equipment.

- 23.8% will be of model years 1972-1974, all of which will have been retrofitted with catalytic mufflers.
  - 5.9% will be of model year 1971, of which 75% will have been retrofitted.
  - 7.6% will be of model years 1966-1970, of which 20% will have been retrofitted.
- (c) Because of the projected availability of unleaded gasoline and assuming that the owners of vehicles equipped with catalytic mufflers will use unleaded gasoline, there should be no problem associated with the impairment of the catalyst by lead.
- (d) There should be no appreciable increase in the emissions of hydrocarbons because of possible increases in the aromatic content of lead free gasoline, since the catalytic mufflers are expected to burn up the additional hydrocarbons. (D-4,8)



TABLE D-1. VEHICLE AGE DISTRIBUTION IN THE AIR BASIN

<u>Years Old</u>	<u>Percent</u>
0	8.0
1	9.4
2	9.2
3	9.9
4	8.9
5	7.8
6	8.2
7	8.4
8	7.2
9	5.9
10	4.6
11+	3.0

TABLE D-2. VEHICLE AGE DISTRIBUTION IN THE AIR BASIN IN 1977

<u>Model Year</u>	<u>Percent</u>	<u>Percent of Model Year Vehicles Equipped with Catalytic Mufflers</u>	
1977	8.0	100	Standard Equipment
1976	9.4	100	
1975	9.2	100	
1974	9.9	100	
1973	8.9	100	
1972	7.8	100	Retrofitted
1971	8.2	75	
1970	8.4	20	
1969	7.2	20	
1969	5.9	20	
1967	4.6	20	
1966	3.0	20	

TABLE D-3. VEHICLE AGE DISTRIBUTION IN THE AIR BASIN IN 1980

<u>Model Year</u>	<u>Percent</u>	<u>Percent of Model Year Vehicles Equipped with Catalytic Mufflers</u>	
1980	8.0	100	Standard Equipment
1979	9.4	100	
1978	9.2	100	
1977	9.9	100	
1976	8.9	100	
1975	7.8	100	Retrofitted
1974	8.2	100	
1973	8.4	100	
1972	7.2	100	
1971	5.9	75	
1970	4.6	20	
1969-1966	3.0	20	

## References

- (D-1) Implications of Lead Removal from Automotive Fuels, An Interim Report of the Commerce Technical Advisory Panel on Automotive Fuels and Air Pollution, Department of Commerce, June, 1970.
- (D-2) A Rational Program for the Control of Lead from Motor Gasoline, California State Air Resources Board, 1970.
- (D-3) Gasoline, Chemical and Engineering News, November 9, 1970.
- (D-4) Automotive Fuels and Air Pollution, U.S. Department of Commerce, March, 1971.
- (D-5) Arthur Hocker, California Air Resources Board, private communications, April 18, 1974.
- (D-6) Private communication, April 17, 1974. (Personnel desired to remain anonymous).
- (D-7) Federal Register, Vol. 38, Number 217, Part II, November 12, 1973.
- (D-8) R. L. Perrine, University of California, Los Angeles, private communication, April, 1974.

## APPENDIX E. CATALYTIC MUFFLERS

To reduce HC emissions, federal regulations stipulate that by 1977, all automobiles in the air basin of model years 1966 through 1974 capable of performing adequately on 91 RON unleaded gasoline are to be retrofitted with catalytic mufflers.<sup>(E-1)</sup> In addition, to meet federal emission standards, two major American automobile manufacturers have elected to install catalytic mufflers as standard equipment on their 1975 model year cars.

With the introduction of these catalytic devices both as retrofit and standard equipment, two major questions are raised with regard to the present study: (1) what are the emission factors for particulates and (2) what effect does lead in gasoline have on the performance of the catalyst?

Before these questions can be answered, two definitions have to be made. Old automobiles are defined as those with an average of 50,000 miles on their odometers and range from model years 1966 through 1972. New automobiles are those with less than 20,000 miles and are of model year 1973. For purposes of comparison, all results discussed later for new automobiles are assumed to hold true for 1975 and later model year cars.

### Emission Factors for Particulates

With new cars equipped with catalytic mufflers only a very limited quantity of research has been conducted and the results obtained were diverse.<sup>(E-2,3)</sup> As a result of conversations with Moran<sup>(E-4)</sup> of the EPA, it was decided to use factors developed by Campion, et al.<sup>(E-2)</sup> of the ESSO Research and Engineering Company. These factors (Table E-1) are regarded by Moran as resulting from the most carefully conducted research programs presently in existence. It must be noted, however, that the composition of the particulates emitted differs dramatically from the composition of particulates emitted from vehicles not equipped with catalytic devices. Over 90% of the catalytic muffler particulate emissions is in the form of sulfates, sulfuric acid and water bound to the sulfuric acid (Table E-1), whereas from unequipped vehicles, sulfates and sulfuric acid compose but a trace amount of particulate emissions.<sup>(E-2)</sup>

The mechanism causing high sulfate and sulfuric acid levels and low levels of other particulates has been attributed to the catalyst.<sup>(E-5)</sup>

The California Air Resources Board's (ARB) preliminary test results on old cars retrofitted with catalytic mufflers are shown in Table E-2.<sup>(E-3)</sup> By comparing the ARB figures with those of Campion's, it would appear that retrofitted old cars emit considerably fewer particulates than new cars. As a result of discussions with knowledgeable personnel<sup>(E-6)</sup> the differences in the results were attributed to the ARB's sampling technique, which consisted of a fiberglass paper filter element mounted on the car trunk with a flexible hose directing exhaust gas from the tailpipe to the filter. Apparently when the exhaust mixture reached the filter, they were hot enough such that sulfates, sulfuric acid and water were in a gaseous state and consequently passed through the filter. The Campion system, on the other hand, allowed for the "collection of particulate matter from an isokinetically sampled portion of diluted exhaust which has been cooled to 90°F by dilution with chilled, dehumidified, filtered air."<sup>(E-2)</sup> Another probable cause of the differences may be in that the ARB did not use the Federal Test Procedure (which Campion did), but rather a 302 mile route selected to represent driving patterns within the Los Angeles Basin. Because of the inaccuracies introduced by the ARB test procedure, the factors in Table E-1 for new automobiles were also used for old automobiles.

#### Effect of Lead in Gasoline on the Catalyst

In the area of cars equipped with catalytic mufflers, the most comprehensive study presently available is one by Holt, et al.<sup>(E-7)</sup> in which the conclusion was drawn that trace amounts of lead up to the 0.07 - 0.10 grams/gallon range have almost no long term (up to 25,000 miles) effect on the performance of the catalyst. At higher trace levels, deterioration effects become increasingly apparent. Brief exposures to fully leaded fuels (3.5 grams/gallon) temporarily decrease the efficiency of the catalyst, but if the automobile is run subsequently on unleaded fuel, the normal efficiency returns. Based on the EPA regulation of a maximum of 0.05 grams of lead/gallon in unleaded gasoline, there should be no problems with lead poisoning if only unleaded fuel is used.

TABLE E-1. PARTICULATE EMISSIONS FROM NEW CARS EQUIPPED  
WITH CATALYTIC MUFFLERS (grams/mile)

<u>Catalyst</u>	<u>Test Cycle</u>	<u>Fuel Sulfur, %</u>	<u>Total Particulates</u>	<u>Sul-Fates</u>	<u>Water</u>	<u>Platinum</u>
Monolithic Noble Metal (1)	1972 Federal Test Cycle	0.067 <sup>(3)</sup>	0.287 <sup>(4)</sup>	0.126 <sup>(4)</sup>	0.111 <sup>(4)</sup>	0.0002
Pelletized Oxidation (2)	1972 Federal Test Cycle	0.065	0.118	0.036	N/A	0.0002

N/A = Not Available

- (1) Characteristic of Ford Motor Company catalytic mufflers
- (2) Characteristic of General Motors Company catalytic mufflers
- (3) This is the average content (percent by weight) of sulfur in Southern California gasoline
- (4) Average

Source: Reference E-2

TABLE E-2. PARTICULATE EMISSION FACTORS FROM OLD CARS  
RETROFITTED WITH CATALYTIC MUFFLERS (grams/mile)

<u>Vehicle</u>	<u>Gasoline</u>	<u>Type of Catalyst</u>	<u>Particulate</u>
1970 American Motors Matador	Non leaded	UOP Miniverter	0.0154

Source: Reference E-3

The only research available concerning old cars retrofitted with catalytic mufflers is from the ARB. (E-8) These results are again preliminary and seem to indicate that if unleaded fuel is used, there will be no effects on the catalyst.

The following summarizes the data used to compute overall emissions of particulate matter and SO<sub>2</sub> from the projected vehicle mix in the air basin.

<u>Year</u>	<u>Program</u>	<u>% of Vehicles Equipped with Catalyst</u>	<u>% of VMT by Catalyst Equipped Vehicles</u>
1977	Present controls	27	32
1977	EPA oxidant plan	65	73
1980	Present controls	53	62
1980	EPA oxidant plan	90	90

This data together with the total LDV VMT data presented in Appendix C yielded the VMT by both catalyst equipped and non-catalyst equipped vehicles.

According to data presented by Campion, roughly 30% of the sulfur in gasoline is converted to sulfate or sulfuric acid by the catalyst. Taking the appropriate fractions, the following LDV emissions of SO<sub>2</sub> result:

1977	Present controls	42.7 tons/day SO <sub>2</sub>
1977	EPA oxidant plan	36.9 "
1980	Present controls	41.4 "
1980	EPA oxidant plan	37.0 "

The emission factor for particulate matter from catalyst equipped vehicles was derived assuming that of the two types of catalysts available (monolithic and pelletized), only Ford Motor Company cars would be equipped with the monolithic type. Both the GM and the UOP catalysts are pelletized, hence the emission factor for the GM catalyst was applied to the remaining vehicle population. From R.L. Polk Company data for 1972, roughly 25% of the registered passenger cars in the basin are made by Ford. The weighted average emission factor for catalyst particulates is therefore

$$0.25 (.287 \text{ gms/mile}) + 0.75 (.118 \text{ gms/mile}) = 0.16 \text{ gms/mile.}$$

Since by 1977 and 1980 all non-catalyst equipped vehicles may be considered "old" ( $\geq 3$  years old), the particulate emission factor used for these vehicles is 0.43 gms/mile. (See Section 2.3.2) Particulate emission factors for the two projections are therefore:

1977 present controls:  $.323 (0.16) + .677(0.43) = 0.34$  gms/mile (76% suspended)\*

1977 EPA oxidant plan:  $.727 (0.16) + .273 (0.43) = 0.23$  gms/mile (87% suspended)\*

1980 present controls:  $.616 (0.16) + .384 (0.43) = 0.26$  gms/mile (82% suspended)\*

1980 EPA oxidant plan:  $.901 (0.16) + .099 (0.43) = 0.19$  gms/mile (94% suspended)\*

Projected daily particulate emissions from light duty vehicles are therefore:

	Present Controls		(Tons) EPA Oxidant Plan	
	<u>Total</u>	<u>Suspended</u>	<u>Total</u>	<u>Suspended</u>
1977 South Coast Air Basin	61.9	47.0	41.9	36.4
1980 South Coast Air Basin	50.8	41.7	37.1	34.9
1977 4-County Area	59.7	45.3	40.4	35.1
1980 4-County Area	49.0	40.2	35.8	33.6

Unfortunately, even though the projections show a net reduction in total particulates with time as well as under the EPA plan, the character of the particles has changed dramatically.

---

\* Assumes that emissions from catalyst-equipped vehicles are 100% suspended.

## References

- (E-1) Federal Register, Vol. 38, No. 217, Part 2. November 12, 1973.
- (E-2) Campion, R. J., Beltzer, M. and Petersen, W. L. Measurement of Vehicle Particulate Emissions. SAE Paper 740186. 1974.
- (E-3) Surveillance of Particulate Emissions from Mobile Sources, Project S-4, Status Report 1. California Air Resources Board. September 1973
- (E-4) J. Moran. EPA, Research Park Triangle. Private Communication. April 1974.
- (E-5) S. K. Friedlander. California Institute of Technology. Private Communication. April 1974.
- (E-6) Private Communication with personnel in the research departments of several oil companies. April 1974.
- (E-7) Holt, E. L., Wegg, E. E. and Neal, A. H. Fuel Effects on Oxidation Catalyst Systems, II. SAE Paper 740248. 1974.
- (E-8) Report on Emissions from Vehicles Equipped with UOP's Catalytic Device. Interim Report No. 2. California Air Resources Board. November 1973.



AN IMPLEMENTATION PLAN FOR SUSPENDED  
PARTICULATE MATTER IN THE LOS ANGELES REGION

TECHNICAL SUPPORT DOCUMENT #3

AIR QUALITY - EMISSION LEVEL RELATIONSHIP

By: J. C. Trijonis

Prepared For  
Environmental Protection Agency  
Region IX - San Francisco, California

**TRW** / TRANSPORTATION AND  
ENVIRONMENTAL ENGINEERING  
OPERATIONS

AIR QUALITY - EMISSION  
LEVEL RELATIONSHIP

AN IMPLEMENTATION PLAN FOR SUSPENDED  
PARTICULATE MATTER IN THE LOS ANGELES REGION

TECHNICAL SUPPORT DOCUMENT #3

AIR QUALITY - EMISSION LEVEL RELATIONSHIP

By: J. C. Trijonis

Prepared For  
Environmental Protection Agency  
Region IX - San Francisco, California

**TRW** / TRANSPORTATION AND  
ENVIRONMENTAL ENGINEERING  
OPERATIONS

## DISCLAIMER

This report was furnished to the Environmental Protection Agency by TRW Transportation and Environmental Operations in fulfillment of Contract Number 68-02-1384. The contents of this report are reproduced herein as received from the contractor. The opinions, findings, and conclusions are those of TRW and not necessarily those of the Environmental Protection Agency. Mention of company or product names does not constitute endorsement by the Environmental Protection Agency.

## TABLE OF CONTENTS

	<u>Page</u>
1.0 INTRODUCTION AND SUMMARY .....	1
1.1 Some Basic Definitions .....	1
1.2 Outline of Support Document #2 .....	2
1.3 Conclusions and Recommendations .....	6
2.0 THE ORIGINS OF SUSPENDED PARTICULATE MATTER IN THE METROPOLITAN LOS ANGELES AIR QUALITY CONTROL REGION .....	9
2.1 National Ambient Air Quality Standards for Par- ticulates -- Annual Average us. 24 Hour Levels .....	11
2.2 Background Aerosol Levels in the Los Angeles Region ...	15
2.2.1 Hi-Vol Measurements at Non-urban California Locations .....	18
2.2.2 Sea Salt and Suspended Soil Dust in the Los Angeles Region .....	22
2.2.3 Characterization of Total Background Aerosol Levels in the Metropolitan Los Angeles Region ..	26
2.3 Average Composition of Hi-Vol Particulate Samples .....	29
2.3.1 Aerosol Composition Data .....	29
2.3.2 Characterization of 1972 Base Year Composition .....	46
2.4 Characterization of Particulate Origins for the Los Angeles Region .....	49
2.4.1 Origin Classification - A First Iteration .....	50
2.4.2 Origin Classification -- Completion of the Characterization .....	57
2.4.3 Spatial Features of the Origin Characterization.	61
3.0 THE DEPENDENCE OF SUSPENDED PARTICULATE LEVELS ON CONTAMINANT EMISSIONS .....	69
3.1 Air Quality Relationship for Non-Background Primary Particulates .....	70
3.2 Sulfate Air Quality Relationship .....	73
3.2.1 Chemical Transformation Processes .....	75
3.2.2 Atmospheric Data .....	78

## TABLE OF CONTENTS (continued)

	<u>Page</u>
3.2.3 An Operational Relationship for Use in Implementation Planning .....	86
3.3 Nitrate Air Quality Relationship .....	89
3.4 Ammonium Air Quality Relationship .....	93
3.5 Secondary Organic Air Quality Relationship .....	94
4.0 BASELINE PARTICULATE AIR QUALITY PROJECTIONS FOR THE METROPOLITAN LOS ANGELES REGION .....	97
4.1 Arithmetic Mean Target Levels Corresponding to the Geometric Mean Standards .....	100
4.2 Air Quality Forecast for the Baseline Emission Projections .....	102
REFERENCES .....	107
APPENDIX A .....	A-1

## LIST OF TABLES

<u>Table</u>	<u>Pages</u>
1-1 Origin Characterization for Annual Mean Hi-Vol Particulate Levels ( $\mu\text{g}/\text{m}^3$ ) .....	4
2-1 National Ambient Air Quality Standards for Particulates ....	11
2-2 Overall Degree of Control Required to Meet the Primary Annual Standard for Particulates .....	12
2-3 Overall Degree of Control Required to Meet the Primary 24 Hour Standard for Particulates .....	13
2-4 Suspended Particulate Measurements at Non-urban California, Locations .....	19
2-5 Results of Chemical Element Tracer Analysis for Sea Salt and Soil Dust in the Los Angeles Region .....	24
2-6 Previously Reported Calculations of Sea Salt and Soil Dust Levels .....	25
2-7 Estimates of Average Sea Salt and Soil Dust Levels in the Los Angeles Region .....	26
2-8 Estimates of Average Total Background Levels .....	27
2-9 Completed Background Aerosol Classification Scheme for the Los Angeles Region .....	28
2-10 Availability of Composition Data From Long Term Monitoring Programs .....	30
2-11 Locations and Data Sources for Aerosol Composition Breakdown .....	32
2-12 Data on Average Composition of Hi-Vol Particulate Samples ..	34
2-13 Differences Between APCD and NASN Composition Data .....	46
2-14 Hi-Vol Particulate Composition: Characterization of the 1972 Base Year .....	48
2-15 Calculated Secondary Organic Aerosol Levels for Various Values of $S_{\text{sec}}$ .....	54
2-16 Aerosol Origin Characterization -- First Iteration (Annual Arithmetic Mean -- $\mu\text{g}/\text{m}^3$ ) .....	56
2-17 Origin Characterization for Annual Mean Hi-Vol Particulate Levels ( $\mu\text{g}/\text{m}^3$ ) .....	62
2-18 General Spatial Patterns in the Aerosol Origin Characterization .....	63
4-1 Hypothetical Illustration of the Model for Predicting Control Strategy Impact on Particulate Air Quality Levels ..	98

LIST OF TABLES (continued)

<u>Table</u>	<u>Page</u>
4-2 Arithmetic Mean Target Levels Corresponding to the Geometric Mean Standards .....	99
4-3 Ratio of Arithmetic Mean to Geometric Mean vs. Geometric Standard for Log Normal Distribution .....	101
4-4 Summary of Emission Projections for the 4 County Sub-Area of the Los Angeles Region .....	102
A-1 Breakdown of Primary Suspended Particulate and SO <sub>2</sub> Emissions at the Kaiser/Edison Complex .....	A-1

## LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
2-1 Sub-Areas for the Background Aerosol Analysis .....	17
2-2 Locations for the Aerosol Origin Characterization .....	33
2-3 Total Nitrate Levels in the Los Angeles Region .....	64
2-4 Estimated Non-Background Secondary Organic Levels in the Los Angeles Region .....	65
2-5 Total Sulfate Levels in the Los Angeles Region .....	66
2-6 Estimated Non-Background Primary Particulate Levels in the Los Angeles Region .....	67
3-1 Particulate Emission Density Map for the Metropolitan Los Angeles Region .....	71
3-2 Sulfur Dioxide Emissions and Wind Patterns in the Metro- politan Los Angeles Region .....	74
3-3 Schematic Illustrations of the dependence of Sulfate Levels on SO <sub>2</sub> Input .....	79
3-4 Historical Relationship between SO <sub>2</sub> Emissions and SO <sub>4</sub> <sup>=</sup> Concentrations -- Los Angeles County, 1957 to 1970 .....	81
3-5 Sulfur Dioxide/Sulfate Relationship for 18 U.S. Cities .....	83
3-6 Aerometric Relationship between Sulfate and Sulfur Dioxide in the Metropolitan Los Angeles AQCR .....	85
3-7 Average SO <sub>2</sub> Emissions vs. Average SO <sub>4</sub> <sup>=</sup> Air Quality for Los Angeles County .....	87
3-8 Aerometric Relationship between Nitrate and NO <sub>x</sub> in the Metropolitan Los Angeles AQCR .....	92
4-1 Suspended Particulate Air Quality Forecasts for the Base- line Emission Projections .....	105



## 1.0 INTRODUCTION AND SUMMARY

Under contract to the Environmental Protection Agency, TRW Environmental Services has developed a particulate implementation plan for the Metropolitan Los Angeles Air Quality Control Region. Specifically, TRW has investigated strategies for approaching and achieving the National Ambient Air Quality Standards (NAAQS) for suspended particulate matter in the Los Angeles Region. The present report, the third of four technical support documents associated with the project, develops a methodology for relating measured (Hi-Vol) suspended particulate levels to emissions of both primary particulates and gaseous precursors of secondary particulates.

### 1.1 SOME BASIC DEFINITIONS

Throughout this study, the terms, suspended particulates and aerosol, are used interchangeably. Both refer to suspended particles, (liquid or solid), in air. The basic measuring unit used here is total aerosol mass concentration, ( $\mu\text{g}/\text{m}^3$ ); thus, the details of the particle size distribution are usually neglected.

One very important distinction that is made involves the concept of primary particulates versus secondary particulates, (or alternatively primary aerosol versus secondary aerosol).<sup>\*</sup> Primary aerosols are directly emitted; they enter the atmosphere as particles. Secondary particulates are formed in the atmosphere from the conversion of gases to particles by chemical reaction process. The four principal types of secondary

<sup>\*</sup> The reader should not confuse this concept with the terms "primary" and "secondary" standards. The national primary and secondary standards refer to different target levels for total particulate air quality, i.e., each standard applies to the sum of both primary and secondary aerosol.

aerosol are sulfate ( $\text{SO}_4^{=}$ ), nitrate ( $\text{NO}_3^-$ ), ammonium ( $\text{NH}_4^+$ ), and secondary organics. The gaseous precursors of these aerosols are sulfur dioxide ( $\text{SO}_2$ ), nitrogen oxides ( $\text{NO}_x$ ), ammonia ( $\text{NH}_3$ ), and reactive hydrocarbons (RHC), respectively.

A distinction is sometimes made between ambient total suspended particulates and Hi-Vol total suspended particulates. The former refers to total particulate mass loading in the atmosphere, while the latter refers to the mass loading which is measured by a Hi-Vol monitor. As discussed in Support Document #1, Hi-Vol measurements are sometimes not fully representative of ambient conditions.

A third distinction involves the concept of background particulates versus non-background particulates. For the purposes of this study, non-background aerosol is defined as that which is subject to direct emission regulations in the Metropolitan Los Angeles Region. Conversely, background aerosol consists of the part which is non-controllable by direct emission regulations in Los Angeles. In this sense, there are three main background aerosol sources: natural sources, suspended soil dust from man-related activities such as traffic or agriculture, and anthropogenic\* sources exterior to the Metropolitan Los Angeles Region. This definition of background sources differs from the more common usage which refers to natural sources only.

## 1.2 OUTLINE OF SUPPORT DOCUMENT #2

This report develops an air quality-emission level relationship for suspended particulates in the Metropolitan Los Angeles Region. Essentially,

\* Man-made

a methodology, or "model", is formulated which predicts Hi-Vol measurements of total suspended particulates as functions of contaminant emission levels. Included are the effects of four types of pollutant emissions: primary particulates, sulfur dioxide, nitrogen oxides, and reactive hydrocarbons. The methodology is applied to twelve monitoring sites within the Metropolitan Los Angeles Region.

Although federal air quality standards for particulates have been established for both long term (annual) and short term (24 hour) concentrations, the present analysis addresses only long term annual levels. Section 2.1 presents justifications for this restriction in scope. The basic reason is that the annual particulate standard appears to be the binding constraint.

The first major input to the air quality-emission level model is a characterization of aerosol origins. Chapter 2 provides this input through an analysis of aerometric data taken by several monitoring programs and through the use of recently developed techniques for tracing aerosol origins. Table 1-1 summarizes the results; the origins of annual average particulate levels at twelve locations are broken down into several background and non-background (controllable) categories. There are many uncertainties involved in the derivation of Table 1-1; Chapter 2 includes discussions which serve to illustrate the limitations in the analysis.

The second major input for the model is a set of relationships which describe the dependence of each controllable origin category on contaminant emission levels. Chapter 3 provides these relationships. The linear rollback formula is chosen to relate the non-background primary particulate category to man-made primary particulate emissions in the Los Angeles

TABLE 1-1 ORIGIN CHARACTERIZATION FOR ANNUAL MEAN HI-VOL PARTICULATE LEVELS  
( $\mu\text{g}/\text{m}^3$ )

LOCATION	BACKGROUND CONTRIBUTIONS						TOTAL BACK- GROUND	NON-BACKGROUND CONTRIBUTIONS (Anthropogenic Sources within LA Region)					TOTAL AAM
	PRIMARY			SECONDARY				PRIMARY	SECONDARY				
	Sea Salt	Suspended Dust	Primary Man-made Sources Exterior to the L.A. Region	SO <sub>4</sub> <sup>=</sup>	NO <sub>3</sub> <sup>-</sup>	Secondary Organics			SO <sub>4</sub> <sup>=</sup>	NO <sub>3</sub> <sup>-</sup>	NH <sub>4</sub> <sup>+</sup>	Secondary Organics	
COASTAL AREA LOCATIONS													
1. Lennox	8	16	3	4	1	3	35	84	9	6	1	10	145
2. West Los Angeles	8	14	3	4	1	3	33	36	5	6	1	9	90
3. Long Beach	8	16	3	4	1	3	35	47	7	5	1	10	105
CENTRAL-VALLEY AREA LOCATIONS													
4. Downtown Los Angeles	6	27	3	4	1	3	44	54	10	11	1	20	140
5. Pasadena	6	21	3	4	1	3	38	42	9	10	1	20	120
6. Anaheim	6	23	3	4	1	3	40	36	5	6	1	17	105
7. Reseda	6	26	3	4	1	3	43	58	9	7	1	22	140
EASTERN-INLAND AREA LOCATIONS													
8. Azusa	4	38	3	4	1	3	53	41	11	17	1	37	160
9. Ontario	4	34	3	4	1	3	49	24	6	10	1	30	120
10. San Bernardino	4	33	3	4	1	3	48	26	9	12	1	29	125
11. Riverside	4	45	3	4	1	3	60	30	3	14	1	37	150
WESTERN SAN BERNARDINO COUNTY HOT SPOT													
12. Chino	4	45	3	4	1	3	60	89	18	17	1	35	220

Region. For the non-background secondary aerosol categories, Chapter 3 reviews existing theoretical and empirical evidence pertaining to the dependence on gaseous precursor emissions. It is found that a great deal of uncertainty exists concerning this dependence. In the end, a linear form is assumed for each of the sulfate/SO<sub>2</sub>, nitrate/NO<sub>x</sub>, and organic/RHC relationships.

The air quality-emission level model is completed by synthesizing the origin characterization and the relationships which link controllable categories to emission levels. Chapter 4 illustrates the model by forecasting air quality levels for the baseline emission projections derived in Support Document #2, [18]. The final report of this project uses the model to predict the effect of various control strategies on total suspended particulate levels in the Metropolitan Los Angeles Region.

The uncertainties involved in the emission level-air quality relationship developed here should not be underestimated. As documented in the text of this report, existing data are deficient in many respects both for characterizing aerosol origins and for estimating the dependence of secondary aerosol categories on gaseous precursor emissions. Further, the very aggregated model formulated herein deals only with total emission levels and cannot account for changes in the emission spatial distribution. Changes in the spatial pattern of emissions is thus another potential source of error.

Although considerable uncertainty exists, the model developed here is based on a systematic analysis of existing data. It should provide an approximate, but useful tool for evaluating the impact of control strategies on average suspended particulate levels. Further, it provides a framework for incorporating improvements as further data become available.

### 1.3 CONCLUSIONS AND RECOMMENDATIONS

This study of the relationship between measured suspended particulate levels and emissions of both primary particulates and gaseous precursors of secondary particulates has resulted in the following conclusions and recommendations:

#### Conclusions

- In order to construct a systematic relationship between suspended particulate levels and emissions of primary particulates,  $\text{SO}_2$ ,  $\text{NO}_x$ , and RHC, two separate analyses must be performed. The first is to characterize the origins (e.g., background, non-background primary, non-background sulfate, etc.) of suspended particulate levels at various locations. The second is to determine the dependence of each origin category on emission levels.
- Existing aerosol composition data (from the county APCD's, NASN, and other monitoring programs) are sufficient to support an approximate aerosol origin characterization for annual arithmetic means (AAM's) at twelve locations in the Los Angeles Region. Existing data are not sufficient to characterize aerosol origins on episode days. The latter result may not be a severe handicap to control policy formulation since it appears that the annual national standards for particulates are more restrictive than the 24 hour max. national standards in the Los Angeles Region.
- Existing data indicate that background (non-controllable) particulate levels are about  $30\text{-}40\ \mu\text{g}/\text{m}^3$  AAM in the coastal areas of the Los Angeles Region. Background aerosol levels appear to increase with distance inland to about  $45\text{-}60\ \mu\text{g}/\text{m}^3$  AAM in the eastern-inland parts of the region. The existence of significant background levels limits the air quality effectiveness of emission controls in the Los Angeles Region.
- Non-background primary particulate contributions generally tend to be highest in the coastal and central-valley portions of the Los Angeles Region. The one exception involves the very high primary contributions estimated for the Western San Bernardino County Hot-Spot (Chino-Rialto) which is apparently affected by the Kaiser/Edison complex. Sulfate levels tend to be uniformly distributed over the basin at around  $10\text{-}15\ \mu\text{g}/\text{m}^3$  AAM, (again the Hot-Spot is an exception). Measured nitrate and estimated secondary organic levels tend to increase considerably with distance inland. The above spatial trends appear to be consistent with known aspects of source distribution, meteorology, and atmospheric chemistry.

- For the purposes of this study, the linear rollback formula appears to be generally adequate for relating primary suspended particulate emissions to non-background primary aerosol levels. In order to assess air quality changes for the special case of the Western San Bernardino County Hot-Spot, a modification of the linear rollback approach must be made.
- Considerable uncertainty surrounds the relationship between non-background sulfate air quality and  $\text{SO}_2$  emissions. However, theoretical analysis and empirical data both suggest a slightly less than linear dependence. At low  $\text{SO}_2$  levels, sulfate yield appears to increase linearly with  $\text{SO}_2$  input. At higher  $\text{SO}_2$  levels, the sulfate yield tends to level off. For the purpose of this study, (the prediction of total suspended particulate levels), it appears sufficient to assume a linear relationship.
- Very little is known concerning the dependence of nitrate levels on  $\text{NO}_x$  emissions and the dependence of secondary organic levels on RHC emissions. In this study a simple linear form is assumed for each relationship. The main justification is that there is no evidence to support the use of any specific non-linear relationship.

#### Recommendations

- In order to improve the aerosol origin estimates, more comprehensive data are needed on particulate chemical composition. Specifically, it is recommended that further sodium and aluminum data be taken to verify the sea salt and soil dust levels calculated here. Also, it would be very useful to devise and apply a method for measuring secondary organic particulate levels. Existing data on ambient organic aerosol, (benzene or cyclohexane solubles), are essentially only measures of primary organic contributions.
- Further research effort should be allocated to determine the dependence of secondary aerosol levels on gaseous precursor emissions. Much of the research to date has been directed toward identifying the reaction mechanisms and understanding the physico-chemical processes. This work should be continued since it supplies a scientific base for explaining the relationship. However, it may be possible to obtain reasonable answers in a shorter time by emphasizing an empirical approach. Ambient and experimental measurements of  $\text{NO}_x$  (or  $\text{SO}_2$ ) input vs. nitrate (or sulfate) yield may be able to supply a relationship that is adequate for present planning purposes.

## 2.0 THE ORIGINS OF SUSPENDED PARTICULATE MATTER IN THE METROPOLITAN LOS ANGELES AIR QUALITY CONTROL REGION

The development of a systematic relationship between pollutant emissions and measured suspended particulate levels requires identification of the origins of the suspended particulate matter. The portion of total particulates that is associated with each general source type must be determined. This chapter provides the required origin characterizations for the Metropolitan Los Angeles AQCR.

The aerosol origin characterization will consist of a breakdown of annual mean Hi-Vol levels according to the following classification scheme:

### I. Background Contributions

#### A. Primary

Sea Salt \_\_\_\_\_  
Soil Dust \_\_\_\_\_  
Primary Anthropogenic  
Sources Exterior to  
the Los Angeles  
Region \_\_\_\_\_

#### B. Secondary

Sulfate \_\_\_\_\_  
Nitrate \_\_\_\_\_  
Secondary  
Organics \_\_\_\_\_

### II. Non-Background Contributions (Anthropogenic Sources within the Los Angeles Region)

#### A. Primary

Total Primary \_\_\_\_\_

#### B. Secondary

Sulfate \_\_\_\_\_  
Nitrate \_\_\_\_\_  
Ammonium \_\_\_\_\_  
Secondary  
Organics \_\_\_\_\_



This classification scheme will be completed for 12 locations in the region which have sufficient aerosol composition data to support the origin analysis. The latter part of the classification, (Non-Background), will be fundamental to control strategy evaluation, since it is this portion of the aerosol that is subject to emission regulations within the control region.

It should be noted that federal air quality standards have been established for both long term (annual geometric mean) and short term (24 hour maximum) particulate concentrations. However, the present study will provide an air quality/emission level relationship only for the long term, annual levels. The justification for this restriction in scope is discussed in Section 2.1. The basic reason is that the annual standard appears to be the binding constraint for the Metropolitan Los Angeles Region.

Section 2.2 provides estimates for the first part of the origin classification scheme, (Background Contributions). These estimates are derived from an analysis of suspended particulate levels in nonurban California locations and from the results of chemical element tracer techniques as applied to recent measurements within the Los Angeles Region.

Section 2.3 presents and analyzes aerosol chemical composition data for twelve locations in the Los Angeles Region. These data are pertinent to estimating non-background contributions.

Section 2.4 combines the results of Sections 2.2 and 2.3 to complete the aerosol origin characterization for the twelve sites in the Los Angeles Region.

## 2.1 NATIONAL AMBIENT AIR QUALITY STANDARDS FOR PARTICULATES -- ANNUAL AVERAGE VS. 24 HOUR LEVELS

Table 2-1 summarized the National Ambient Air Quality Standards (NAAQS) for suspended particulates. Standards have been established for both long term (annual geometric mean) and short term (24 hour) concentrations. A particulate implementation plan should contain provisions

---

TABLE 2-1  
NATIONAL AMBIENT AIR QUALITY STANDARDS FOR PARTICULATES

	Annual Geometric Mean	Maximum: Not to be Exceeded More than Once a Year
Primary Standard	75 $\mu\text{g}/\text{m}^3$	260 $\mu\text{g}/\text{m}^3$ for 24 hours
Secondary Standard	60 $\mu\text{g}/\text{m}^3$ *	150 $\mu\text{g}/\text{m}^3$ for 24 hours

\* EPA guide for the attainment of the secondary 24 hour standard

---

for meeting both the short and long term standards. However, in this study, only the long term (annual geometric mean) standard will be considered. The justification for this restriction in scope is presented below.

The main argument for considering only the annual standard is that it appears to be the binding constraint in the Los Angeles Region, i.e., attaining the annual standard implies attaining the 24 hour standard, (but not vice versa). \*\* To illustrate this, we first considered the overall degree of control of man-made particulates (primary and secondary) that is required to achieve the primary annual standard,

---

\*\* The only exception to this rule for Los Angeles appears to be the case where the 24 hour standard is exceeded due almost exclusively to natural causes, (e.g., a dust storm). In this case, no control strategy applied to Los Angeles pollution sources can achieve the 24 hour standard.

(75  $\mu\text{g}/\text{m}^3$ , AGM). The left side of Table 2-2 lists the expected 1972 annual arithmetic mean, the background level, and the target AAM for attaining the primary AGM standard at four monitoring locations in the Los Angeles Region with severe particulate levels. The right side of Table 2-2 calculates the overall degree of control required to meet the primary, annual air quality standard for particulates at each station.

TABLE 2-2 OVERALL DEGREE OF CONTROL REQUIRED TO MEET THE PRIMARY ANNUAL STANDARD FOR PARTICULATES

LOCATION	EXPECTED 1972 AAM ( $\mu\text{g}/\text{m}^3$ )	BACKGROUND LEVEL ( $\mu\text{g}/\text{m}^3$ )	TARGET AAM FOR ATTAINING PRIMARY STD. ( $\mu\text{g}/\text{m}^3$ )	OVERALL DEGREE OF CONTROL REQUIRED
Chino	220 <sup>a</sup>	60 <sup>b</sup>	80 <sup>c</sup>	$\frac{(220-80)}{(220-60)} = 87\%$
Azusa	160 <sup>a</sup>	53 <sup>b</sup>	80 <sup>c</sup>	$\frac{(160-80)}{(160-53)} = 75\%$
Riverside	150 <sup>a</sup>	60 <sup>b</sup>	80 <sup>c</sup>	$\frac{(150-80)}{(150-60)} = 78\%$
Lennox	145 <sup>a</sup>	35 <sup>b</sup>	80 <sup>c</sup>	$\frac{(145-80)}{(145-35)} = 59\%$

- a. From Support Document #1 of this project, [1].
- b. See Section 2.4 of this report, (Table 2-17).
- c. See Section 4.1 of this report.

Next, we consider the overall degree of control required to achieve the 24 hour primary standard for particulates, (260  $\mu\text{g}/\text{m}^3$ ). Table 2-3, which is similar to Table 2-2, summarizes the calculations for the 24 hour standard. These latter results are more uncertain than those in

TABLE 2-3 OVERALL DEGREE OF CONTROL REQUIRED TO MEET THE PRIMARY 24 HOUR STANDARD FOR PARTICULATES

LOCATION	EXPECTED 1972 24 HOUR MAX ( $\mu\text{g}/\text{m}^3$ )	BACKGROUND LEVEL ( $\mu\text{g}/\text{m}^3$ )	PRIMARY 24 HOUR STANDARD ( $\mu\text{g}/\text{m}^3$ )	OVERALL DEGREE OF CONTROL REQUIRED
Chino	1000 <sup>a</sup>	60 <sup>b</sup>	260	$\frac{(1000-260)}{(1000-60)} = 79\%$
Azusa	380 <sup>a</sup>	53 <sup>b</sup>	260	$\frac{(380-260)}{(380-53)} = 37\%$
Riverside	620 <sup>a</sup>	60 <sup>b</sup>	260	$\frac{(620-260)}{(620-60)} = 64\%$
Lennox	340 <sup>a</sup>	35 <sup>b</sup>	260	$\frac{(340-260)}{(340-35)} = 26\%$

a. From Support Document #1 of this project. These are the expected 24 hour maxima assuming samples were taken every day of the year. At present monitoring frequencies, measured yearly maxima are somewhat lower than these values, [1].

b. These are annual mean background levels as reported in Section 2.4 of this report, (Table 2-17). Background levels on days of maximum particulate levels are very poorly documented. However, a few recent measurements indicate that background levels are not particularly great on days of intense pollution, [2]. Rather, it may be that background levels are highest on windy days with higher suspended dust levels, [3], [4]; by their nature, these windy days are not days of intense man-made pollution.

Table 2-2 due to the lack of documentation on background levels for days of maximal particulate pollution, (see Footnote b to Table 2-3).

Although the results must be qualified by the aforementioned uncertainty, a comparison of Tables 2-2 and 2-3 reveals that considerably greater degree of control is required to attain the primary annual standard at each station than is required to attain the primary 24 hour standard. A similar conclusion arises from a comparative analysis of the secondary annual and 24 hour standards. Even in light of the uncertainties in the above calculations, it appears sufficient to formulate particulate control strategies for the Los Angeles Region only around the annual standards.

Actually, it would be best to calculate the impact of control strategies on both annual geometric mean and 24 hour maximum particulate levels. However, relating emission levels to particulate air quality levels requires detailed documentation of the origins of suspended particulates. In the course of this study, it was found much easier to document origins of annual average levels than to document origins of 24 hour maximal levels. Alternative data sources for annual averages could be compared and combined. In contrast, it was very difficult to construct a consistent picture of particulate origins with the sparse data for rare episode type days. This study will consider only the long term (annual) standards for suspended particulates.

## 2.2 BACKGROUND AEROSOL LEVELS IN THE LOS ANGELES REGION

As a first step in characterizing the origins of annual average Hi-Vol particulate levels in the Los Angeles Region, this section will derive estimates of background contributions. For the purposes of this study, the background aerosol will be defined as that resulting from sources which are not subject to direct emission regulations in the Los Angeles Region. Thus, the total aerosol minus background will represent the portion that is subject to direct control. There are three main types of background sources:

### 1. Natural Sources

examples: ... sea salt  
... naturally occurring soil dust  
... secondary organic aerosol from  
vegetation related hydrocarbons.

### 2. Anthropogenic Sources Exterior to the Metropolitan Los Angeles Region

examples: ... primary particulates emitted in other California regions or worldwide,  
.... secondary aerosol from  $\text{SO}_2$ ,  $\text{NO}_x$  or HC emissions in other areas.

### 3. Suspended Dust from Man-Related Activities

examples: ... dust from agricultural activity  
... suspended soil dust from traffic (street dust).

In compiling a breakdown of the background aerosol into various categories, it is not always possible to distinguish the contributions from the three types of sources listed above, (e.g. it may be difficult to separate natural soil dust from soil dust created by human activities). Thus, the background aerosol classification given here will not correspond exactly to the above list of source types. Rather, the following breakdown will be used to classify the background aerosol:

## BACKGROUND AEROSOL CLASSIFICATION SCHEME

### PRIMARY CONTRIBUTIONS

Sea Salt \_\_\_\_\_  
Suspended Dust \_\_\_\_\_  
Anthropogenic Sources Exterior  
to the Los Angeles Region \_\_\_\_\_

### SECONDARY CONTRIBUTIONS

Sulfate \_\_\_\_\_  
Nitrate \_\_\_\_\_  
Secondary Organics \_\_\_\_\_

Water aerosol is not included in the background classification because there are indications that, unlike the ambient aerosol, equilibrated Hi-Vol samples contain negligible amounts of water, (see Support Document #1 for a discussion).

Background aerosol levels may undergo significant spatial variations within the Los Angeles Region. The coastal areas should have higher sea salt concentrations, while the inland agricultural areas should demonstrate greater soil dust levels. The present analysis estimates background aerosol concentrations in three general areas: the coastal area, the central-valley area, and the eastern-inland area, (see Figure 2-1). In Section 2.4, adjustments will be made, where warranted, for individual monitoring sites within these general areas.

Two basic types of atmospheric measurements will be used to complete the background aerosol classification scheme listed above. Section 2.2.1 will review Hi-Vol data at nonurban California locations. These data will help to quantify background sulfate, nitrate, and secondary organic levels and will also provide a general indication of overall background levels for the Los Angeles Region. Section 2.2.2 will use recent measurements of sodium and aluminum concentrations within the Los Angeles Region, [2],

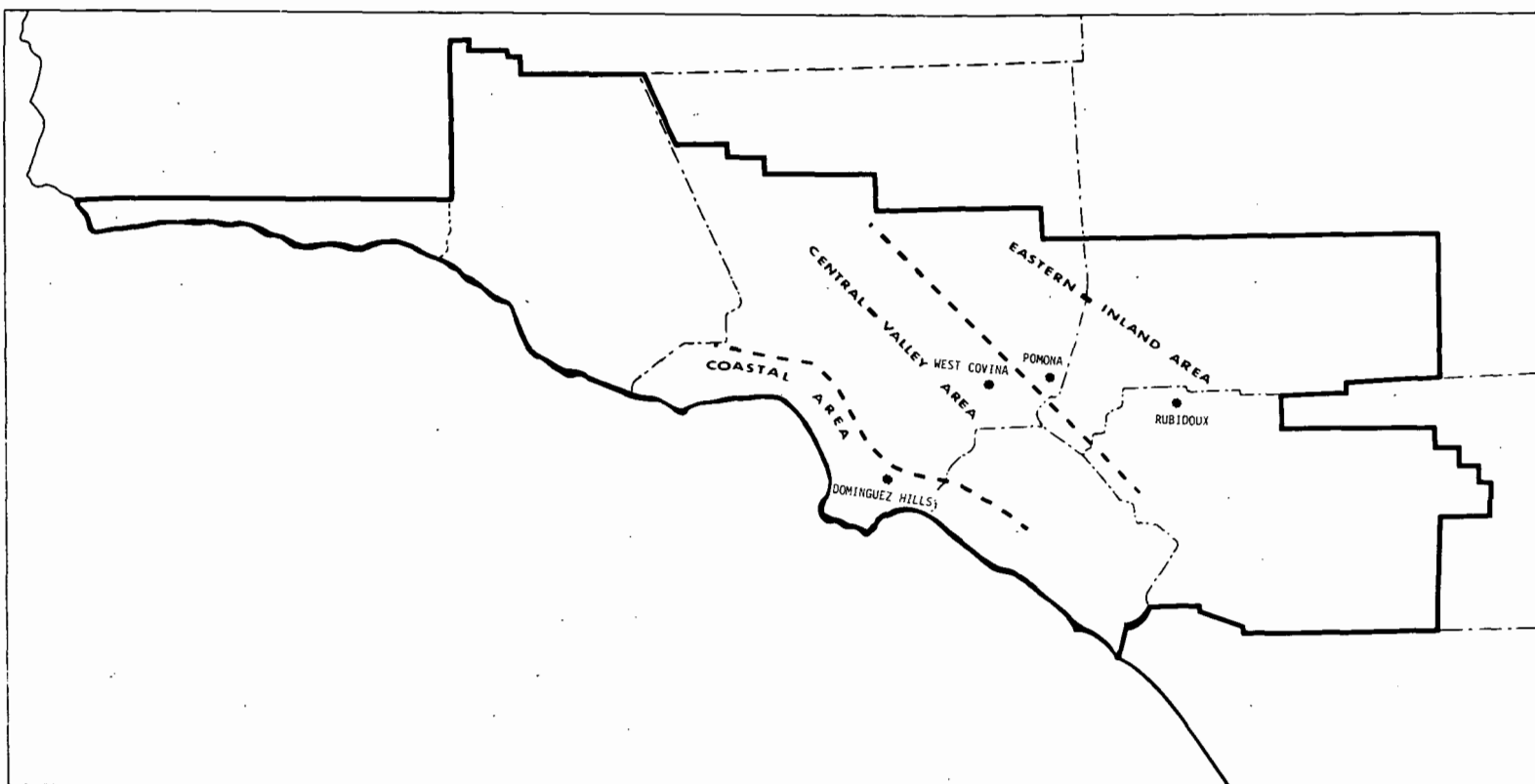


Figure 2-1 Sub-Areas For The Background Aerosol Analysis



to estimate sea salt and soil dust contributions. Section 2.2.3 will combine all the results to complete the classification scheme for the background aerosol in each of the three subareas of the Los Angeles Region.

#### 2.2.1. Hi-Vol Measurements at Nonurban California Locations

Table 2-4 summarizes Hi-Vol measurements taken at several nonurban sites in California. The locations have been distinguished as to marine and desert environments. Values are given for total suspended particulates as well as for the sulfate, nitrate, and organic components of the aerosol. All values are arithmetic means except the data from Reference [5] which were reported as geometric means.

One striking feature of Table 2-4 is the occurrence of very high particulate levels ( $180\text{--}290\ \mu\text{g}/\text{m}^3$ ) at several marine locations. These high averages appear to be due to sea salt aerosol resulting from wave action near the monitoring site. Sea salt is implicated by the singularly high sulfate levels at most of these sites; it has been estimated that sulfate comprises around 7% of sea salt aerosol, [6], [7]. The recent value ( $30\ \mu\text{g}/\text{m}^3$ ) obtained at San Nicolas Island,\* [8], appears to be more representative of average background levels in areas not subject to very proximate sea salt sources. The coastal region of Los Angeles should have average background levels at about this value. Actually, one might expect greater suspended dust concentrations in the coastal Los Angeles area than at San Nicolas, due to higher levels of human activity. Thus, the coastal area of the Los Angeles Region should have a background level of around  $30\text{--}40\ \mu\text{g}/\text{m}^3$ .

\*San Nicolas Island is located around 130 km southwest of Los Angeles. For typical wind patterns, San Nicolas should receive essentially no intrusion of Los Angeles pollution aerosol.

TABLE 2-4 SUSPENDED PARTICULATE MEASUREMENTS  
AT NONURBAN CALIFORNIA, LOCATIONS

L O C A T I O N	DATA SOURCE (REFERENCE)	NUMBER OF SAMPLES	AVERAGE SUSPENDED PARTICULATES ( $\mu\text{g}/\text{m}^3$ )			
			TOTAL	SO <sub>4</sub> <sup>=</sup>	NO <sub>3</sub> <sup>-</sup>	ORGANICS
MARINE ENVIRONMENT						
Crescent City (Lighthouse)	[ 9 ]	24	184	13.2	2.3	5.5 <sup>b</sup>
S.E. Farallon Island (Lighthouse)	[ 9 ]	46	184	13.8	1.0	4.1 <sup>b</sup>
Point Pedras Blancos (Lighthouse)	[ 9 ]	28	291	18.6	2.2	2.5 <sup>b</sup>
San Nicolas Island (150 meter elevation)	[ 9 ]	9	69	8.4	2.0	3.6 <sup>b</sup>
San Nicolas Island (200 meter elevation)	[ 8 ]	22	30	5.3	1.7	0.6 <sup>c</sup>
Point Reyes (USCG Station)	[ 0 ]	1	129	6.2	0.4	4.5 <sup>c</sup>
Point Arguello (USGG Station)	[ 0 ]	1	185	6.5	1.0	3.3 <sup>c</sup>
Trinidad (Lighthouse)	[ 1 ]	49	44	2.4	0.4	2.5 <sup>b</sup>
DESERT ENVIRONMENT						
Amboy	[ 5 ]	140	31*	3.3*	2.2*	3.4* <sup>b</sup>
Kramer Jct.	[ 5 ]	142	46*	4.5*	4.0*	3.5* <sup>b</sup>
29 Palms	[ 5 ]	145	61*	5.7*	3.6*	4.2* <sup>b</sup>
Needles	[ 5 ]	141	38*	3.3*	2.4*	4.1* <sup>b</sup>
Baker	[ 5 ]	141	44*	3.8*	2.8*	4.1* <sup>b</sup>
Goldstone	[ 0 ]	2	46	1.7	1.6	4.0 <sup>c</sup>

\* Geometric Means

b Extracted with Benzene

c Extracted with Cyclohexane

The measurements in the desert environment should give an indication of background levels in the eastern-inland areas of the Los Angeles Region. In terms of an annual arithmetic mean, (AAM), the Hi-Vol measurements in the Southern California desert area are typically around  $45-55 \mu\text{g}/\text{m}^3$ . Actually, in one sense, these values may overstate the background level. This is because the desert aerosol contains some nonbackground contribution from Los Angeles Region pollution sources. However, for another reason, the desert measurements may be less than background levels in the eastern-inland area of the Los Angeles Region. This is because more intensive agriculture and other human activity occurs in the eastern-inland area of the Los Angeles Region. These activities may lead to higher dust levels than the dust levels found in the desert. All considered, the desert Hi-Vol measurements are indicative of a  $45-60 \mu\text{g}/\text{m}^3$  average background level in the eastern-inland portion of the Los Angeles Region.

The average background sulfate level in the Los Angeles Region appears to be around  $3-5 \mu\text{g}/\text{m}^3$ . In the desert environment, arithmetic mean values tend to be around  $4-5 \mu\text{g}/\text{m}^3$ . The San Nicolas measurements indicate an average background sulfate level of around  $5 \mu\text{g}/\text{m}^3$ . However, measured  $\text{SO}_4^{=}$  levels in the desert and at San Nicolas both might be slightly higher than background levels in the Los Angeles Region. The Southern California desert stations receive some nonbackground sulfate from Los Angeles pollution sources. Sulfate levels at San Nicolas may be slightly elevated by sea salt contributions. Allowing for these possibilities, an average background sulfate level of  $3-5 \mu\text{g}/\text{m}^3$  seems reasonable.

Measurements at nonurban marine locations yield average nitrate values of around  $1-2 \mu\text{g}/\text{m}^3$ . In the Southern California desert area, east of the Los Angeles Region, average nitrate values tend to be around  $2-4 \mu\text{g}/\text{m}^3$ . The latter values may not be representative of background nitrate because of the influence of Los Angeles sources. It is known that nitrate values increase considerably from west to east in the Los Angeles Region; the high nitrate concentrations in the eastern part of the Los Angeles Region (around  $15 \mu\text{g}/\text{m}^3$ )\* are likely to cause somewhat elevated levels in the downwind desert area. Thus, the  $1-2 \mu\text{g}/\text{m}^3$  values measured at nonurban marine locations may be more representative of average background nitrate concentrations in the Los Angeles Region.

Measurements in the Southern California desert indicate a background organic aerosol level of around  $3-4 \mu\text{g}/\text{m}^3$ \*\*. With the exception of the San Nicolas Island results, most marine environment measurements support this value. San Nicolas may be an anomaly due to its distance out at sea and the island's rather sparse vegetation. Background organic concentrations appear to be sensitive to the amount of overall vegetation cover. Recent measurements in highly vegetated remote California locations have yielded organic aerosol levels of around  $5-10 \mu\text{g}/\text{m}^3$ , [10]. Here, the value of  $3-4 \mu\text{g}/\text{m}^3$  will be taken as representative of the Los Angeles Region.

In summary, the examination of measured particulate levels at nonurban California locations indicates the following:

\* See Section 2.3

\*\* Actually, these measurements are of soluble (in benzene or cyclohexane) organics. However, naturally occurring organic aerosol is probably highly extractable by these solvents, [17]. It will be assumed that total background organics are equivalent to soluble background organics.

ESTIMATED TOTAL BACKGROUND LEVELS FOR THE LOS ANGELES REGION:

Coastal Areas .....	30-40 $\mu\text{g}/\text{m}^3$
Eastern-Inland Areas .....	45-60 $\mu\text{g}/\text{m}^3$

BACKGROUND LEVELS FOR THREE SPECIFIC COMPONENTS:

Sulfate .....	3-5 $\mu\text{g}/\text{m}^3$
Nitrate .....	1-2 $\mu\text{g}/\text{m}^3$
Organics .....	3-4 $\mu\text{g}/\text{m}^3$

2.2.2 Sea Salt and Suspended Soil Dust in the Los Angeles Region

It is difficult to use particulate measurements taken within the Los Angeles Region to determine background levels for that region. The basic problem is how to distinguish the background aerosol from the pollution aerosol, (e.g., how does one distinguish between background sulfate or nitrate and sulfate or nitrate from Los Angeles pollution sources). However, for some types of background sources, the chemical element tracer method developed by Friedlander and co-workers at Caltech, [12], [7], [13], [14], can be applied to estimate the total contributions from that source.

The basic idea of the chemical element tracer method is to estimate the contribution of various sources by measuring the levels of certain elements which are characteristic of those sources. For instance, since gasoline powered motor vehicles provide essentially all of the ambient lead aerosol in urban areas, measured Pb can be used as an indicator of automotive contributions. The total primary automotive aerosol contribution is estimated by dividing the ambient Pb concentration by the fraction of Pb in suspended automotive particulate emissions. In some cases, more than one source and more than one

element are involved; this leads to a system of simultaneous equations, (one for each element), which are solved for source contributions.

The two background sources to be examined here with the chemical element tracer method are sea salt and soil dust. The calculations will use aluminum (Al) and sodium (Na) as tracers. Soil dust and sea salt contribute nearly all of the aluminum and sodium to the Los Angeles aerosol, [13]. Sodium constitutes around 2.5% of soil dust and around 30.6% of sea salt. Aluminum is 8.2% of soil dust and is a negligible fraction of sea salt, [13]. Thus, if AL and NA represent measured values of aerosol aluminum and sodium, the level of salt (SS) and soil dust (SD) present can be found by solving:

$$\begin{aligned}
 & .306 \text{ SS} + .025 \text{ SD} = \text{NA} \\
 & \text{and} \\
 & .082 \text{ SD} = \text{AL},
 \end{aligned}$$

or

$  \begin{aligned}  \text{and} \quad \text{SD} &= \frac{1}{.082} \text{ AL} \\  \text{SS} &= \frac{1}{.306} [\text{NA} - \frac{.025}{.082} \text{ AL}]  \end{aligned}  $	(2-1)
--	-------

Unfortunately, there are few measurements to which Equations 2-1 can be applied. Some data have recently been provided by the ACHEX Study, [2]. These data are for three days at West Covina and Rubidoux and for two days at Dominguez Hills and Pomona. These locations were shown in Figure 2-1.

The result of applying Equations (2-1) to the recent ACHEX data are presented in Table 2-5. Table 2-5 also gives a qualitative indication of distance inland for each location. By examining the results and the trends as to distance inland, the following pattern emerges: Sea salt levels in the coastal, central-valley, and eastern-inland areas appear to be around 9-11, 8-9, and 5-8  $\mu\text{g}/\text{m}^3$ , respectively. Soil dust levels appear to follow a pattern of 15-20, 20-30, and 30-35  $\mu\text{g}/\text{m}^3$ .

TABLE 2-5

RESULTS OF CHEMICAL ELEMENT TRACER ANALYSIS FOR  
SEA SALT AND SOIL DUST IN THE LOS ANGELES REGION\*

	COSTAL AREA	CENTRAL-VALLEY AREA	EASTERN-INLAND AREA	
SEA SALT ESTIMATES ( $\mu\text{g}/\text{m}^3$ )	9.7	8.9	8.2	5.1
SOIL DUST ESTIMATES ( $\mu\text{g}/\text{m}^3$ )	18.5	25.6	29.9	34.6
	DOMINGUEZ HILLS	WEST COVINA	POMONA	RUBIDOUX

> ————— DISTANCE INLAND —————>

\* Based on ACHEX Data,[2].

Table 2-6 presents results obtained by previous researchers using the chemical element tracer method. With the exception of soil dust estimates for Riverside, the values in Table 2-6 are somewhat lower than those obtained above. The reasons for the discrepancy are not obvious; much of the difference is probably due to the particular meteorology that occurred when the samples were taken.

TABLE 2-6  
PREVIOUSLY REPORTED CALCULATIONS OF SEA SALT  
AND SOIL DUST LEVELS

	CENTRAL-VALLEY AREA	EASTERN-INLAND AREA
SEA SALT ESTIMATES ( $\mu\text{g}/\text{m}^3$ )	Pasadena: 2.5* 2.3**	Pomona: 5.6** Riverside: 0.7**
SOIL DUST ESTIMATES ( $\mu\text{g}/\text{m}^3$ )	Pasadena: 9.8*	Pomona: 15.1** Riverside: 35.7**

\* Reference [7], (based on an 11 hour sample, 1969)

\*\* Reference [14], (based on single 24 hour sample, 1972)

In light of the previous results by other researchers, the estimates in Table 2-5 might be somewhat high. However, since the values in Table 2-5 are based on two to three days data while the values in Table 2-6 are each based on one day or less data, more weight should be attached to the former. Overall, the following estimates for average sea salt and soil dust seem reasonable:



TABLE 2-7

ESTIMATES OF AVERAGE SEA SALT AND SOIL DUST  
LEVELS IN THE LOS ANGELES REGION

	SEA SALT ( $\mu\text{g}/\text{m}^3$ )	SOIL DUST ( $\mu\text{g}/\text{m}^3$ )
COASTAL AREA	6-10	10-20
CENTRAL-VALLEY AREA	4-8	15-25
EASTERN-INLAND AREA	2-6	25-35

Considerable variance has been included in the above estimates as a reflection of the limited number of sampling days on which they are based.

### 2.2.3 Characterization of Total Background Aerosol Levels in the Metropolitan Los Angeles Region

Section 2.2.1 estimated background sulfate, nitrate, and secondary organic levels for the Los Angeles Region by analyzing data taken at nonurban California locations. Section 2.2.2 estimated sea salt and soil dust levels by using the chemical element tracer method developed by Friedlander, [13]. The only category in the BACKGROUND AEROSOL CLASSIFICATION SCHEME (see page 12) which has not been examined is the contribution from "primary anthropogenic sources exterior to the Los Angeles Region." It is very difficult to derive estimates of this latter category from existing data; nearly pure conjecture must be relied upon. A value in the range of 1-5  $\mu\text{g}/\text{m}^3$  seems to be about the right order of magnitude, [6].\*

\* Using Pb as a tracer for man-made primary emissions, calculations with San Nicolas data indicate about 2  $\mu\text{g}/\text{m}^3$  for the transported man-made particulate category. However, it is not certain whether the San Nicolas value represents sources exterior to the Los Angeles Region or sources within the Los Angeles Region.

Estimates, (although in some cases very approximate), have now been obtained for the contributions from each category in the BACKGROUND AEROSOL CLASSIFICATION SCHEME, (page 12). It is of interest to compare the total of all these various categories to the total background levels indicated by nonurban measurements, (Section 2.2.1). Table 2-8 makes this comparison. Although the variance in the estimates is large, the agreement of overall levels and of the trends from coast to inland is extremely good.

---

TABLE 2-8  
ESTIMATES OF AVERAGE TOTAL BACKGROUND LEVELS

	AVERAGE TOTAL BACKGROUND BY ANALYSIS OF TOTAL NONURBAN LEVELS (Section 2.2.1)	AVERAGE TOTAL BACKGROUND BY ADDITION OF ESTIMATES FOR EACH CATEGORY IN THE CLASSIFICATION SCHEME
COASTAL AREA	30-40 $\mu\text{g}/\text{m}^3$	24-46 $\mu\text{g}/\text{m}^3$
CENTRAL-VALLEY AREA	35-50 <sup>a</sup> $\mu\text{g}/\text{m}^3$	27-49 $\mu\text{g}/\text{m}^3$
EASTERN-INLAND AREA	45-60 $\mu\text{g}/\text{m}^3$	35-57 $\mu\text{g}/\text{m}^3$

a: Interpolation of the Coastal and Eastern Inland Results.

To summarize, the total average background levels obtained by analyzing measured particulate levels in nonurban California locations agree quite well with the total average background levels obtained by estimating each individual background category. Total background levels in the Los Angeles Region appear to vary from around 30-40  $\mu\text{g}/\text{m}^3$  in the coastal area, to around 35-45  $\mu\text{g}/\text{m}^3$  in the central-valley area, to around 45-55  $\mu\text{g}/\text{m}^3$  in the eastern-inland area. An approximate origin breakdown for each area (according to the BACKGROUND AEROSOL CLASSIFICATION SCHEME), is as given in Table 2-9 below.

TABLE 2-9

COMPLETED BACKGROUND AEROSOL CLASSIFICATION SCHEME  
FOR THE LOS ANGELES REGION

SUB-AREA	APPROXIMATE ANNUAL AVER- AGE BACK- GROUND LEVEL	BACKGROUND CLASSIFICATION SCHEME ( $\mu\text{g}/\text{m}^3$ )					
		PRIMARY			SECONDARY		
		SEA SALT	SOIL DUST	MAN-MADE SOURCES EXTERIOR TO L.A. REGION	$\text{SO}_4^{=}$ 4	$\text{NO}_3^-$	SECONDARY ORGANICS
COASTAL	$\sim 35 \mu\text{g}/\text{m}^3$	8	16	3	4	1	3
CENTRAL-VALLEY	$\sim 40 \mu\text{g}/\text{m}^3$	6	23	3	4	1	3
EASTERN-INLAND	$\sim 50 \mu\text{g}/\text{m}^3$	4	35	3	4	1	3

### 2.3 AVERAGE COMPOSITION OF HI-VOL PARTICULATE SAMPLES

The previous section established estimates of average background aerosol concentrations in the Metropolitan Los Angeles Region. The remainder of measured suspended particulate levels originates from man-made sources within the Los Angeles Region. For the purpose of control strategy evaluation, it is necessary to classify this (non-background) remainder according to the following categories:

- Primary Aerosol -- man-made Los Angeles sources
- Secondary Aerosol -- man-made Los Angeles sources
  - Sulfates
  - Nitrates
  - Ammonium
  - Secondary Organics

In order to perform this latter classification, information is required on the chemical composition of the aerosol. This section develops compositional information for several locations in the Los Angeles Region. Section 2.3.1 assembles compositional data recorded by various monitoring programs in recent years. Section 2.3.2 combines this data with estimates of expected 1972 total suspended particulate levels (as determined in Support Document #1) to yield compositional breakdowns representative of the 1972 base year. The following section, 2.4, will use this compositional breakdown to characterize the origins of annual average aerosol concentrations at various locations in the Los Angeles Region.

#### 2.3.1 Aerosol Composition Data

For the purpose of the present study, annual average compositional data are required for lead (Pb), sulfate ( $\text{SO}_4^{--}$ ), nitrate ( $\text{NO}_3^-$ ), ammonium ( $\text{NH}_4^+$ ), and benzene solubles. The lead data will be used to estimate the contribution of primary, man-made sources. The other data

will provide a basis for estimating secondary aerosol levels. Three long term monitoring programs exist in the Los Angeles Region which measure most or all of these aerosol constituents: 1) the National Air Surveillance Network (NASN), 2) the Los Angeles County APCD Network, and 3) the San Bernardino County APCD Network. Table 2-10 summarizes the data which are available from each program. The availability of data for any particular monitoring site depends on the year since different stations were established in different years and since some NASN stations have not operated continuously.

TABLE 2-10. AVAILABILITY OF COMPOSITION DATA FROM LONG TERM MONITORING PROGRAMS

Monitoring Program	Years for which composition data are presently available	Pb	SO <sub>4</sub> <sup>=</sup>	NO <sub>3</sub> <sup>-</sup>	NH <sub>4</sub> <sup>+</sup>	Benzene Solubles
NASN	1957-1970	X	X	X	X	X
Los Angeles APCD	1965-1972	X	X	X		
San Bernardino APCD	1968-1972	X	X	X		X

As a supplement to the data which are available from these programs, compositional data will also be used from the following monitoring projects:

- Orange County APCD Monitoring Program
- California Air Resources Board Monitoring System, [5]
- University of Southern California Study, (Gordon & Bryan, [6])
- State Air Pollution Research Center Study, (Lundgren, [3])
- Air Resources Board/Rockwell International Aerosol Characterization Study, (ACHEX), (Hidy, [10])

The last three of these five programs have been only temporary in nature. Data from the last two programs, (Lundgren and ACHEX), include a very limited number of samples and emphasize the summer-fall photochemical smog season.

For the first two programs, (Orange APCD and California ARB), compositional data are available only for lead.

A review of the available data reveals that the existing information is sufficient to provide an adequate compositional breakdown of annual average particulate levels at twelve locations in the 4 County Sub-Areas of the Los Angeles Region. These locations and the corresponding data sources are listed in Table 2-11. Figure 2-2 illustrates the position of the twelve locations within the basin. Table 2-11 also lists other nearby locations for which data are available to supplement and check the compositional breakdowns. For the purpose of analysis in later sections of this report, the 12 locations have been distinguished as to four general areas: coastal area, central-valley area, eastern-inland area, and west San Bernardino County "Hot Spot", (see Support Document #1, [1].

Tables 2-12A through 2-12L present composition data for each of the twelve locations. Values are given for measured total suspended particulate, and composition breakdowns are listed in % for Pb,  $\text{SO}_4^{=}$ ,  $\text{NO}_3^-$ ,  $\text{NH}_4^+$ , and benzene solubles. The chemical analysis methods employed by the various APCD's and by NASN have been reviewed and briefly evaluated in Report #1, [1]. The analysis methods used for the ARB, Lundgren, ACHEX, and Gordon & Bryan data are discussed in references [5], [3], [0], and [6].

Considering the potential errors in sampling and analysis procedures, the compositional breakdowns from the various data sources appear to be very consistent. The agreement is most apparent in comparing NASN and APCD compositional data. Table 2-13 summarizes the average difference between APCD and NASN data for Pb,  $\text{SO}_4^{=}$ , and  $\text{NO}_3^-$ , (very little APCD data are available for  $\text{NH}_4^+$  and benzene solubles). The compositional data from other studies are

TABLE 2-11 LOCATIONS AND DATA SOURCES FOR AEROSOL COMPOSITION BREAKDOWN

LOCATION	PRINCIPAL DATA SOURCES	SUPPLEMENTARY DATA
COASTAL AREA SITES		
1. Lennox	• Los Angeles APCD	• Torrance: (NASN)
2. West Los Angeles	• Los Angeles APCD	
3. Long Beach	• NASN	• Northwest Long Beach: (Gordon and Bryan)
CENTRAL VALLEY AREA SITES		
4. Downtown Los Angeles	• Los Angeles APCD • NASN	• East and South of Downtown: (Gordon and Bryan)
5. Pasadena	• Los Angeles APCD • NASN • ACHEX	• Glendale: (NASN)
6. Anaheim	• Orange Co. APCD • NASN	
7. Reseda	• Los Angeles APCD	• Burbank: (NASN)
EASTERN INLAND AREA SITES		
8. Azusa	• Los Angeles APCD	
9. Ontario	• San Bernardino APCD • NASN	• Pomona: (ACHEX)
10. San Bernardino	• San Bernardino APCD • NASN	• Fontana: (San Bern. APCD) • Redlands: (San Bern. APCD)
11. Riverside	• NASN • State Air Poll. Res. Ctn. • ACHEX • California ARB	
WEST SAN BERNARDINO COUNTY AREA HOT-SPOT		
12. Chino	• San Bernardino APCD	• Rialto: (San Bern. APCD)

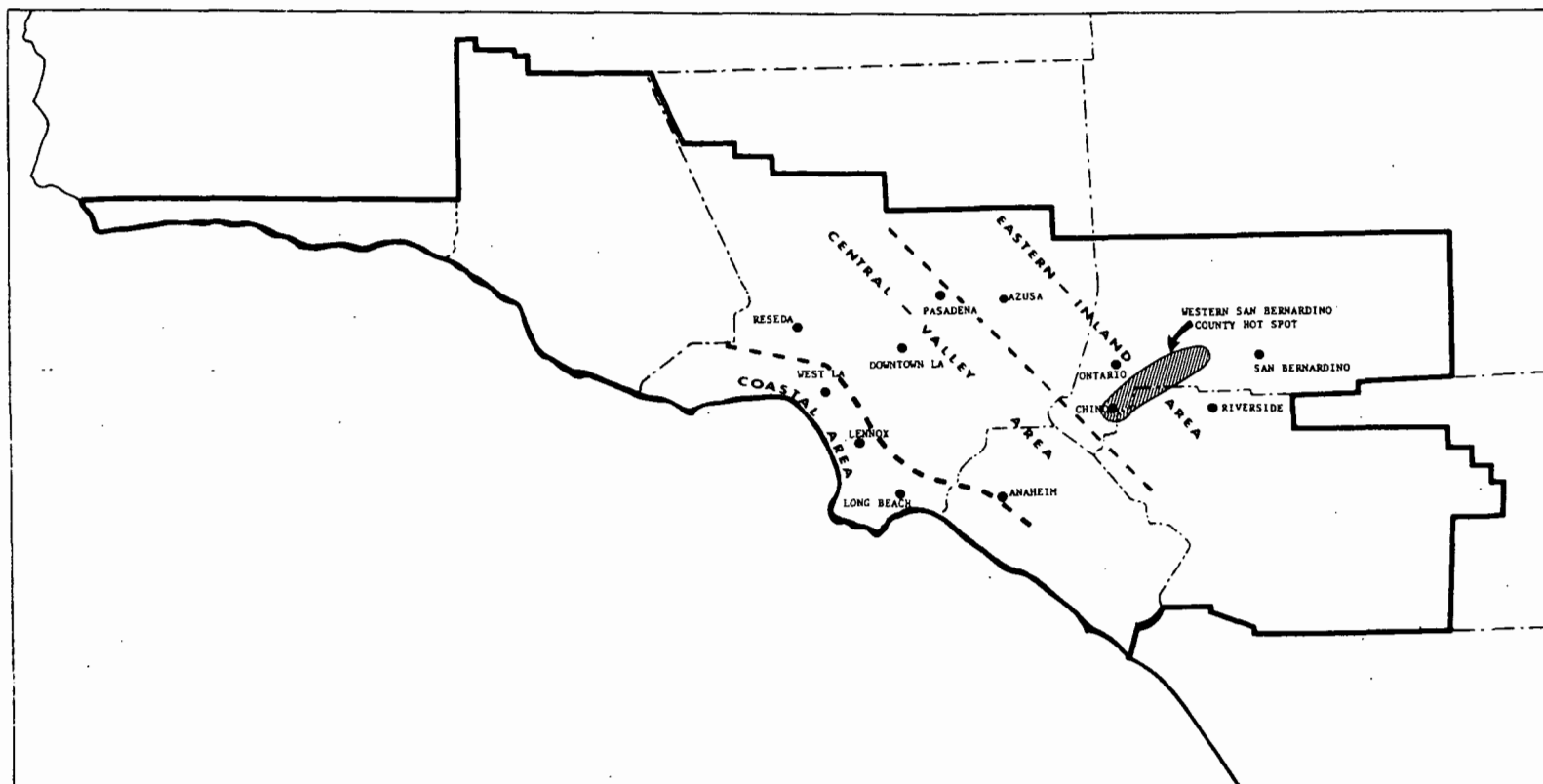


Figure 2-2 Locations For The Aerosol Origin Characterization



TABLE 2-12A DATA ON AVERAGE COMPOSITION OF HI-VOL PARTICULATE SAMPLES

LOCATION: 1. LENNOX

DATA SOURCE	STATION	DATES AND NUMBER OF SAMPLES	MEASURED LEVEL OF TOTAL SUSPENDED PARTICULATES ( $\mu\text{g}/\text{m}^3$ )		COMPOSITION OF ARITHMETIC MEAN				
			GEO. MEAN	ARITH. MEAN	P <sub>b</sub>	SO <sub>4</sub> <sup>=</sup>	NO <sub>3</sub> <sup>-</sup>	NH <sub>4</sub> <sup>+</sup>	CEMENT SOLUBLES
Los Angeles APCD	Lennox	1969-1972 ~350 samples	146	154	4.6%	9.1%	5.1%	---	-----
SUPPLEMENTARY DATA									
NASN	Torrance	1969-1971 ~ 72 samples	78	85	N/A	11.2%	8.2%	0.9%	N/A

TABLE 2-12B DATA ON AVERAGE COMPOSITION OF HI-VOL PARTICULATE SAMPLES

LOCATION: 2. WEST LOS ANGELES

DATA SOURCE	STATION	DATES AND NUMBER OF SAMPLES	MEASURED LEVEL OF TOTAL SUSPENDED PARTICULATES		COMPOSITION OF ARITHMETIC MEAN				
			GEO. MEAN	ARITH. MEAN	P <sub>b</sub>	SO <sub>4</sub> <sup>=</sup>	NO <sub>3</sub> <sup>-</sup>	NH <sub>4</sub> <sup>+</sup>	ZENZENE SOLVELES
Los Angeles APCD	West Los Angeles	1969-1972 ~230 samples	90	94	3.3%	10.3%	7.6%	-----	-----
SUPPLEMENTARY DATA									

TABLE 2-12C DATA ON AVERAGE COMPOSITION OF HI-VOL PARTICULATE SAMPLES

LOCATION: 3. LONG BEACH

DATA SOURCE	STATION	DATES AND NUMBER OF SAMPLES	MEASURED LEVEL OF TOTAL SUSPENDED PARTICULATES ( $\mu\text{G}/\text{M}^3$ )		COMPOSITION OF ARITHMETIC MEAN				
			GEO. MEAN	ARITH. MEAN	$\text{P}_b$	$\text{SO}_4^{=}$	$\text{NO}_3^-$	$\text{NH}_4^+$	BENZENE SOLUBLES
NASN	Long Beach	1967-1968 ~48 samples	116	132	2.2%	10.9%	4.3%	1.9%	9.7%
		1969-1970 ~48 samples	99	~110	N/A	10.5%	6.5%	0.8%	N/A
SUPPLEMENTARY DATA									
Gordon and Bryan	Northwest of Long Beach	6/71-6/72 ~182 days	-----	102	-----	-----	8.4%	2.2%	6.4%

TABLE 2-12D DATA ON AVERAGE COMPOSITION OF HI-VOL PARTICULATE SAMPLES

LOCATION: 4. DOWNTOWN LOS ANGELES

DATA SOURCE	STATION	DATES AND NUMBER OF SAMPLES	MEASURED LEVEL OF TOTAL SUSPENDED PARTICULATES ( $\mu\text{G}/\text{M}^3$ )		COMPOSITION OF ARITHMETIC MEAN				
			GEO. MEAN	ARITH. MEAN	P <sub>b</sub>	SO <sub>4</sub> <sup>=</sup>	NO <sub>3</sub> <sup>-</sup>	CO <sub>4</sub> <sup>+</sup>	BENZENE SOLUBLES
Los Angeles APCD	Downtown Los Angeles	1969-1972 ~350 samples	145	155	3.0%	10.0%	8.3%	---	---
NASN	Downtown Los Angeles	1967-1968 ~48 samples	110	119	2.8%	10.5%	5.7%	1.4%	10.9%
		1969-1970 ~48 samples	109	120	N/A	10.3%	8.0%	0.6%	N/A
SUPPLEMENTARY DATA									
Gordon and Bryan	East of Downtown Los Angeles	6/71 - 6/72 ~182 days	-----	215	-----	-----	7.2%	1.5%	9.0%
	South of Downtown Los Angeles	6/71 - 6/72 ~182 days	-----	131	-----	-----	14.4%	3.6%	8.8%

TABLE 2-12E DATA ON AVERAGE COMPOSITION OF HI-VOL PARTICULATE SAMPLES

LOCATION: 5. PASADENA

DATA SOURCE	STATION	DATES AND NUMBER OF SAMPLES	MEASURED LEVEL OF TOTAL SUSPENDED PARTICULATES ( $\mu\text{G}/\text{M}^3$ )		COMPOSITION OF ARITHMETIC MEAN				
			GEO. MEAN	ARITH. MEAN	P <sub>b</sub>	SO <sub>4</sub> <sup>-</sup>	NO <sub>3</sub> <sup>-</sup>	NH <sub>4</sub> <sup>+</sup>	BENZENE SOLUBLES
Los Angeles APCD	Pasadena	1972 ~70 samples	110	117	2.8%	10.5%	9.7%	---	----
NASN	Pasadena	1968 ~24 samples	106	113	3.2%	10.1%	6.5%	1.0%	10.7%
		1970 ~24 samples	100	~110	N/A	11.0%	9.7%	0.5%	N/A
ACHEX	Pasadena	11 selected dates, Spring & Fall 1972	---	74	1.9%	6.5%	----	----	-----
SUPPLEMENTARY DATA									
NASN	Glendale	1967-1968 ~48 samples	83	94	3.2%	12.2%	5.8%	1.7%	12.3%
		1969-1970 ~48 samples	81	~90	N/A	11.1%	7.3%	0.9%	N/A

TABLE 2-12F DATA ON AVERAGE COMPOSITION OF HI-VOL PARTICULATE SAMPLES

LOCATION: 6. ANAHEIM

DATA SOURCE	STATION	DATES AND NUMBER OF SAMPLES	MEASURED LEVEL OF TOTAL SUSPENDED PARTICULATES		COMPOSITION OF ARITHMETIC MEAN				
			GEO. MEAN ( $\mu\text{g}/\text{m}^3$ )	ARITH. MEAN	P <sub>b</sub>	SO <sub>4</sub> <sup>=</sup>	NO <sub>3</sub> <sup>-</sup>	NH <sub>4</sub> <sup>+</sup>	BENZENE SOLUBLES
NASN	Anaheim	1969-1970	104	~115	N/A	8.3%	6.2%	0.7%	N/A
Orange Co. APCD	Anaheim	1970-1973	96	~105	2.7%	----	----	----	-----
SUPPLEMENTARY DATA									

TABLE 2-12G DATA ON AVERAGE COMPOSITION OF HI-VOL PARTICULATE SAMPLES

LOCATION: 7. RESEDA

DATA SOURCE	STATION	DATES AND NUMBER OF SAMPLES	MEASURED LEVEL OF TOTAL SUSPENDED PARTICULATES ( $\mu\text{g}/\text{m}^3$ )		COMPOSITION OF ARITHMETIC MEAN				
			GEO. MEAN	ARITH. MEAN	P <sub>b</sub>	SO <sub>4</sub> <sup>=</sup>	NO <sub>3</sub> <sup>-</sup>	PM <sub>10</sub> <sup>+</sup>	BENZENE SOLUBLES
Los Angeles APCD	Reseda	1969-1972 ~230 samples	122	132	3.2%	9.6%	5.8%	----	----
SUPPLEMENTARY DATA									
NASN	Burbank	1968 ~24 samples	103	122	3.0%	9.0%	6.5%	1.1%	11.4%
		1969-1970 ~48 samples	106	~120	N/A	7.5%	5.4%	0.9%	N/A

TABLE 2-12H DATA ON AVERAGE COMPOSITION OF HI-VOL PARTICULATE SAMPLES

LOCATION: 8. AZUSA

DATA SOURCE	STATION	DATES AND NUMBER OF SAMPLES	MEASURED LEVEL OF TOTAL SUSPENDED PARTICULATES ( $\mu\text{G}/\text{M}^3$ )		COMPOSITION OF ARITHMETIC MEAN				
			GEO. MEAN	ARITH. MEAN	Pb	$\text{SO}_4^{=}$	$\text{NO}_3^{-}$	$\text{NH}_4^{+}$	BENZENE SOLUBLES
Los Angeles APCD	Azusa	1972 ~70 samples	150	166	1.9%	9.5%	11.1%	----	----
SUPPLEMENTARY DATA									



TABLE 2-12I DATA ON AVERAGE COMPOSITION OF HI-VOL PARTICULATE SAMPLES  
LOCATION: 9. ONTARIO

DATA SOURCE	STATION	DATES AND NUMBER OF SAMPLES	MEASURED LEVEL OF TOTAL SUSPENDED PARTICULATES ( $\mu\text{G}/\text{M}^3$ )		COMPOSITION OF ARITHMETIC MEAN				
			GEO. MEAN	ARITH. MEAN	Pb	$\text{SO}_4^{=}$	$\text{NO}_3^-$	$\text{NH}_4^+$	ZENZENE SOLUBLES
San Bern. APCD	Ontario	1970-1972 ~180 samples	109	120	1.7%	10.8%	9.2%	---	8.2%
NASN	Ontario	1968 ~24 samples	116	135	N/A	7.3%	8.7%	0.8%	5.5%
		1969-1970 ~48 samples	114	130	1.2%	7.8%	7.1%	0.8%	N/A
SUPPLEMENTARY DATA									
ACHEX	Pomona	5 selected dates in October 1972		126	1.7%	7.7%	14.2%	----	-----

TABLE 2-12J DATA ON AVERAGE COMPOSITION OF HI-VOL PARTICULATE SAMPLES

LOCATION: 10. SAN BERNARDINO

DATA SOURCE	STATION	DATES AND NUMBER OF SAMPLES	MEASURED LEVEL OF TOTAL SUSPENDED PARTICULATES ( $\mu\text{G}/\text{M}^3$ )		COMPOSITION OF ARITHMETIC MEAN				
			GEO. MEAN	ARITH. MEAN	Pb	$\text{SO}_4^{=}$	$\text{NO}_3^-$	$\text{NH}_4^+$	BENZENE SOLUBLES
San Bern. APCD	San Bernardino	1970-1972 ~180 samples	115	~125	1.8%	9.4%	10.6%	---	10.1%
NASN	San Bernardino	1968 ~24 samples	92	108	N/A	9.0%	8.4%	0.7%	6.3%
		1969-1970 ~48 samples	107	~120	1.1%	10.9%	11.0%	0.9%	N/A
SUPPLEMENTARY DATA									
San Bern. APCD	Fontana	1971-1972 ~120 samples	118	~130	1.1%	10.1%	9.4%	---	6.4%
	Redlands	1970-1972 ~180 samples	97	~105	2.2%	11.4%	11.7%	----	11.9%

TABLE 2-12K DATA ON AVERAGE COMPOSITION OF HI-VOL PARTICULATE SAMPLES

LOCATION: 11. RIVERSIDE

DATA SOURCE	STATION	DATES AND NUMBER OF SAMPLES	MEASURED LEVEL OF TOTAL SUSPENDED PARTICULATES ( $\mu\text{G}/\text{M}^3$ )		COMPOSITION OF ARITHMETIC MEAN				
			GEO. MEAN	ARITH. MEAN	Pb	$\text{SO}_4^{=}$	$\text{NO}_3^-$	$\text{NH}_4^+$	BENZENE SOLUBLES
NASN	Riverside	1968 ~24 samples	116	130	----	7.5%	9.9%	1.2%	7.3%
		1969-1970 ~48 samples	121	135	N/A	8.1%	7.8%	0.9%	N/A
Calif. ARB	Riv. Traylor	8/72 - 1/73	---	----	0.8% est.	----	----	----	----
	Riv. Magnolia	5/73 - 9/73	---	----	1.3% est.	----	----	----	----
Lundgren	Riverside	25 days, Aug. 1968	---	176	----	8.5%	14.1%	----	----
		10 day, Nov. 1968	---	82	0.7%	10.1%	14.2%	---	---
ACHEX	Riverside	12 samples, Spring & Fall 1972	---	128	1.2%	4.9%	----	----	----
SUPPLEMENTARY DATA									

TABLE 2-12L DATA ON AVERAGE COMPOSITION OF HI-VOL PARTICULATE SAMPLES

LOCATION: 12. CHINO

DATA SOURCE	STATION	DATES AND NUMBER OF SAMPLES	MEASURED LEVEL OF TOTAL SUSPENDED PARTICULATES ( $\mu\text{G}/\text{M}^3$ )		COMPOSITION OF ARITHMETIC MEAN				
			GEO. MEAN	ARITH. MEAN	PH	$\text{SO}_4^{=}$	$\text{NO}_3^-$	$\text{NH}_4^+$	BENZENE SOLUBLES
San Bern. APCD	Chino	1971-1972 ~120 samples	186	~200	0.9%	----	8.0%	----	4.8%
SUPPLEMENTARY DATA									
San Bern. APCD	Rialto	1971-1972 ~120 samples	150	~165	1.1%	10.3%	10.8%	----	6.6%

TABLE 2-13. DIFFERENCES BETWEEN APCD AND NASN COMPOSITION DATA .

Constituent	Average of Absolute Difference	Average Level	Relative Error
Pb	0.4 $\mu\text{g}/\text{m}^3$	$\sim 2.4 \mu\text{g}/\text{m}^3$	$\sim 17\%$
$\text{SO}_4^-$	1.0 $\mu\text{g}/\text{m}^3$	$\sim 10 \mu\text{g}/\text{m}^3$	$\sim 10\%$
$\text{NO}_3^-$	1.5 $\mu\text{g}/\text{m}^3$	$\sim 8 \mu\text{g}/\text{m}^3$	$\sim 19\%$

somewhat less consistent; in certain instances this may be due to the small numbers of samples which were taken and/or to sampling during one type of season only.

#### 2.3.2 Characterization of 1972 Base Year Composition

Since this study will use 1972 as a base year in formulating a particulate implementation plan, a characterization of total suspended particulate levels and of particulate origins is required specific to that year. As an input to the determination of particulate origins, the compositional breakdown must therefore be found explicitly for 1972. This section combines the compositional data of the previous section with the characteristic 1972 total suspended particulate levels as determined in Support Document #1 [1], to yield the 1972 compositional breakdown.

The compositional data of the previous section involves measurements taken over several years\*; an implicit assumption in the derivation of 1972 values is that major changes in ambient aerosol composition did not

\*The compositional data in Table 2-12 are for the years 1967 to 1973. However, the great majority of measurements which are used are for the shorter time span of 1969 to 1972.

occur during those years. This assumption appears to be justified by the trends in compositional data. The error in this approximation appears to be less significant than the errors involved in the chemical analysis measurements and in the characterization of total suspended particulate levels.

Table 2-14 presents compositional breakdowns for the 1972 base year. Values are given for Pb,  $\text{SO}_4^{=}$ ,  $\text{NO}_3^-$ ,  $\text{NH}_4^+$ , and benzene solubles at the twelve locations which were examined in the previous section. The characteristic annual geometric means and annual arithmetic means for each station, (rounded to the nearest  $5 \mu\text{g}/\text{m}^3$ ), have been taken from Support Document #1, [1]. The constituent breakdown in Table 2-14 has been determined by using the % composition data which was given in the previous section. When only one source of compositional measurements was available for a particular site, those values were translated directly to Table 2-14. When more than one data source was available, an aggregate value was used with weightings according to the number of samples taken by each data source. For sites with abundant APCD and NASN data, other data sources were often excluded due to the low number of samples and to the seasonal biases in some of these other monitoring programs.

TABLE 2-14 HI-VOL PARTICULATE COMPOSITION:  
BREAKDOWN SPECIFIC TO THE 1972 BASE YEAR

Location	Total Suspended Particulates $\mu\text{g}/\text{m}^3$		Pb	$\text{SO}_4^{2-}$	$\text{NO}_3^-$	$\text{NH}_4^+$	Benzene Solubles
	AGM	AAM					
Coastal Area Sites							
1. Lennox	135	145	6.7 (4.6%)	13.2 (9.1%)	7.4 (5.1%)	N/A	N/A
2. West LA	85	90	3.0 (3.3%)	9.3 (10.3%)	6.8 (7.6%)	N/A	N/A
3. Long Beach	95	105	2.3 (2.2%)	11.2 (10.7%)	5.6 (5.3%)	1.5 (1.4%)	10.2 (9.7%)
Central Valley Sites							
4. Downtown LA	130	140	4.1 (2.9%)	14.3 (10.2%)	11.6 (8.3%)	1.4 (1.0%)	14.0 (10.0%)
5. Pasadena	110	120	3.6 (3.0%)	12.7 (10.5%)	11.4 (9.5%)	1.2 (1.0%)	13.8 (11.5%)
6. Anaheim	95	105	2.8 (2.7%)	8.7 (8.3%)	6.5 (6.2%)	0.8 (0.8%)	--
7. Reseda	130	140	4.3 (3.1%)	12.9 (9.2%)	8.4 (6.0%)	1.4 (1.0%)	16.0 (11.4%)
Eastern Inland Area Sites							
8. Azusa	150	160	3.0 (1.9%)	15.2 (9.5%)	17.7 (11.1%)	---	---
9. Ontario	110	120	1.9 (1.6%)	10.2 (9.5%)	10.8 (9.0%)	1.0 (0.8%)	9.4 (7.8%)
10. San Bernardino	115	125	2.0 (1.6%)	12.6 (10.1%)	13.1 (10.5%)	1.0 (.8%)	11.3 (9.0%)
11. Riverside	140	150	1.8 (1.2%)	11.7 (7.8%)	15.1 (10.1%)	1.5 (1.0%)	11.0 (7.3%)
Western San Bernardino County Hot Spot							
12. Chino	200	220	2.2 (1.0%)	22.0 (10.0%)	17.6 (8.0%)	----	12.1 (5.5%)

( ) Indicates Percentage of Total AAM

## 2.4 CHARACTERIZATION OF PARTICULATE ORIGINS FOR THE LOS ANGELES REGION

This section characterizes the origins of annual average Hi-Vol particulate levels in the Metropolitan Los Angeles Region. The characterization is derived from calculations involving previously presented data on background particulate concentrations (Section 2.2) and on total particulate chemical composition (Section 2.3). The aerosol origins at twelve locations are categorized according to the following classification scheme:

### I. Background Contributions

#### A. Primary

Sea Salt \_\_\_\_\_  
Soil Dust \_\_\_\_\_  
Primary Anthropogenic  
Sources Exterior to  
the Los Angeles  
Region \_\_\_\_\_

#### B. Secondary

Sulfate \_\_\_\_\_  
Nitrate \_\_\_\_\_  
Secondary  
Organics \_\_\_\_\_

### II. Non-Background Contributions (Anthropogenic Sources within the Los Angeles Region)

#### A. Primary

Total Primary \_\_\_\_\_

#### B. Secondary

Sulfate \_\_\_\_\_  
Nitrate \_\_\_\_\_  
Ammonium \_\_\_\_\_  
Secondary  
Organics \_\_\_\_\_



Section 2.4.1 describes an initial attempt to calculate the contribution associated with each category in the above list of particulate origins. The total particulate levels accounted for by this "first iteration" are then compared to total measured particulate levels. Section 2.4.2 discusses the discrepancies which remain and makes adjustments so that measured particulate levels are fully accounted for at each location by the origin classification. Section 2.4.3 discusses spatial features of the origin characterization.

#### 2.4.1 Origin Classification - A First Iteration

Section 2.2 presented estimates of annual average background aerosol contributions at coastal, central-valley, and eastern-inland areas of the Los Angeles Region. Table 2-9 summarized the origins of the background aerosol. Here, calculations are performed with the background estimates and with the aerosol composition data of Section 2.3 to yield approximate annual means for non-background aerosol contributions. These non-background contributions are classified according to primary and secondary origins, with the latter disaggregated as to sulfate, nitrate, ammonium, and secondary organics. Calculations are performed for each of the twelve locations which were examined in Section 2.3.

The following discussion summarizes the methods and assumptions involved in computing the non-background aerosol contributions. The methodology is described separately for primary particulates and for each type of secondary particulate:

##### Non-Background Primary Contribution

As a first approximation, the contribution of primary anthropogenic sources within the Los Angeles Region will be computed using lead (Pb) as a tracer for primary particulate emissions. The total primary contribution at each site will be estimated by factoring the Pb concentration

at that site by the ratio of total regional suspended particulate emissions to total regional suspended Pb emissions.

Ambient lead concentrations result almost exclusively from exhaust emissions from gasoline powered vehicles, [13]. The principal approximation in the proposed method for computing total, man-made, primary contributions is that each site is affected by gasoline powered vehicles and by other primary sources in the same ratio. Of course, this approximation can be grossly in error for certain cases; primary particulate levels at some sites may be dominated by automobiles, while primary contributions at other sites may be more reflective of other sources such as power plants or industry. In Section 2.4.2, corrections will be made for certain sites where the approximation appears to be inappropriate.

The explicit formula for estimating non-background, primary contributions is developed below:

$$\left[ \frac{\text{Suspended Particulate Emissions from Gasoline Powered Vehicles}}{\text{Suspended Particulate Emissions from all Primary Sources}} \right] = .30^*$$

$$\left[ \frac{\text{Suspended Pb Emissions from Gasoline Powered Vehicles}}{\text{Suspended Particulate Emissions from Gasoline Powered Vehicles}} \right] = .26^{**}$$

Thus,

$$\frac{\text{Suspended Pb Emissions}}{\text{Suspended Total Primary Emissions}} = .26 \times .30 = .078$$

And,

$\begin{aligned} \text{Total, Non-Background Primary Contribution} &= \frac{1}{.078} \times [\text{Measured Suspended Pb}] \\ &= 12.8 \times [\text{Measured Suspended Pb}]. \end{aligned}$	(2-1)
---	-------

\* See Support Document #2, 1972 Base Year Inventory, [18]. This value is for the 4 County Sub-Area of the Los Angeles Region. Each of the twelve stations to be examined is located in the sub-area.

\*\* See Support Document #2, [18]. This ratio is based on data only from light duty motor vehicles.

### Non-Background Sulfate Contribution

The non-background sulfate contribution can be determined for each location by simply subtracting the background sulfate level from the total measured sulfate concentration. In Section 2.2, the background  $\text{SO}_4$  was estimated to be around  $4 \mu\text{g}/\text{m}^3$ . Thus,

$$[\text{Non-Background Sulfate}] = \text{Annual Mean Sulfate} - 4 \mu\text{g}/\text{m}^3 \quad (2-2)$$

### Non-Background Nitrate Contribution

The computation for non-background nitrate is entirely analogous to the sulfate case above. Background nitrate was estimated at around  $1 \mu\text{g}/\text{m}^3$  in Section 2.2. Thus,

$$[\text{Non-Background Nitrate}] = \text{Annual Mean Nitrate} - 1 \mu\text{g}/\text{m}^3 \quad (2-3)$$

### Non-Background Ammonium

Background levels of ammonium are not well documented. Mean values of around  $.1 \mu\text{g}/\text{m}^3$  and  $.6 \mu\text{g}/\text{m}^3$  have been measured at two remote sites in the California coastal region, [8], [1]. Here it will be arbitrarily assumed that the ammonium associated with the background aerosol is  $.3 \mu\text{g}/\text{m}^3$ . This background level, when compared to the average total ammonium measured in the Los Angeles Region, is in the same ratio as background sulfate plus nitrate to total measured sulfate plus nitrate. The overall results of this study will be very insensitive to this assumption since ammonium ion represents only a small fraction of total suspended particulate levels, (on the order of 1%).

Thus,

$$[\text{Non-Background Ammonium}] = \text{Annual Mean Ammonium} - .3 \mu\text{g}/\text{m}^3 \quad (2-4)$$

### Non-Background Secondary Organics

The estimation of non-background secondary organics will be the most complex and uncertain of the aerosol origin calculations. The principal aerometric measurement used will be data for "benzene solubles", BSOL. Total BSOL can be expressed as follows:

$$\text{BSOL} = \text{BSOL}_{\text{bkgd.}} + S_{\text{prm}} \bullet \text{PRM} + S_{\text{sec}} \bullet \text{SEC}$$

where

$\text{BSOL}_{\text{bkgd}}$  = background benzene soluble organics,

PRM = primary non-background organics,

$S_{\text{prm}}$  = solubility of PRM in benzene,  
 SEC = secondary non-background organics,  
 and  
 $S_{\text{sec}}$  = solubility of SEC in benzene.

Secondary, non-background organics thus can be found according to the following formula:

$$\text{SEC} = \frac{1}{S_{\text{sec}}} \cdot [\text{BSOL} - \text{BSOL}_{\text{bkgd}} - S_{\text{prm}} \cdot \text{PRM}] \quad (2-5)$$

The data for the parameters within the bracket of equation (2-5) are as follows:

BSOL: given for 8 locations in Table 2-14

$\text{BSOL}_{\text{bkgd}}$ :  $3 \mu\text{g}/\text{m}^3$ , as estimated in Section 2.2

$S_{\text{PRM}}$ : approximately .80, (+.10), references [17] and [19]

PRM: approximately 2-1/2 to 3 times the measured Pb level at each location.\* A value of 2.8 will be used below.

The one critical parameter that is very uncertain is  $S_{\text{sec}}$ , the solubility of secondary organics in benzene. It is generally agreed that the secondary organic aerosol, which contains highly oxidized materials such as carboxylic acids, is of very low solubility in benzene, [17], [19]. However, little is known quantitatively.

Table 2-15 examines the sensitivity of calculated secondary organic levels, as given by equation (2-5), to the assumption for  $S_{\text{sec}}$ . Estimates are derived for all eight stations with available BSOL data and for  $S_{\text{sec}}$  values of .10, .20, .30, and .50. Table 2-15 reveals that estimated secondary organic levels are highly sensitive to the uncertainties in  $S_{\text{sec}}$ . This is because calculated secondary organics are proportional to  $1/S_{\text{sec}}$ , and  $S_{\text{sec}}$  is a small, highly uncertain number.

\*Suspended organic emissions from gasoline powered vehicles are approximately 2 to 2-1/4 times suspended lead emissions from those vehicles, [20], [21]. There are essentially no other significant sources of Pb particulate. However, other small sources of organic particulate exist, e.g., some industrial sources and a small fraction of diesel and aircraft emissions. The suspended organic to suspended lead ratio is thus estimated to be around 2-1/2 to 3.

TABLE 2-15 CALCULATED SECONDARY ORGANIC  
AEROSOL LEVELS FOR VARIOUS VALUES OF  $S_{sec}$

LOCATION		SECONDARY ORGANIC AEROSOL ( $\mu\text{g}/\text{m}^3$ )			
		$S_{sec} = .10$	$S_{sec} = .20$	$S_{sec} = .30$	$S_{sec} = .50$
Coastal Area	Long Beach	20.5	10.3	6.8	4.1
Central Area	Downtown LA	18.2	9.1	6.1	3.6
	Pasadena	27.4	13.7	9.1	5.5
	Reseda	33.7	16.9	11.2	6.7
Eastern Inland Area	Ontario	21.4	10.7	7.1	4.3
	San Bernardino	38.2	19.1	12.7	7.6
	Riverside	39.7	19.9	13.2	8.0
	Chino	29.4	14.7	9.8	5.9

There is another difficulty with this method for calculating secondary organics, as evidenced by Table 2-15. The relative values for different stations do not follow the expected pattern. One would expect that secondary organic aerosol levels, the result of photochemical reactions, would demonstrate a marked increase with distance inland; other photochemical smog indications, such as oxidant and particulate nitrate, demonstrate this tendency. It appears that the uncertainties in the other data, (e.g., BSOL,  $S_{prm}$ , and PRM), are also significant and preclude the use of equation (2-5) as a general method for calculating secondary organic levels.

With the above method being not applicable, there appears to be no way of systematically estimating secondary organic aerosol levels at the various locations in the Los Angeles Region. Data have been gathered on organic aerosol concentrations by the California ARB, [22], and by the ACHEX Study, [10], but these data are only for a very limited number of days in the photochemical smog season. However, these data do support a very important qualitative conclusion: secondary organic aerosol levels on photochemical smog type days tend to be

higher than nitrate aerosol levels, (possibly by a factor of 2 or more), [19].

In the absence of reliable, systematic indications of average secondary organic levels, the first iteration assumption will be that coastal, central-valley, and eastern-inland areas experience average non-background secondary organic levels of 10, 20, and 30  $\mu\text{g}/\text{m}^3$  respectively. The general order of magnitude of these levels is in line with estimates in references [12], [13], and [14]. The increasing trend with distance inland is in close correspondence with the trend of non-background nitrate, (See Table 2-14). However, the assumption is still rather arbitrary, and the uncertainties involved should be kept in mind. For stations where it appears warranted, these assumed values will be adjusted in the next section, (2.4.2).

Thus, the first iteration assumptions for secondary organics is as follows:

AREA	NON-BACKGROUND SECONDARY ORGANICS
Coastal	10 $\mu\text{g}/\text{m}^3$
Central-Valley	20 $\mu\text{g}/\text{m}^3$
Eastern-Inland	30 $\mu\text{g}/\text{m}^3$

With the above methodologies for estimating non-background primary aerosol and non-background sulfate, nitrate, ammonium, and secondary organic aerosol, a first iteration can be made of the origin characterization. Table 2-16 presents the results of applying the methodologies to each of the twelve locations listed in Table 2-14. Calculated values have been rounded to the nearest 1  $\mu\text{g}/\text{m}^3$ . Background estimates for each area have been taken from Section 2.2.

The last two columns of Table 2-16 compare the total suspended particulate level at each site to the amount accounted for by the origin classification. For all sections except Long Beach, Riverside, and Chino, the relative difference between the actual total suspended particulates and the total accounted for is less than 8%. The agreement is remarkable considering

TABLE 2-16 AEROSOL ORIGIN CHARACTERIZATION -- FIRST ITERATION

(ANNUAL ARITHMETIC MEAN --  $\mu\text{g}/\text{m}^3$ )

LOCATION	APPROXIMATE BACKGROUND AEROSOL  Natural Contribution, Suspended Dust, and Man-made Sources Exterior to the L.A. Region	NON-BACKGROUND CONTRIBUTIONS (Anthropogenic, excluding suspended dust and sources exterior to the Los Angeles Region)					ACCOUNTED FOR ANNUAL MEAN	TOTAL 1972 ANNUAL MEAN	RELATIVE DIFFERENCE
		PRIMARY	SO <sub>4</sub>	NO <sub>3</sub>	NH <sub>4</sub> <sup>+</sup>	SECONDARY ORGANICS			
COASTAL AREA									
1. Lennox	35	86	9	6	1	10	147	145	+1%
2. West Los Angeles	35	38	5	6	1	10	95	90	+6%
3. Long Beach	35	29	7	5	1	10	87	105	-17%
CENTRAL-VALLEY AREA									
4. Downtown Los Angeles	40	52	10	11	1	20	134	140	-4%
5. Pasadena	40	46	9	10	1	20	126	120	+5%
6. Anaheim	40	36	5	6	1	20	108	105	+3%
7. Reseda	40	55	9	7	1	20	132	140	-6%
EASTERN-INLAND AREA									
8. Azusa	50	38	11	17	1	30	147	160	-8%
9. Ontario	50	24	6	10	1	30	121	120	+1%
10. San Bernardino	50	26	9	12	1	30	128	125	+2%
11. Riverside	50	23	8	14	1	30	126	150	-17%
WESTERN SAN BERNARDINO COUNTY HOT-SPOT									
12. Chino	50	28	18	17	1	30	144	220	- 35%

the simplicity of many of the assumptions inherent in the origin classification. In the next section, the discrepancies between actual TSP and the amount accounted for by the origin classification will be discussed, and further analysis will be performed to yield an approximate but complete origin classification for each site.

#### 2.4.2 Origin Classification -- Completion of the Characterization

In order to perform a systematic evaluation of the effect of control strategies on suspended particulate levels, the total particulate level at each site should be fully accounted for by the origin classification scheme. This section analyses the discrepancies in Table 2-16, and adjusts the values for various origin classes so that the total particulate level at each site is fully accounted for. The adjustments are made in the most uncertain origin classifications: the non-background secondary organic, non-background primary, and background categories. Values for sulfate, nitrate, and ammonium represent direct measurement and are not adjusted.

The following paragraphs discuss the rationale behind the adjustments which are made for each location. Large changes are made with distinct reason; but some small changes are rather arbitrary. The only locations which require very significant alterations are Long Beach, Riverside, and Chino.

##### 1. Lennox

The origin characterization for Lennox agrees almost exactly with the total suspended particulate level, (level accounted for =  $147 \mu\text{g}/\text{m}^3$ , total level =  $145 \mu\text{g}/\text{m}^3$ ). To achieve exact agreement,  $2 \mu\text{g}/\text{m}^3$  are subtracted from the non-background primary category. At Lennox, this category is far and away the largest of the origin classes, and  $2 \mu\text{g}/\text{m}^3$  represents only a very minor relative change.

##### 2. West Los Angeles

The level accounted for at West Los Angeles is  $95 \mu\text{g}/\text{m}^3$ , while the total particulate level is  $90 \mu\text{g}/\text{m}^3$ . To achieve exact correspondence,



$2 \mu\text{g}/\text{m}^3$  are subtracted from the non-background primary and background categories, and  $1 \mu\text{g}/\text{m}^3$  is subtracted from the secondary organic category. These adjustments have been chosen to minimize the relative changes among the origin categories.

### 3. Long Beach

At Long Beach, major disagreement exists between accounted for and total particulate levels, ( $87$  and  $105 \mu\text{g}/\text{m}^3$  respectively). Compared to other coastal areas, the non-background primary category appears to be unusually low for Long Beach, a heavily industrialized area. The Pb measurements which have been used as a tracer for the non-background primary category may be in error. Stationary sources may be disproportionately important in Long Beach so that Pb is not an adequate indicator of primary particulate levels there. To achieve exact correspondence in the origin classification, the discrepancy ( $18 \mu\text{g}/\text{m}^3$ ) is made up for in the non-background primary category.

### 4. Downtown Los Angeles

The accounted for level at Downtown L.A. ( $134 \mu\text{g}/\text{m}^3$ ) agrees fairly well with the total particulate level ( $140 \mu\text{g}/\text{m}^3$ ). To achieve exact correspondence,  $4 \mu\text{g}/\text{m}^3$  are added to the background category and  $2 \mu\text{g}/\text{m}^3$  are added to the non-background primary category. The background category is given an extra increase because of the possibility of higher suspended dust levels existing in the city due to intense traffic and other activities. The secondary organic category is kept fixed since it would not be expected that Downtown Los Angeles would have higher photochemical organics than other central-valley locations such as Pasadena or Reseda.

### 5. Pasadena

The accounted for value at Pasadena ( $126 \mu\text{g}/\text{m}^3$ ) is slightly above the total particulate level ( $120 \mu\text{g}/\text{m}^3$ ). To achieve agreement,  $2 \mu\text{g}/\text{m}^3$  are subtracted from the background category and  $4 \mu\text{g}/\text{m}^3$  are subtracted from the non-background primary category. The non-background primary category is given the largest decrease since the method of estimation for that category (using Pb as an indicator) may lead to an over-estimate due to automobiles being an unusually important source in Pasadena. The secondary organic category is held fixed since it

would not be expected that Pasadena has lower photochemical organics than other central-valley sites.

#### 6. Anaheim

The disagreement at Anaheim is  $3 \mu\text{g}/\text{m}^3$ , (level accounted for =  $108 \mu\text{g}/\text{m}^3$ , total level =  $105 \mu\text{g}/\text{m}^3$ ). Exact correspondence is attained by subtracting  $3 \mu\text{g}/\text{m}^3$  from the secondary organic category. A recent air monitoring study appears to show that Anaheim has low secondary organic levels for a central-valley site, [9]. This conclusion also seems to be supported by the low nitrate level at Anaheim.

#### 7. Reseda

The accounted for value at Reseda is  $132 \mu\text{g}/\text{m}^3$  while the total particulate level is  $140 \mu\text{g}/\text{m}^3$ . There does not appear to be a strong case for making the  $8 \mu\text{g}/\text{m}^3$  adjustment in any particular origin class. To minimize relative changes among the origin categories,  $2 \mu\text{g}/\text{m}^3$  are added to the secondary organic category and  $3 \mu\text{g}/\text{m}^3$  are added to the background and non-background primary categories.

#### 8. Azusa

The discrepancy at Azusa is  $13 \mu\text{g}/\text{m}^3$ , (level accounted for  $147 \mu\text{g}/\text{m}^3$ , total level =  $160 \mu\text{g}/\text{m}^3$ ). To attain exact agreement,  $7 \mu\text{g}/\text{m}^3$  are added to the secondary organic category and  $3 \mu\text{g}/\text{m}^3$  are added to the non-background primary and background categories. The secondary organic category is given an extra increase because Azusa experiences particularly intense photochemical smog; this is evidenced by very high oxidant and nitrate levels, [23]. The division of the rest of the increase among the non-background primary and background categories is arbitrary.

#### 9. Ontario

The origin characterization at Ontario agrees almost exactly with the total suspended particulate level, (level accounted for =  $121 \mu\text{g}/\text{m}^3$ , total level =  $120 \mu\text{g}/\text{m}^3$ ). To achieve exact correspondence,  $1 \mu\text{g}/\text{m}^3$  is subtracted from the background category. This adjustment has been chosen to minimize the relative change among the origin categories.

#### 10. San Bernardino

The accounted for level at San Bernardino ( $128 \mu\text{g}/\text{m}^3$ ) is close to the total level ( $125 \mu\text{g}/\text{m}^3$ ). Exact correspondence is attained by subtracting  $1 \mu\text{g}/\text{m}^3$  from the secondary organic category and  $2 \mu\text{g}/\text{m}^3$  from the background category. These alternations minimize the relative changes among the origin classes.

#### 11. Riverside

The accounted for level at Riverside ( $126 \mu\text{g}/\text{m}^3$ ) is significantly lower than the total suspended particulate level ( $150 \mu\text{g}/\text{m}^3$ ). To attain exact correspondence,  $7 \mu\text{g}/\text{m}^3$ ,  $10 \mu\text{g}/\text{m}^3$ , and  $7 \mu\text{g}/\text{m}^3$  are added to the secondary organic, background, and non-background primary categories respectively. The greatest increase is given to the background category since suspended dust levels in Riverside may be abnormally high due to agricultural activity in that part of the region. Secondary organics may be high at Riverside since the area experiences high photochemical smog levels (e.g., nitrate data). The non-background primary category may be higher than estimated due to influences from a large industrial/utility complex (see Chino discussion below).

#### 12. Chino

At Chino, the accounted for level ( $144 \mu\text{g}/\text{m}^3$ ) is far below the total suspended particulate level ( $220 \mu\text{g}/\text{m}^3$ ). This is actually expected because the "Pb tracer method" used to calculate non-background primary emissions is not appropriate for Chino. The Chino station is strongly influenced by a local industrial utility complex,\* [24], and the Pb tracer method does not adequately reflect this important source. Another reason for the discrepancy at Chino is the possibility of especially large background levels. Suspended dust levels may be atypically high due to agricultural activity in that part of the region. To achieve exact correspondence between accounted for levels and total suspended particulates, the non-background primary category is increased by  $61 \mu\text{g}/\text{m}^3$ , the background category is increased by  $10 \mu\text{g}/\text{m}^3$ , and the secondary organic category is increased by  $5 \mu\text{g}/\text{m}^3$ .

\* The impact of this major point source can be seen in the high sulfate reading at Chino. Chino also demonstrates particularly high iron levels.

With the addition of the above alterations, the expected 1972 annual mean H-Vol levels at each location are totally accounted for by the origin classification scheme. Table 2-17 summarizes the complete origin characterization. The background values in Table 2-17 are taken from Section 2-2, with modifications according to the above discussion. The non-background values are as derived in Section 2.4.1, again with modifications as discussed above. Although an attempt has been made to derive the best origin characterization that is possible with existing data, there is still considerable uncertainty in many of the values given in Table 2-17. The determination of the origin breakdown has involved several simplistic approximations. It is difficult to perform a quantitative error analysis of these approximations; however, a subjective indication of the errors involved may be useful in interpreting the results. The most uncertain category appears to be the non-background secondary organic category. Very little data were available to support firm conclusions concerning secondary organics. Subjectively, the error in this category may be as high as 20-40%. The other categories, (total background, non-background primary, sulfate, nitrate, and ammonium), are better documented. The error in these categories should be on the order of 10 to 20%.

#### 2.4.3 Spatial Features of the Origin Characterization

Table 2-18 summarizes the general spatial pattern of the aerosol origin characterization given in Table 2-17. Table 2-18 indicates a slight increasing trend of total particulate levels with distance inland. This increase is due to higher secondary aerosol levels and

TABLE 2-17 ORIGIN CHARACTERIZATION FOR ANNUAL MEAN HI-VOL PARTICULATE LEVELS  
( $\mu\text{g}/\text{m}^3$ )

LOCATION	BACKGROUND CONTRIBUTIONS						TOTAL BACK- GROUND	NON-BACKGROUND CONTRIBUTIONS (Anthropogenic Sources within LA Region)					TOTAL AAM
	Sea Salt	Suspended Dust	PRIMARY	SECONDARY				PRIMARY	SECONDARY				
			Primary Man-made Sources Exterior to the L.A. Region	SO <sub>4</sub> <sup>-</sup>	NO <sub>3</sub> <sup>-</sup>	Secondary Organics			SO <sub>4</sub> <sup>-</sup>	NO <sub>3</sub> <sup>-</sup>	NH <sub>4</sub> <sup>+</sup>	Secondary Organics	
COASTAL AREA LOCATIONS													
1. Lennox	8	16	3	4	1	3	35	84	9	6	1	10	145
2. West Los Angeles	8	14	3	4	1	3	33	36	5	6	1	9	90
3. Long Beach	8	16	3	4	1	3	35	47	7	5	1	10	105
CENTRAL-VALLEY AREA LOCATIONS													
4. Downtown Los Angeles	6	27	3	4	1	3	44	54	10	11	1	20	140
5. Pasadena	6	21	3	4	1	3	38	42	9	10	1	20	120
6. Anaheim	6	23	3	4	1	3	40	36	5	6	1	17	105
7. Reseda	6	26	3	4	1	3	43	58	9	7	1	22	140
EASTERN-INLAND AREA LOCATIONS													
8. Azusa	4	38	3	4	1	3	53	41	11	17	1	37	160
9. Ontario	4	34	3	4	1	3	49	24	6	10	1	30	120
10. San Bernardino	4	33	3	4	1	3	48	26	9	12	1	29	125
11. Riverside	4	45	3	4	1	3	60	30	8	14	1	37	150
WESTERN SAN BERNARDINO COUNTY HOT SPOT													
12. Chino	4	45	3	4	1	3	60	89	18	17	1	35	220

TABLE 2-18 GENERAL SPATIAL PATTERNS IN THE AEROSOL ORIGIN CHARACTERIZATION

SUBAREA OF THE LOS ANGELES REGION	TOTAL SUSPENDED PARTICULATE LEVEL (AAM -- $\mu\text{g}/\text{m}^3$ )	APPROXIMATE CONTRIBUTIONS		
		BACKGROUND	NON-BACKGROUND	
			PRIMARY	SECONDARY
Coastal	90-145	30%	50%	20%
Central-Valley	105-140	35%	35%	30%
Eastern-Inland	120-160	40%	20%	40%

to greater background contributions. The higher secondary aerosol and background levels apparently more than compensate for a marked drop in man-made primary particulates with distance inland.

The spatial trends in the aerosol origin categories make sense in view of the meteorology and emission source distributions in the Los Angeles Region. The increasing trend of secondary aerosol levels with distance inland agrees with the distribution of photochemical smog in the Los Angeles Region. Photochemical smog, as measured by oxidant levels, demonstrates an increase in severity with distance inland in the Los Angeles Region, [15]. This increase is apparently due to the continuous production of secondary photochemical pollutants as the air mass moves inland under the typical daily sea breeze dominated meteorology. As shown in Figures 2-3 and 2-4, measured nitrate levels and estimated secondary organic levels show marked increases with distance inland. Sulfate levels, (Figure 2-5), are more uniformly distributed throughout the basin.

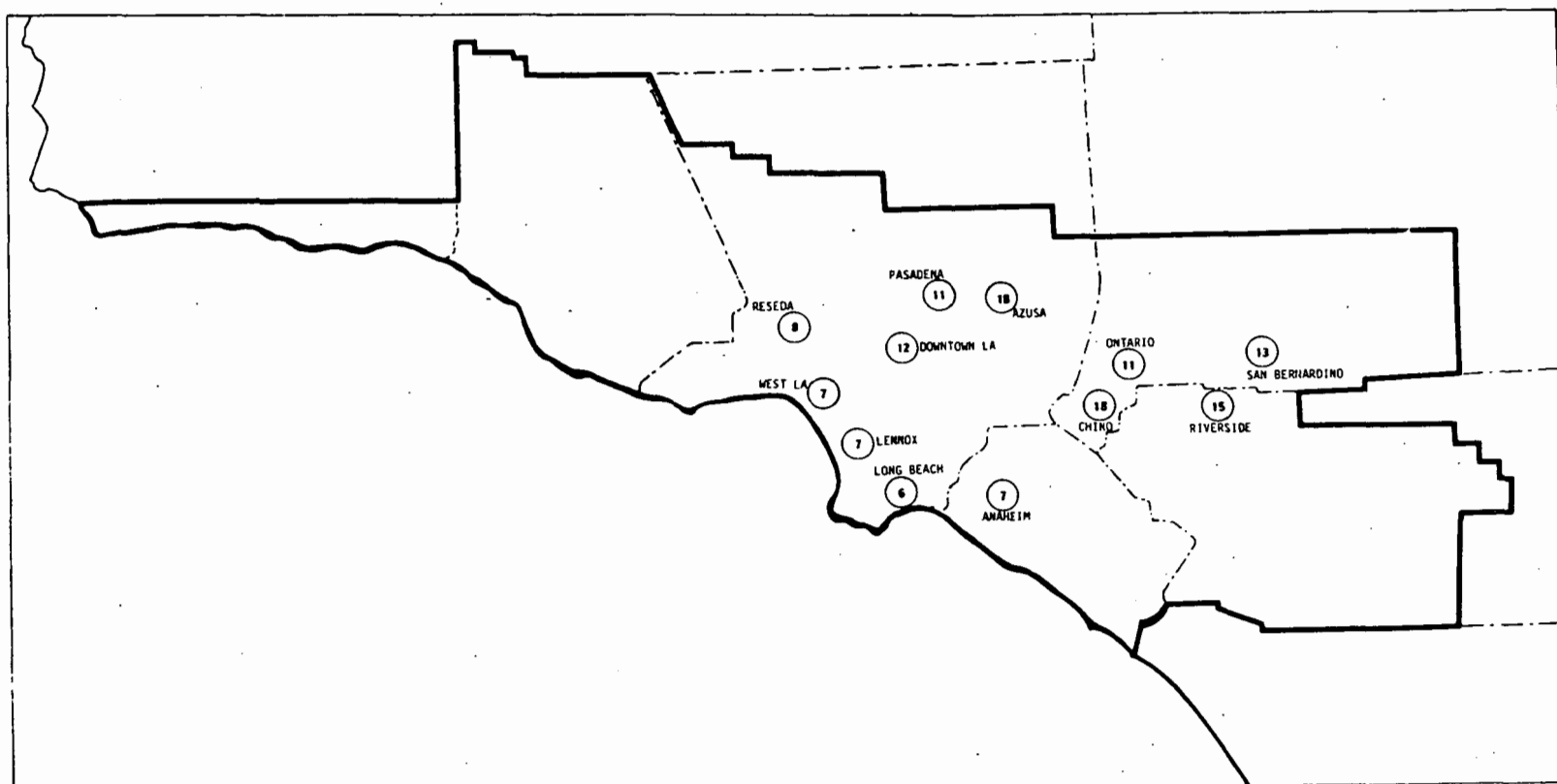


Figure 2-3 Total Nitrate Levels In The Los Angeles Region ( $\mu\text{g}/\text{m}^3$ )

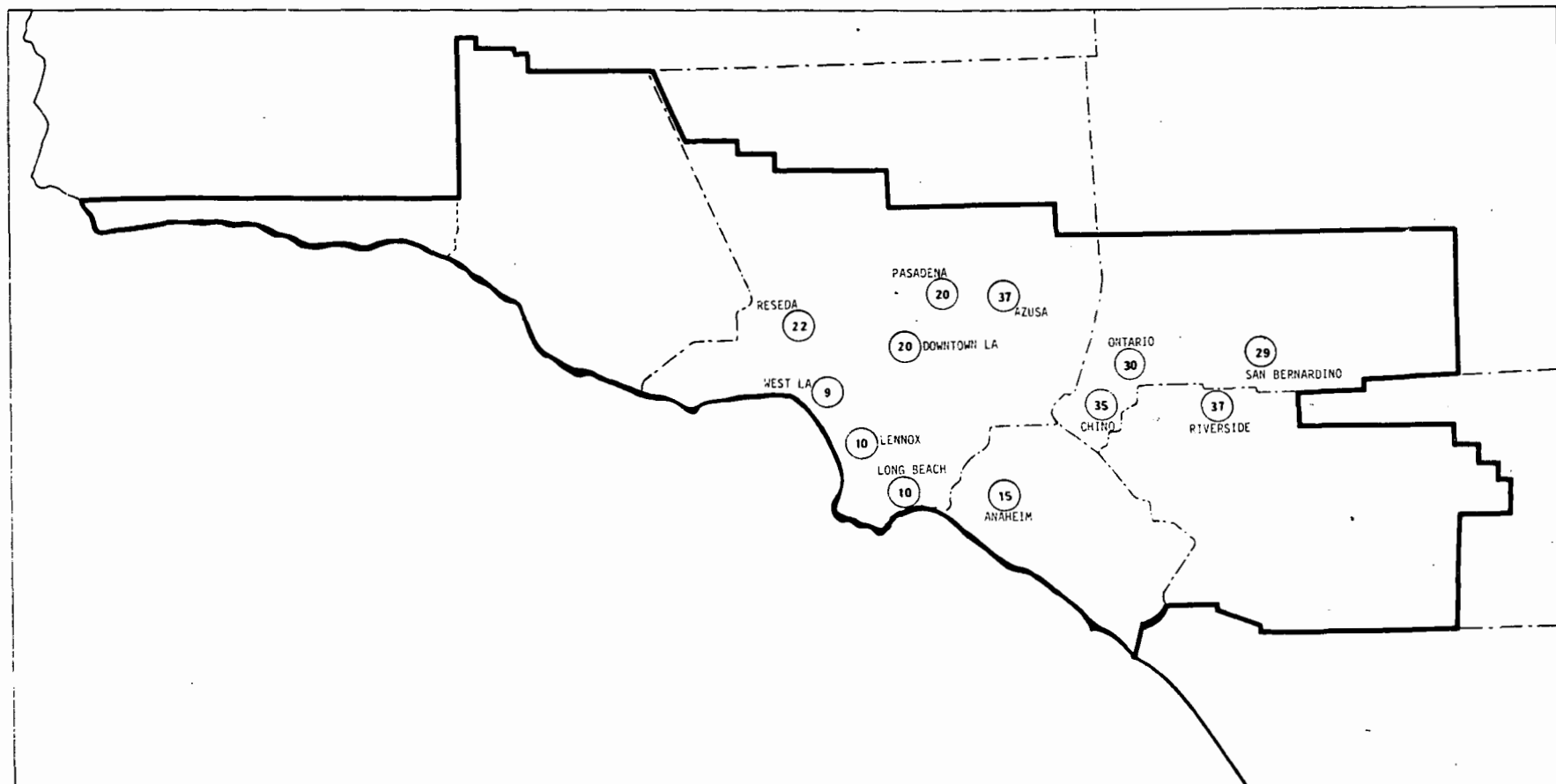


Figure 2-4 Estimated Non-Background Secondary Organic Levels in the Los Angeles Region ( $\mu\text{g}/\text{m}^3$ )



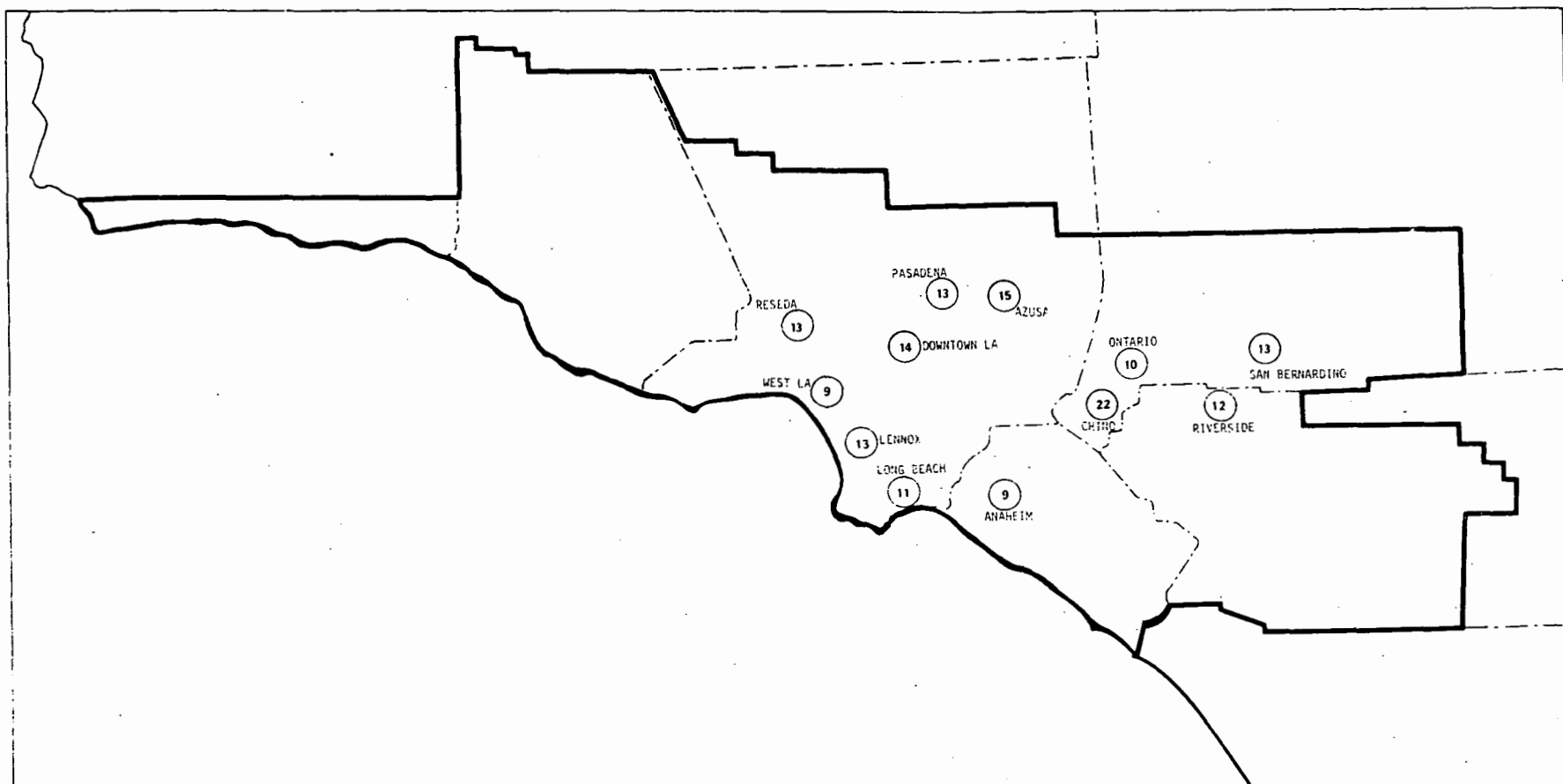


Figure 2-5 Total Sulfate Levels in The Los Angeles Region ( $\mu\text{g}/\text{m}^3$ )

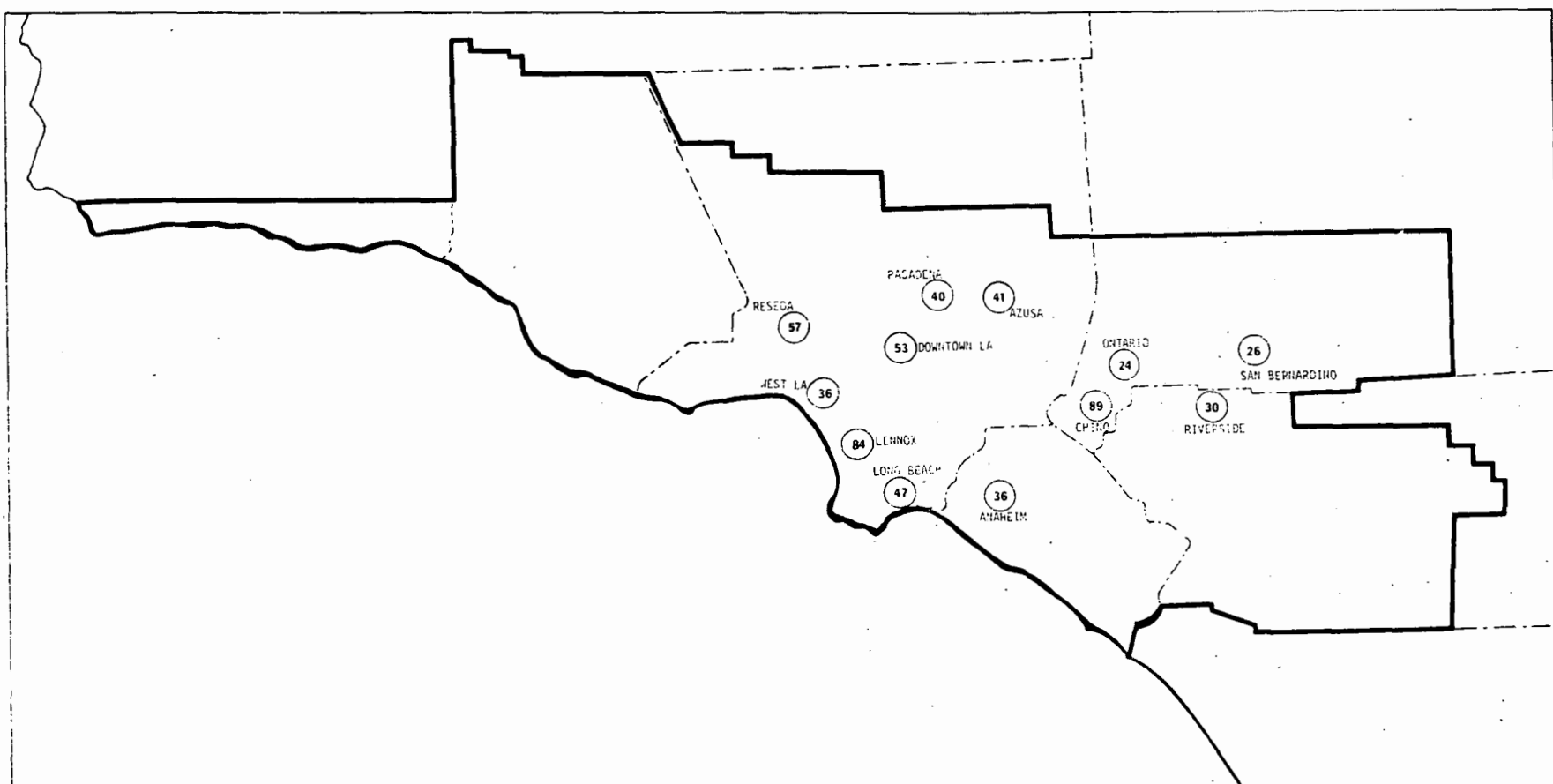


Figure 2-6 Estimated Non-Background Primary Particulate Levels In The Los Angeles Region ( $\mu\text{g}/\text{m}^3$ )

The decrease of man-made primary particulate contributions with distance inland, (Table 2-18 and Figure 2-6), is apparently due to a dilution effect. As shown later in Figure 3-1, primary particulate sources are more concentrated in the western and central areas. As the air mass moves inland under the typical sea breeze wind patterns, the contributions from these sources are evidently somewhat dispersed. Contributing to the lower primary particulate levels in inland areas is the increasing inversion height with distance inland.

As explained in Section 2.2, increases in suspended dust levels apparently account for greater background levels in the inland areas. The higher dust levels inland may be due to the concentration of agricultural activity in the eastern-inland area of the Los Angeles Region.

### 3.0 THE DEPENDENCE OF SUSPENDED PARTICULATE LEVELS ON CONTAMINANT EMISSIONS

The previous Chapter characterized the origins of annual average suspended particulate matter at several locations in the Metropolitan Los Angeles Region. The portion of the aerosol that is subject to direct emission control in the Los Angeles Region was classified as non-background. Non-background particulates were subdivided according to the following origin categories:

- Non-background primary particulates
- Non-background secondary particulates
  - Sulfates
  - Nitrates
  - Ammonium
  - Secondary organics

Having identified the contributions from various controllable origin categories, the final step in determining the relationship between total suspended particulate levels and emission levels is to find the functional dependence of each origin category on emission levels. The present Chapter discusses these functional relations.

Section 3.1 deals with primary particulates. The linear roll-back formula is chosen to relate measured non-background primary particulate levels to man-made emissions of primary particulates in the Los Angeles Region. Some of the approximations inherent in this choice are discussed. Sections 3.2 through 3.5 deal with non-background secondary particulates: sulfates, nitrates, ammonium, and organics respectively. For each type of secondary aerosol a review is made of existing theoretical and empirical evidence pertaining to the

dependence on gaseous precursor emissions. It is found that much uncertainty exists concerning the relationship between secondary aerosol levels and precursor emission levels. In the end, a linear form is assumed for each of the sulfate/SO<sub>2</sub>, nitrate/NO<sub>x</sub>, and organic/RHC relationships.

### 3.1 AIR QUALITY RELATIONSHIP FOR NON-BACKGROUND PRIMARY PARTICULATES

In this study, the simple "linear rollback" technique will be used to provide the air quality/emission level relationship for primary particulates. That is, non-background\* primary particulate levels at each location will be taken as directly proportional to total primary suspended particulate emissions from man-made sources in the region. Expressed mathematically,

$$\frac{\text{NBSPSP}_i(E)}{\text{NBSPSP}_i(E_0)} = \frac{E}{E_0}, \quad (3-1)$$

where

NBSPSP<sub>i</sub> = non-background primary suspended particulate level at location "i",

E = total primary suspended particulate emissions from anthropogenic sources in the region,

and the subscript "o" refers to base year values.

The applicability of the linear rollback formula to inert primary contaminants is supported by the linearity of the equation of advective diffusion with one main proviso. The proviso is that the space and time distribution of emissions does not change when the total emission level goes from E<sub>0</sub> to E. For instance, Figure 3-1 gives the geographical

\* The reader is reminded that non-background levels have been defined in Section 2 as those levels attributable to man-made pollution sources within the control region.

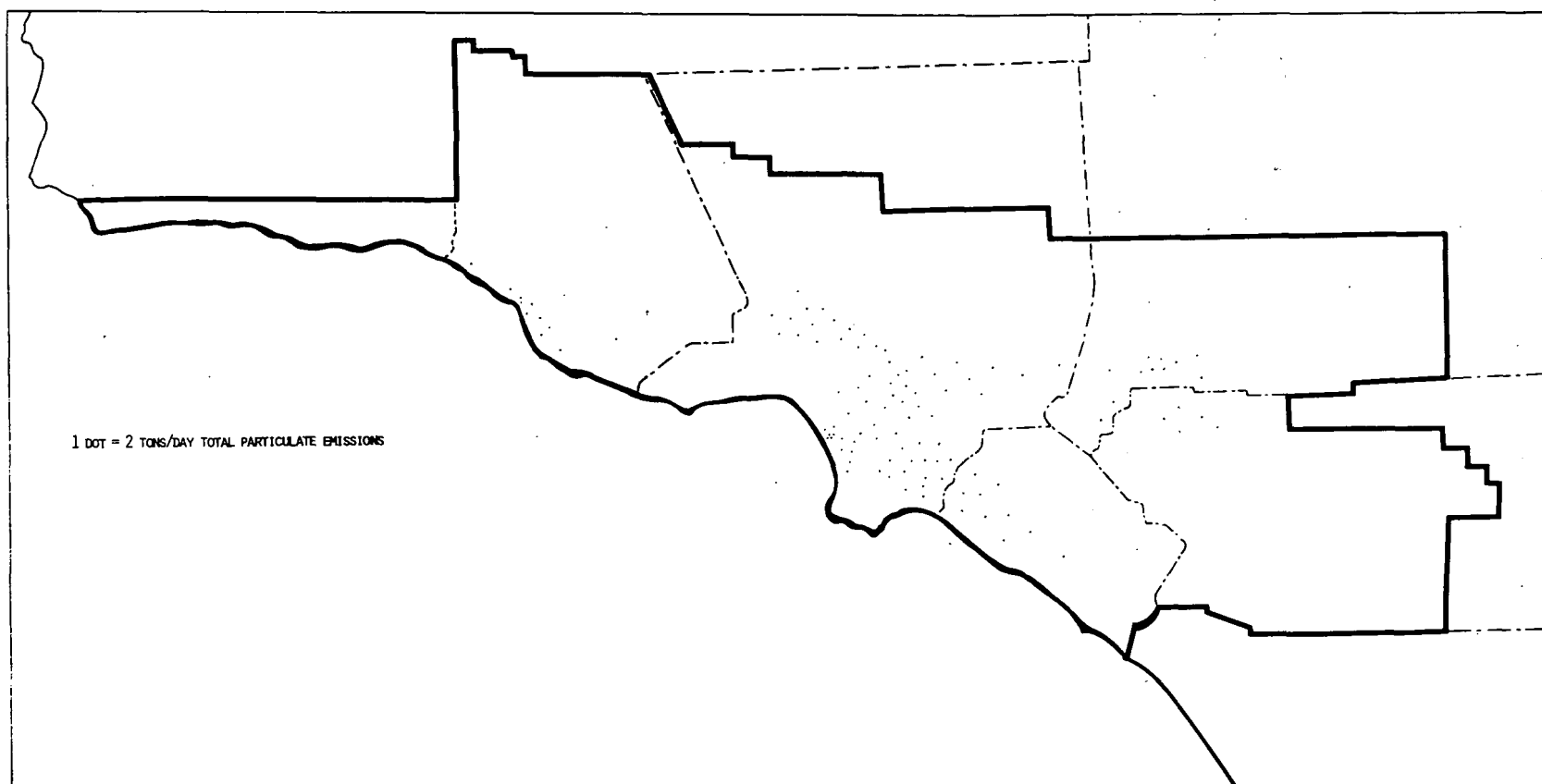


Figure 3-1. Particulate Emission Density Map for the Metropolitan Los Angeles Region

distribution of primary particulate emissions in the Metropolitan Los Angeles Region for the 1972 base year. The main theoretical assumption underlying the rollback formula for primary particulates is that the spatial pattern remains the same after control strategy implementation.

The assumption of fixed emission spatial pattern should be fairly well met by the control strategies proposed in the final report of this study. Large reductions in primary particulate emissions will be required from all significant source categories in order to approach the federal air quality standards. Thus, the spatial pattern should not change a great deal due to preferential control of certain types of sources. Further, the changes in emission pattern that are brought about by nonhomogenous source growth, (certain parts of the region are growing faster than other parts), should be outweighed by the large, uniform emission reductions due to the stringent control strategies. The error in using the rollback formula for primary particulates should be of lesser uncertainty than many other aspects of this study. Greater potential for error appears to be involved in other aspects of the study, (e.g. the origin characterization or the estimation of control impacts on emissions).

### 3.2 SULFATE AIR QUALITY RELATIONSHIP

Sulfur oxide emissions in the Metropolitan Los Angeles AQCR basically result from stationary source fuel combustion (mostly power plants) - 49%, sulfur recovery plants - 20%, transportation fuel use - 15%, and petroleum refining - 12%, 1972 Inventory, Support Document #2.  $\text{SO}_2$  constitutes nearly all of the gaseous sulfur oxide emissions, although small amounts of  $\text{SO}_3$  are also present, [25]. Both during emission and while in residence in the atmosphere, the  $\text{SO}_2$  gas can become oxidized to form sulfate ( $\text{SO}_4^{=}$ ) particulate. The sulfate aerosol consists mainly of sulfuric acid and corresponding salts such as ammonium sulfate,  $(\text{NH}_4)_2\text{SO}_4$ , [25], [26].

Measured annual average sulfate levels (from Hi-Vols) are rather uniformly distributed over the 4 County sub-area of the Los Angeles Region, ranging from around 9-15  $\mu\text{g}/\text{m}^3$ , AAM.\* The uniformity over the 4 County area indicates a general balance between dilution effects and the oxidation of  $\text{SO}_2$  to  $\text{SO}_4^{=}$  as the polluted air mass moves inland from the source intensive, coastal area, (see Figure 3-2). Average ambient  $\text{SO}_2/\text{SO}_4^{=}$  ratios vary from around 3 or 4 in coastal areas to around 1.5 or 2 in the eastern, inland areas.\*\* The  $\text{SO}_2/\text{SO}_4^{=}$  ratios in Los Angeles are distinctly lower than the average ratio for cities east of the Mississippi, (4.7:1), reported by Altshuller, [27]. This could result from the high oxidizing potential of Los Angeles photochemical smog.

---

\* The one notable exception is the Western San Bernardino County "Hot-Spot", which experiences an AAM of around 20  $\mu\text{g}/\text{m}^3$ .

\*\* See data presented in Section 3.2.2.



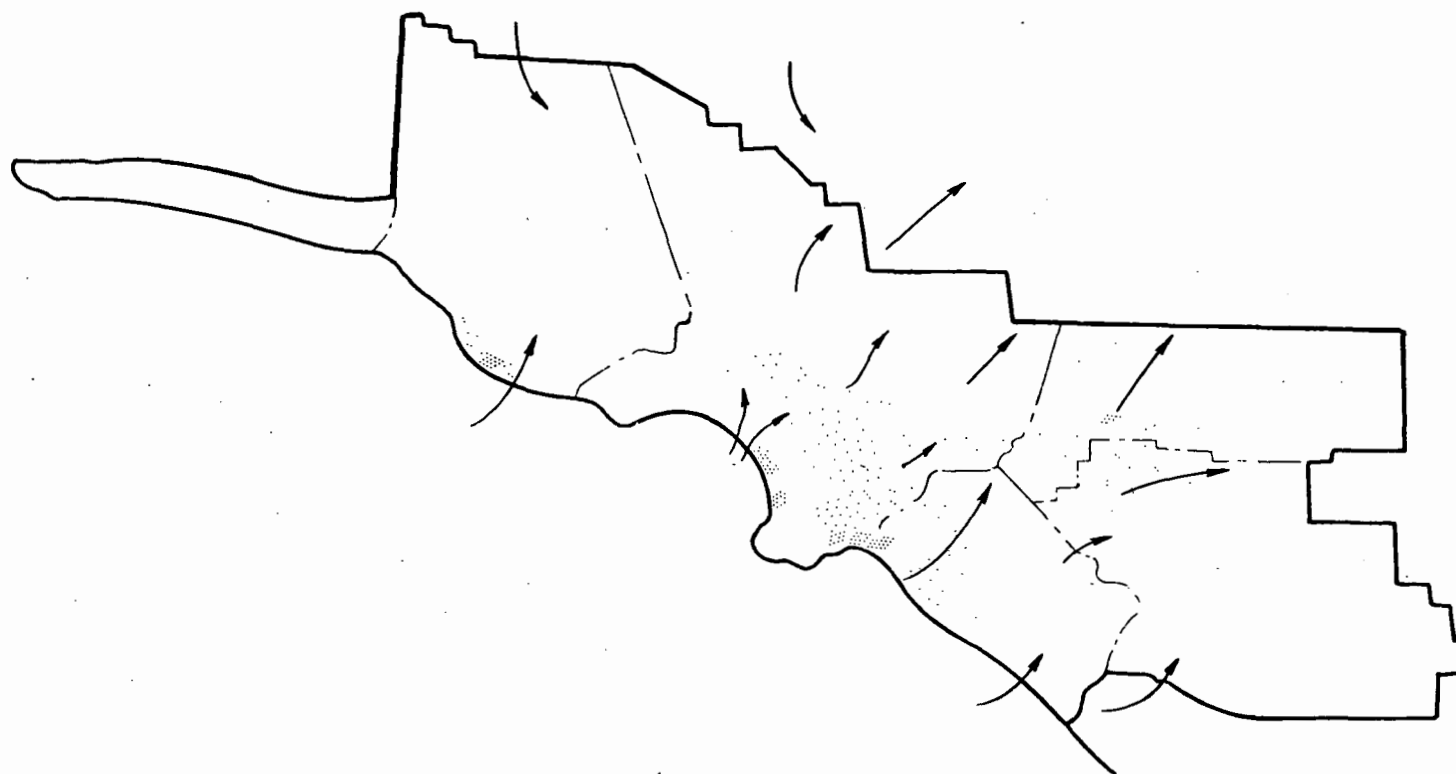


Figure 3-2 Sulfur Dioxide Emissions and Wind Patterns in the Metropolitan Los Angeles Region

Not all of the measured sulfate originates from anthropogenic Los Angeles sources. A background level exists due to natural contributions and to man-made sources exterior to the Los Angeles Region. In Section 2.2, the average sulfate background was estimated to be  $4 \mu\text{g}/\text{m}^3$ . Thus, out of the typical  $9\text{--}15 \mu\text{g}/\text{m}^3$  sulfate annual averages, only around  $5\text{--}11 \mu\text{g}/\text{m}^3$  are due to man-made sources in Los Angeles. It is the purpose here to determine how this non-background sulfate will depend on  $\text{SO}_2$  emissions in the Los Angeles Region.

The relationship between emitted  $\text{SO}_2$  and ambient  $\text{SO}_4^{=}$  is very complex and is the subject of current research; considerable uncertainty exists at the present state of knowledge, [28], [29], [30]. No definitive models are available for relating  $\text{SO}_2$  emissions to atmospheric  $\text{SO}_4^{=}$  concentrations. In the following sections, the general form of the relationship will be analyzed by considering known aspects of the chemical transformation processes (Section 3.2.1) and by examining certain atmospheric empirical evidence (Section 3.2.2). In the end, a linear relation will be adopted; Section 3.3.3 will present supportive arguments for this assumption.

### 3.2.1 Chemical Transformation Processes

A variety of avenues exist for oxidizing atmospheric  $\text{SO}_2$  to yield sulfate aerosol. The chemical and physical processes involved have been reviewed in references [25] and [26]. The relative contribution of various possible oxidation mechanisms is uncertain. However, three avenues have been identified which appear to be significant:

- (1) Photochemically induced oxidation of  $\text{SO}_2$  to  $\text{SO}_3$  in the gas phase with subsequent reactions yielding sulfuric acid or sulfates. (Homogeneous gas phase oxidation)

It has been found that irradiation of  $\text{SO}_2$ /clean air/water vapor systems yields  $\text{SO}_2$  oxidation rates which are too slow to be significant in urban areas [29], [25], [26], [31], [32], [33]. However, the photolysis of  $\text{SO}_2$ /HC/ $\text{NO}_x$  systems can yield substantial oxidation rates [29], [25], [26], [34], [35]. This latter form of photochemically induced reaction may be a prime source of sulfate production in the Los Angeles Region [29]. It has been postulated that a principal oxidation mechanism in this process involves the reaction of  $\text{SO}_2$  with an ozone-hydrocarbon intermediary, [26], [36].<sup>2</sup> Once  $\text{SO}_2$  is oxidized to  $\text{SO}_3$ , subsequent reactions involving water (and particles) yield sulfuric acid and sulfates.

- (2) Absorption of  $\text{SO}_2$  in aqueous droplets with subsequent catalytic oxidation. (Homogeneous catalysis in liquids)

Data indicate that numerous substances are effective in catalytically oxidizing  $\text{SO}_2$ . Among these are various oxides (of iron, manganese, chromium, vanadium, lead, aluminum, and nitrogen), and other metallic salts, [25], [37]. The absorption of  $\text{SO}_2$  in aqueous solutions, followed by catalytic oxidation can be an important mechanism of sulfate production [29], [25]. For this oxidation mechanism, atmospheric ammonia may play a significant role by neutralizing some of the acidity built up in the aqueous droplet ( $\text{SO}_2$  becomes less soluble as the acidity increases) [25], [37].

- (3) Adsorption of  $\text{SO}_2$  on solid particles and subsequent reaction with adsorbed oxygen. (Heterogeneous gas-particle interactions).

There is evidence that adsorption and subsequent oxidation of  $\text{SO}_2$  on particle surfaces is an important mechanism of sulfate production in ambient atmospheres. Experimental studies with metal oxide particles (oxides of aluminum, calcium, chromium, iron, lead, and vanadium) and carbon have demonstrated this effect [26], [32], [38]. A recent analysis of ACHEX data indicates that Los Angeles aerometric observations are qualitatively consistent with the occurrence of this oxidation mechanism, [28]. The ACHEX study implicates carbonaceous (soot) particles as possible sites for the process.

From the description of the above processes, it is apparent that several factors are important in determining the degree to which  $\text{SO}_2$  will be converted to sulfate aerosol. Significant atmospheric factors are :

- presence of HC and  $\text{NO}_x$
- solar radiation intensity
- temperature
- humidity
- presence of catalysts
- presence of atmospheric ammonia
- presence of absorbing particles (e.g. metal oxides or carbon)

Another very important factor is the residence time in the atmosphere: the longer the time for reaction - the greater the conversion of  $\text{SO}_2$  to sulfate.

As to the dependence on  $\text{SO}_2$  concentrations, (the main issue of interest here), it appears that at low  $\text{SO}_2$  concentration all three mechanisms are such that the rate of oxidation is directly proportional to  $\text{SO}_2$  concentration, [29]. Mathematically, the processes would be described by a first order rate equation in  $\text{SO}_2$ . For given values of other relevant parameters and for given residence time, the amount of sulfate produced would be directly proportional to  $\text{SO}_2$  input. However, at higher  $\text{SO}_2$  concentrations, there are reasons to expect that the sulfate yield would be less than proportional to  $\text{SO}_2$  input. For one, at higher  $\text{SO}_2$  and sulfate levels, insufficient ammonia may be available to prevent aqueous airborne droplets from becoming strongly acidic. Since  $\text{SO}_2$  is less soluble in acid solutions, the depletion of  $\text{NH}_3$  would lead to reduced rates for aerosol sulfate formation in process

(2) above [29], [25], [37]. Second, theoretical analysis of the gaseous reactions in mechanism (1) indicates that the relative rate of  $\text{SO}_2$  oxidation to  $\text{SO}_3$  should tend to decrease at higher  $\text{SO}_2$  levels, [29], [39].\* The details of this analysis are beyond the scope of this study, and the interested reader is referred to [39]. Third, mechanism (3) may yield nonlinear results at high  $\text{SO}_2$  levels due to saturation of adsorption sites, [29].

The implications of the above discussion are summarized in Figure 3.3a which gives a qualitative illustration of the dependence of sulfate levels on  $\text{SO}_2$  input, (for fixed residence time and other parameters). At small  $\text{SO}_2$  levels, the dependence is nearly linear. For large values of  $\text{SO}_2$ , nonlinear effects take hold and the relation becomes less than proportional. The  $\text{SO}_2$  level at which nonlinearities set in will depend on several of the key parameters described previously, (e.g., amounts of  $\text{NH}_3$ ,  $\text{HC}/\text{NO}_x$ , and adsorbent surface).

Actually, in a real air basin one would expect a slightly modified picture. There will exist a background sulfate from natural processes as well as from man-made emissions exterior to the basin in question. Thus, the effect of  $\text{SO}_2$  emissions within the basin on sulfate levels would be as illustrated in Figure 3-3b. Figure 3-3b is similar to Figure 3-3a, except that the  $\text{SO}_2/\text{SO}_4^{=}$  curve has a positive intercept at the background  $\text{SO}_4^{=}$  level.

### 3.2.2 Atmospheric Data

The analysis of actual atmospheric monitoring data provides an empirical approach for determining the relationship between  $\text{SO}_2$

\* At  $\text{SO}_2$  levels typically found in Los Angeles this effect may not be significant.

Figure 3-3a Hypothetical Experiment

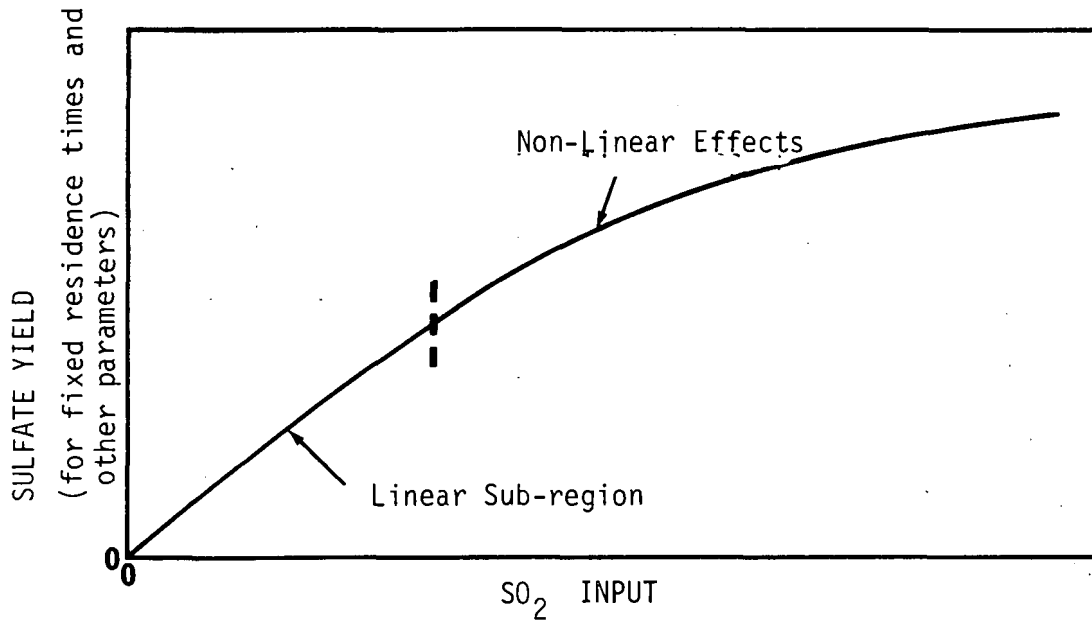


Figure 3-3b Hypothetical Air Basin

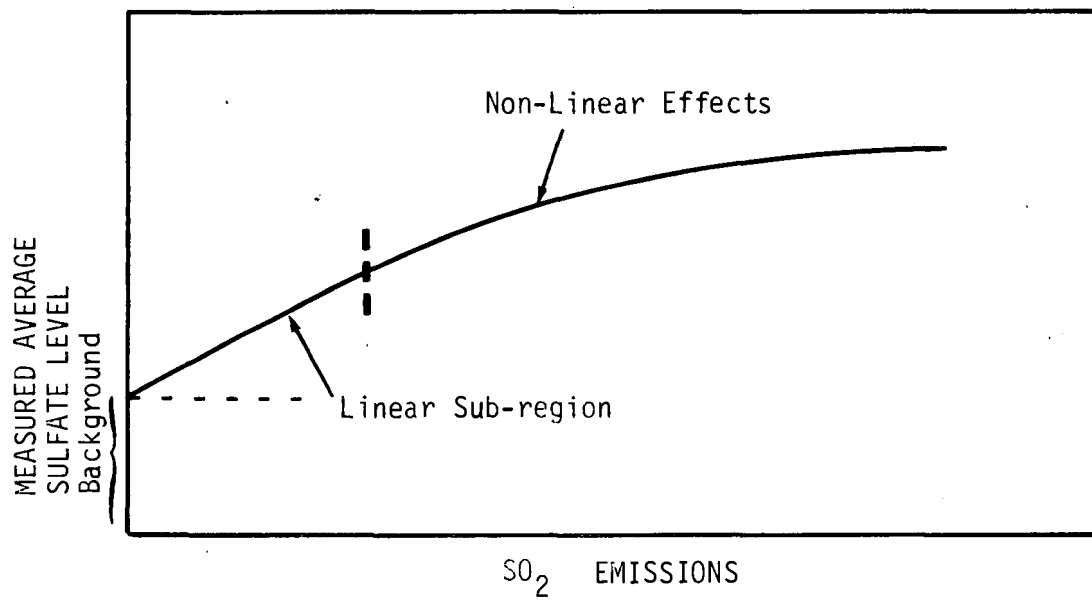
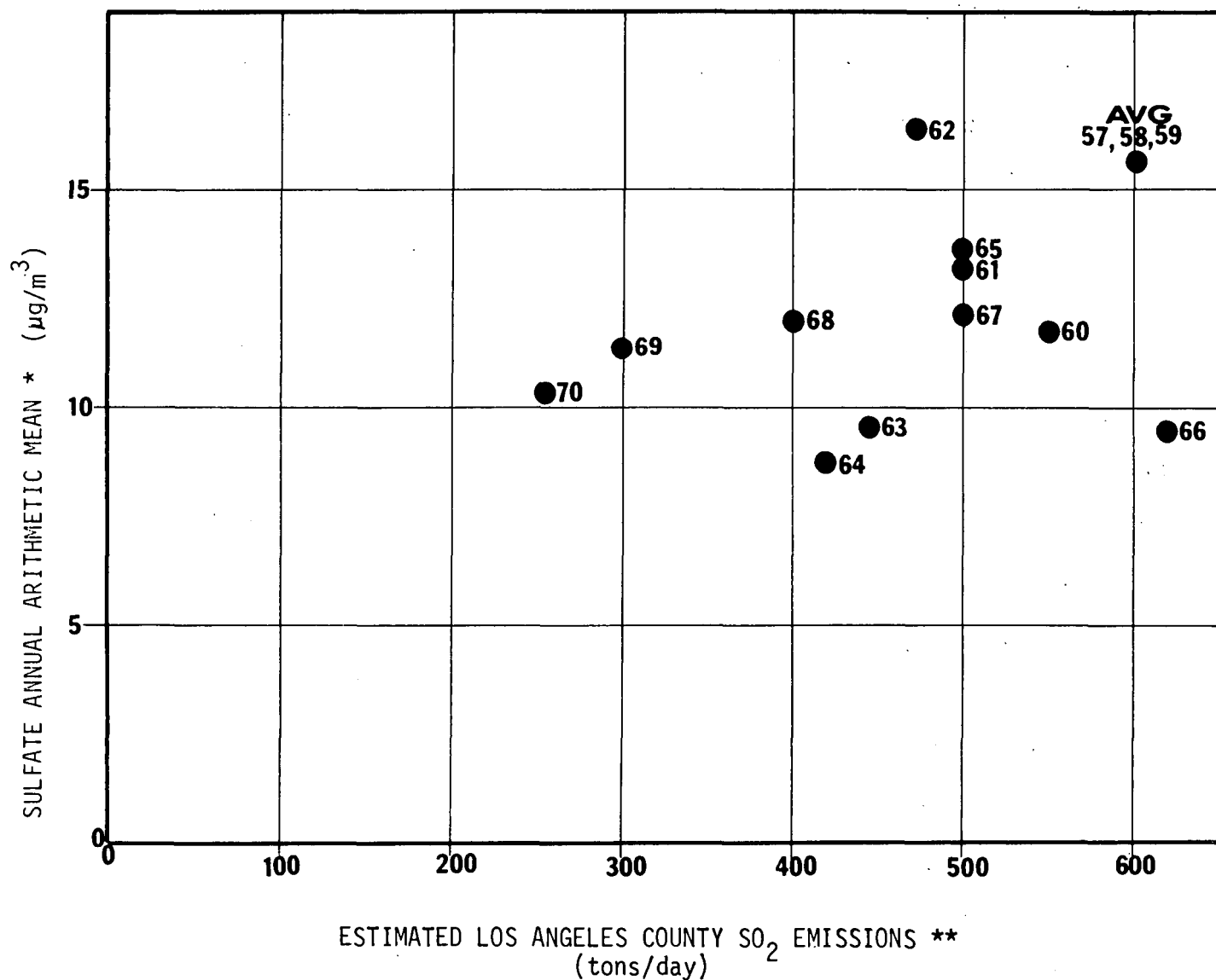


Figure 3-3 Schematic Illustration of the Dependence of Sulfate Levels on  $\text{SO}_2$  Input

emissions and ambient sulfate concentrations. Ideally, the method would use many years of historical data on  $\text{SO}_2$  emissions and corresponding data on ambient  $\text{SO}_4^{=}$  levels. Hopefully, the method would be applied to several locations so that the form of the relationship could be found for alternative residence times and climatological conditions.

Unfortunately, the ideal empirical method outlined above appears to be impractical with existing data. Figure 3-4 presents the results of an attempt to relate historical  $\text{SO}_4^{=}$  levels (from NASN sites) to  $\text{SO}_2$  emissions (from APCD estimates) in Los Angeles County. These results do not yield a meaningful emission-air quality relationship. The main difficulties encountered with this method were the following:

- Figure 3-4 shows that there is considerable scatter in measured  $\text{SO}_4^{=}$  levels for given emission levels. These fluctuations obscure the relationship between ambient  $\text{SO}_4^{=}$  levels and estimated  $\text{SO}_2$  emission levels. Much of the fluctuation is probably statistical in nature and is the result of the small number of annual samples, 24, taken in the NASN Monitoring program. Some of the scatter is also due to errors in the emission estimates and possibly to historical changes in NASN monitoring procedures.
- The use of Los Angeles County APCD air quality data might have eliminated some of the statistical fluctuations since the APCD has taken samples at the rate of 50-100 per year. However, APCD data is available only back to 1965. Also, the usefulness of long term APCD sulfate data is marred by an unexplained increase (about 50%) in mean  $\text{SO}_4^{=}$  levels beginning in 1969. This increase, counter to the decreasing trend in  $\text{SO}_2$  emissions, is probably due to changes in monitoring equipment and/or techniques, [40].
- Figure 3-4 shows that yearly average Los Angeles County  $\text{SO}_2$  emissions have varied from around 250-620 tons/day in the period under investigation. This range is not sufficiently wide enough to provide an indication of the impact of a stringent control strategy. To extrapolate down to an  $\text{SO}_2$  emission level of around 40-80 tons/day based on the data given in Figure 3-4 would involve great uncertainty.



\* Average of NASN values for Los Angeles, Burbank, Glendale, Long Beach and Pasadena. Prior to 1967 data are available for at most three stations during any given year, and the available sites changed from year to year. Since all stations demonstrated the same general sulfate level, around 10-12 ug/m<sup>3</sup>, averages were taken of all available data.

\*\* Los Angeles County Air Pollution Control District, Reference [4].

Figure 3-4 Historical Relationship Between SO<sub>2</sub> Emissions and SO<sub>4</sub><sup>=</sup> Concentrations -- Los Angeles County, 1957 to 1970



The above results are especially disappointing since the emission and air quality data base for Los Angeles is among the best available. If the application to Los Angeles does not provide useful results, there is little probability that this method will yield a definitive air quality/emission level relationship when applied elsewhere.

An alternate, more indirect, empirical method for relating  $\text{SO}_2$  emissions and  $\text{SO}_4^{=}$  air quality is based solely on air quality data for both species. A relationship is determined between measured ambient  $\text{SO}_2$  and sulfate levels. This relationship is then used as an approximate model for the dependence of sulfate levels on  $\text{SO}_2$  emissions.

The most comprehensive study of the relationship between annual average  $\text{SO}_2$  and sulfate concentrations was performed by Altshuller, [27]. He analyzed NASN data at urban sites from 1964 to 1968. Figure 3-5 presents the  $\text{SO}_2$ /sulfate relationship which he found with data from 18 U.S. cities.\* The lines drawn to the data are linear regression lines for  $\text{SO}_2$  sub-ranges of 6-80  $\mu\text{g}/\text{m}^3$  and 100-200  $\mu\text{g}/\text{m}^3$ .

There is considerable scatter in the data plotted by Altshuller. This is because the points represent varied locations with different climatological conditions and  $\text{SO}_2$  residence times. These differences alter the amount of sulfate associated with given  $\text{SO}_2$ . However, the general pattern in Figure 3-4 does appear to verify the qualitative conclusion derived from an analysis of the chemical process in Section 3.2.1; sulfate initially increases above background in proportion to  $\text{SO}_2$  increases but levels off as nonlinear processes become important.

For the sites which he studied, Altshuller appeared to find an average

\* Los Angeles was not included.

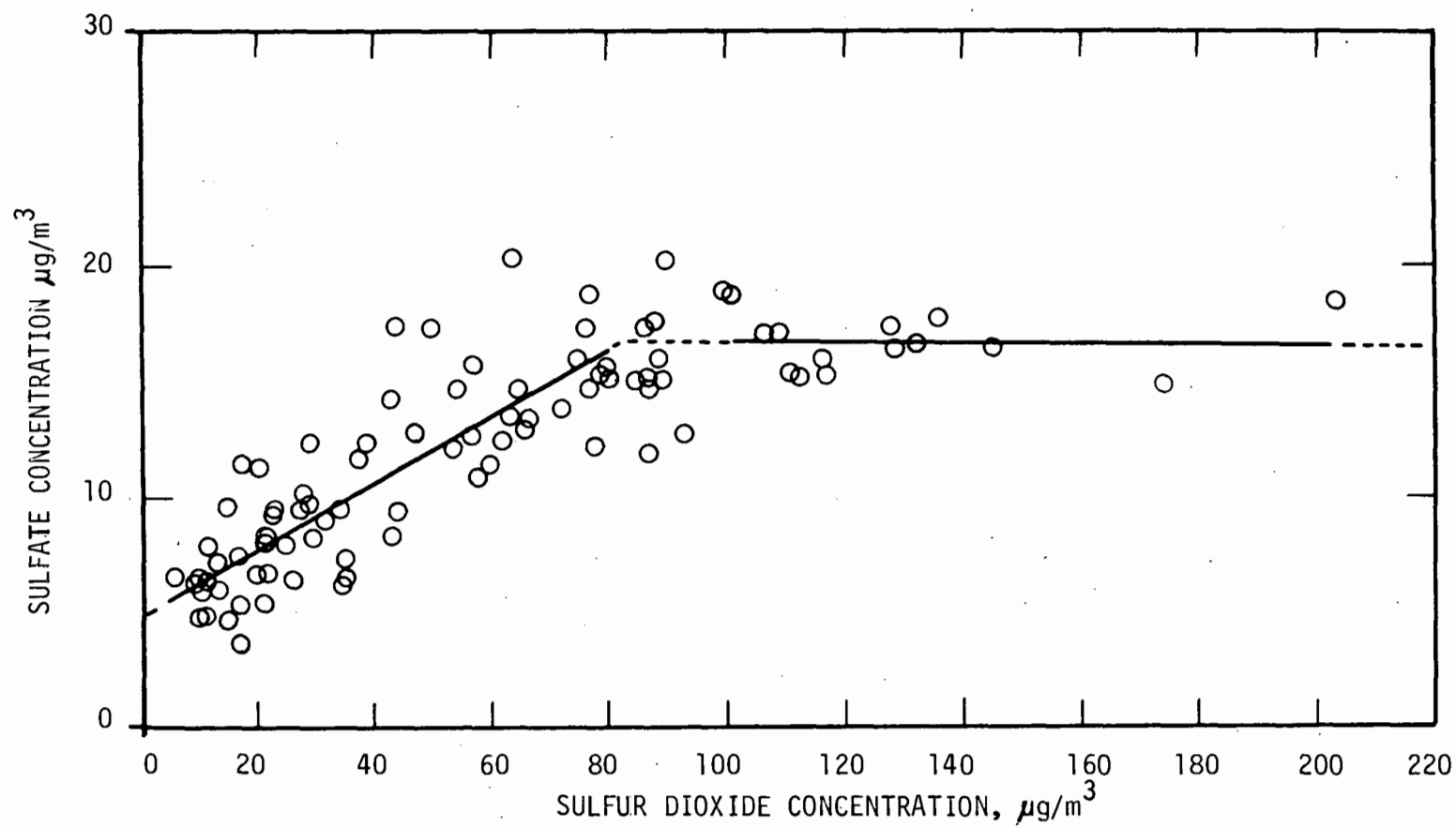


Figure 3-5 Sulfur Dioxide/Sulfate Relationship for 18 U. S. Cities

REFERENCE: Altshuller [27].

background sulfate of around  $5 \mu\text{g}/\text{m}^3$ . The average background level, the result of long term transport from anthropogenic sources as well as from natural sources, is indicated by the intercept on the vertical axis.

In the present project, a similar empirical study was performed using aerometric data from Los Angeles. Figure 3-6 compares annual average sulfate and sulfur dioxide at eleven stations in the Metropolitan Los Angeles AQCR.  $\text{SO}_2$  levels are lower in Los Angeles than in many eastern cities; all of the Los Angeles  $\text{SO}_2$  averages are below  $60 \mu\text{g}/\text{m}^3$  and within the bottom  $\text{SO}_2$  range of the data which was investigated by Altshuller. The Los Angeles Points show a high sulfate/ $\text{SO}_2$  conversion ratio; all points in Figure 3-6 lie above the lower Altshuller regression line in Figure 3-5. However, the Los Angeles points are within the scatter of Altshuller's data.

As with Altshuller's results, the raw Los Angeles data in Figure 3.6 show considerable variance. However, if a qualitative distinction is made as to distance inland, a much more consistent pattern is revealed. Figure 3-6 demonstrates that for given  $\text{SO}_2$  level, sulfate increases with distance inland. This apparently reflects increased residence time under the sea breeze dominated wind pattern. For given distance inland, sulfate increased above background ( $4 \mu\text{g}/\text{m}^3$ )\* in a slightly less than linear way with increasing  $\text{SO}_2$ . This non-linearity is in agreement with the previous discussion of the sulfate/ $\text{SO}_2$  relationship.

---

\* See Section 2.

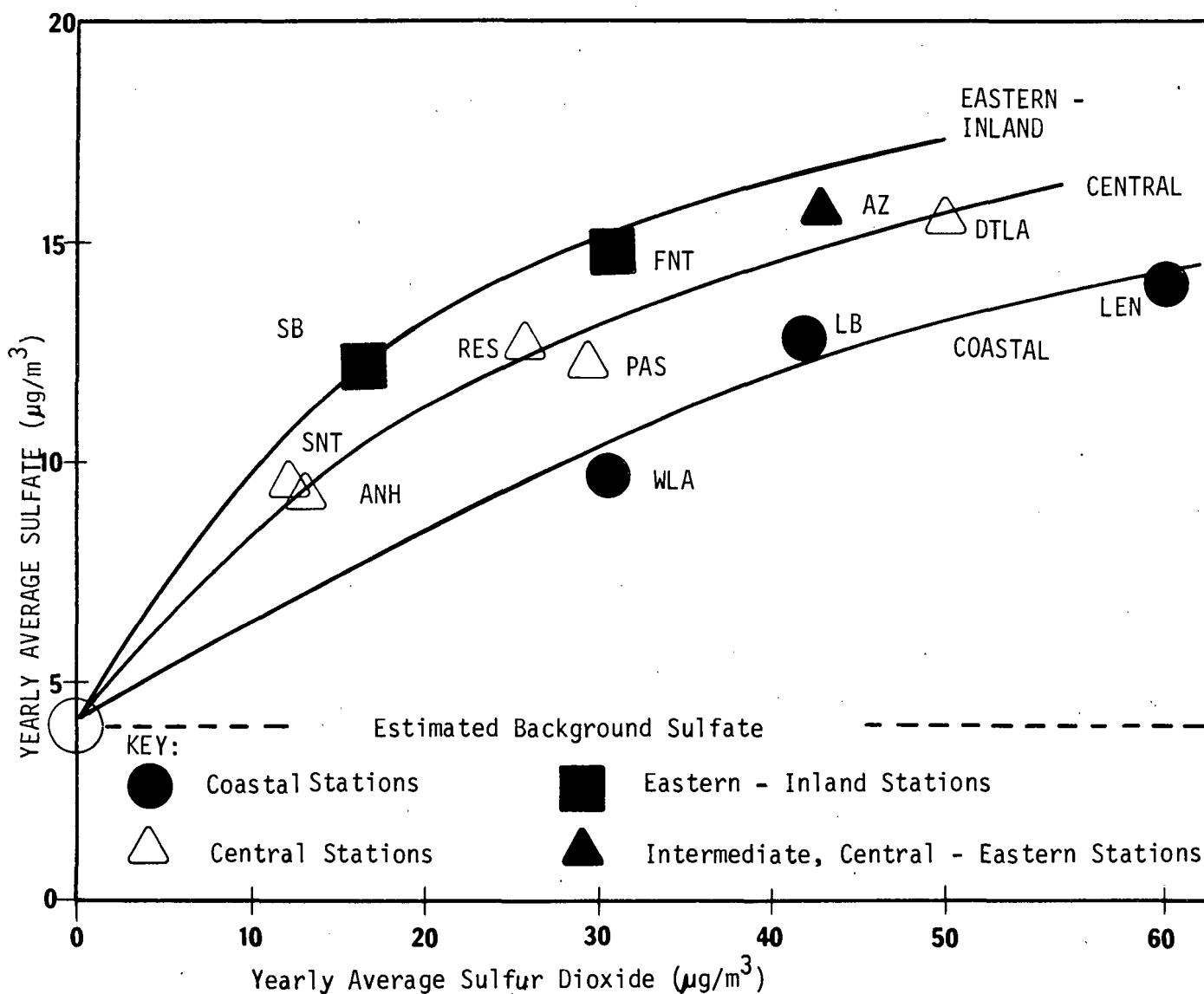


Figure 3-6 Aerometric Relationship Between Sulfate and Sulfur Dioxide in the Metropolitan Los Angeles AGCR

DATA SOURCES:

- WLA - West Los Angeles (LA APCD 1969-1972)\*
- LB - Long Beach (NASN 1968 - 1970)
- LEN - Lennox (LA APCD 1969-1972)\*
- SNT - Santa Ana (NASN 1969)
- ANH - Anaheim (NASN 1969)
- RES - Reseda (LA APCD 1969-1972)\*
- PAS - Pasadena (LA APCD 1972)\*
- DTLA - Downtown Los Angeles (LA APCD 1969-1972)\*
- SB - San Bernadino (SB APCD 1972 & NASN 1968-1969)
- FNT - Fontana (SB APCD 1972)
- AZ - Azusa (LA APCD 1972)\*

\* Los Angeles APCD SO<sub>2</sub> data have been corrected to allow for systematic round off error; the LA APCD reports all SO<sub>2</sub> values from 0 to .015 ppm as .01 ppm.

It is interesting to note that the sulfate air quality/SO<sub>2</sub> emission data of Figure 3-4 is in qualitative agreement with the data just discussed. Figure 3-7 averages the data in Figure 3-4 and gives two emission/air quality points which are means for years below 450 tons/day SO<sub>2</sub> emissions and years above 500 tons/day SO<sub>2</sub> emissions respectively. Although these two points do not support statistically definitive conclusions, in conjunction with the 4 µg/m<sup>3</sup> background value they do suggest a slightly nonlinear dependence of sulfate concentrations on SO<sub>2</sub> emissions.

### 3.2.3 An Operational Relationship for Use in Implementation Planning

The above discussions present a consistent picture of the relationship to be expected between annual average sulfate levels and SO<sub>2</sub> emissions in the Los Angeles Region. The background sulfate level, a result of man made sources exterior to the Los Angeles Region as well as natural sources, is around 4 µg/m<sup>3</sup>. In response to SO<sub>2</sub> emissions within the basin, sulfate levels increase initially in a linear way. Gradually, nonlinear processes become important, and further increases in sulfate are less than linear.

For the purpose of simplicity in implementation planning, it is here proposed that a simple linear relation be assumed for the sulfate/SO<sub>2</sub> relationship. The assumption will be that measured sulfate, minus the 4 µg/m<sup>3</sup> background, is linearly proportional to total emissions. Stated mathematically,

$$\frac{S_i(E) - S_b}{S_i(E_0) - S_b} = \frac{E}{E_0} ,$$

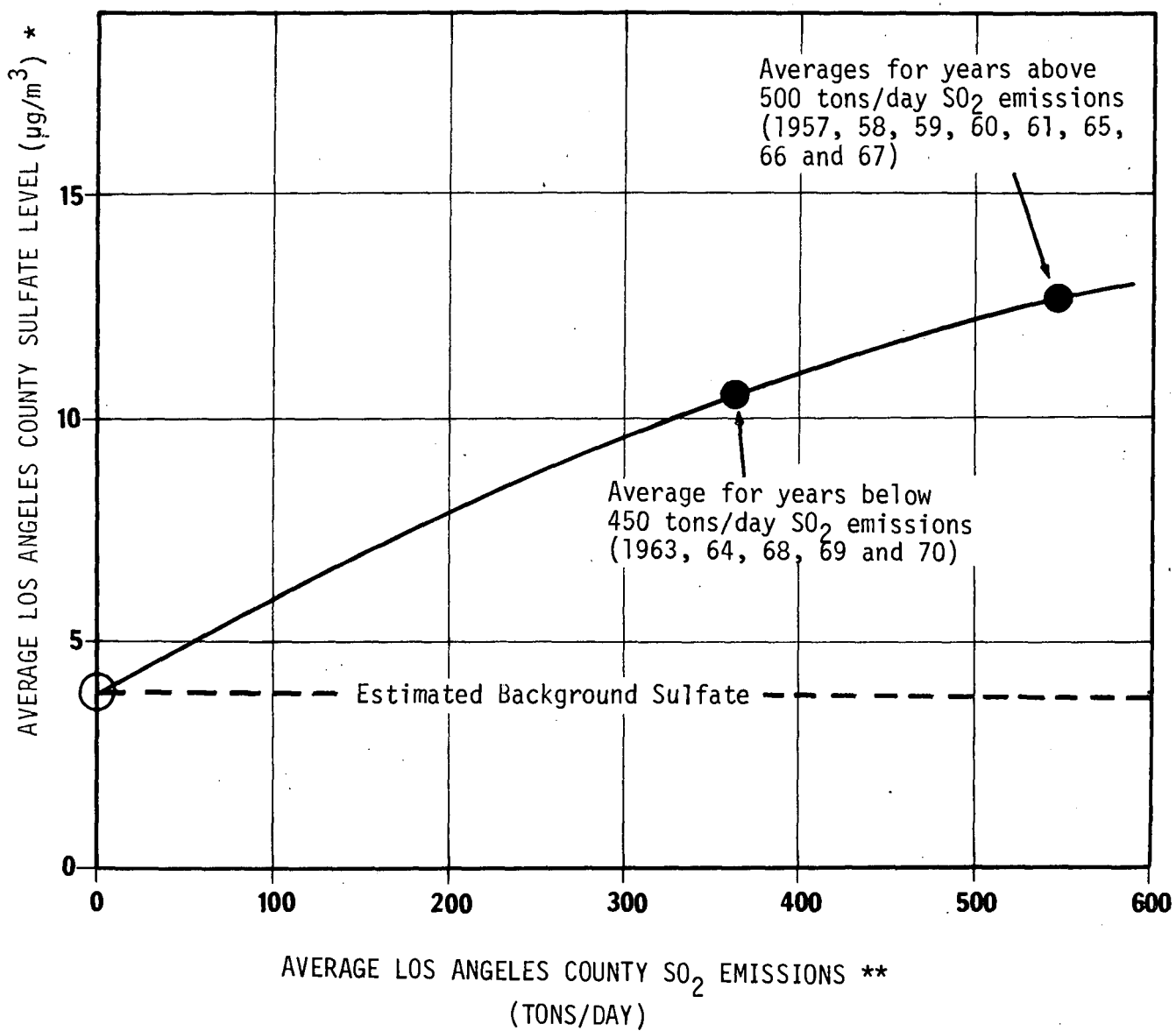


Figure 3-7 Average  $\text{SO}_2$  Emissions vs. Average  $\text{SO}_4^{=}$  Air Quality for Los Angeles County

\* NASN data for Los Angeles, Burbank, Glendale, Long Beach and Pasadena.

\*\* Los Angeles County APCD Estimates

where,

$S_i$  = sulfate level at location  $i$ ,  
 $E_i$  = total  $\text{SO}_2$  emission level in the Los Angeles Region,  
 $E_o$  = total  $\text{SO}_2$  emission level for the base year (1972),  
and  $S_b^o$  = background sulfate ( $4 \mu\text{g}/\text{m}^3$ ).

The error in the linear model will depend on the station to which it is applied. The error will tend to be greatest for stations which have the highest present  $\text{SO}_2$  levels since nonlinear processes become more important at higher  $\text{SO}_2$  levels. A sensitivity analysis was performed comparing the nonlinear curves in Figure 3.6 with the predictions that would result from the linear model. This analysis indicated that the maximum error in the linear model would be  $3 \mu\text{g}/\text{m}^3$ , with most errors typically around  $1 \mu\text{g}/\text{m}^3$ . Although this is a significant fraction of the ambient sulfate concentration, it is not significant when compared to the total annual average level of suspended particulates, which is on the order of  $100 \mu\text{g}/\text{m}^3$ . Since the implementation strategy in this study will be based on total suspended particulates, the error in the linearity assumption for sulfate should be of minor overall importance. Much larger errors are encountered in attempting to use present Hi-Vol data to characterize base year air quality levels for total suspended particulates, (See Support Document #1).

In further defense of the linearity assumption, it should be noted that control strategies will be prepared for HC and  $\text{NO}_x$  as well as  $\text{SO}_2$ . Reducing HC and  $\text{NO}_x$  should help to decrease sulfate levels by weakening the photochemical oxidation mechanism for  $\text{SO}_2$ . The error in neglecting the synergistic effect of HC and  $\text{NO}_x$  reductions will be directly counter to the error in assuming a linear sulfate/ $\text{SO}_2$  air quality relation.

### 3.3 NITRATE AIR QUALITY RELATIONSHIP

Secondary nitrate aerosol is a product of a complex series of reactions involving gaseous  $\text{NO}_x$  emissions.  $\text{NO}_x$ , (the sum of  $\text{NO}$  and  $\text{NO}_2$ ), originates essentially from fuel combustion sources and is emitted mostly as  $\text{NO}$ , [18], [42]. In the atmosphere, much of the  $\text{NO}$  is oxidized to  $\text{NO}_2$ . Further oxidation processes can take place which produce secondary nitrate ( $\text{NO}_3^-$ ) aerosol. Some of this secondary aerosol is organic nitrate and is included as part of the secondary organic origin category. The nitrate category of interest here is inorganic nitrate. Inorganic nitrate, probably the most prevalent form of nitrate, [28], consists of nitric acid and nitrate salts, particularly ammonium nitrate, [3], [16].

The purpose of this section is to determine how secondary inorganic nitrate levels in the Los Angeles Region will respond to changes in  $\text{NO}_x$  emission levels. This problem directly parallels the subject of previous section which dealt with the sulfate --  $\text{SO}_2$  relationship. It was noted in the previous section that considerable uncertainty surrounded the relationship of sulfate levels and  $\text{SO}_2$  emissions. Unfortunately, much less is known for the case of the nitrate --  $\text{NO}_x$  relationship. The nitrate problem seems to be a more difficult one to solve, and to compound the trouble, less research effort seems to have been devoted to the nitrate issue, [29], [30].

It is not now possible to build a sound theoretical case for the form of the nitrate --  $\text{NO}_x$  relationship because the important conversion mechanisms have not been defined and documented. Although



there are no definitive results on what specific reaction mechanisms predominate, there is some evidence that photochemical processes are significant. As was shown in Figure 2-3, nitrate values are greatest in the inland portions of the Los Angeles Region which experience the most intense photochemical smog levels. Also, an analysis of atmospheric data at Riverside has indicated a correlation between nitrate levels and photochemical smog, [3]. However, the explicit photochemical (or other) reactions involved in nitrate reduction are not well understood.\* In the absence of knowledge concerning the reactions, a systematic theoretical argument cannot be made concerning the form of the  $\text{NO}_3^-$  --  $\text{NO}_x$  relationship.

An alternative method of finding the nitrate --  $\text{NO}_x$  relationship is the empirical approach based on atmospheric monitoring data. However, again, less work has been done with nitrates than with sulfates. No empirical study has been published for  $\text{NO}_3^-$  --  $\text{NO}_x$  that is equivalent to Altshuller's work with  $\text{SO}_4^{=}$  --  $\text{SO}_2$ , [27], (See Figure 3-5).\*\*

---

\* Some potentially important reactions have been identified, [30], e.g.,

- the thermal reaction of  $\text{NO}_2$  + oxygen + water to yield nitric acid
- or
- the reaction of  $\text{NO}_2$  with ozone or other photochemical oxidants to yield  $\text{N}_2\text{O}_5$  which combines with water to form nitric acid.

However, more research is needed before the reaction mechanisms can be described with confidence.

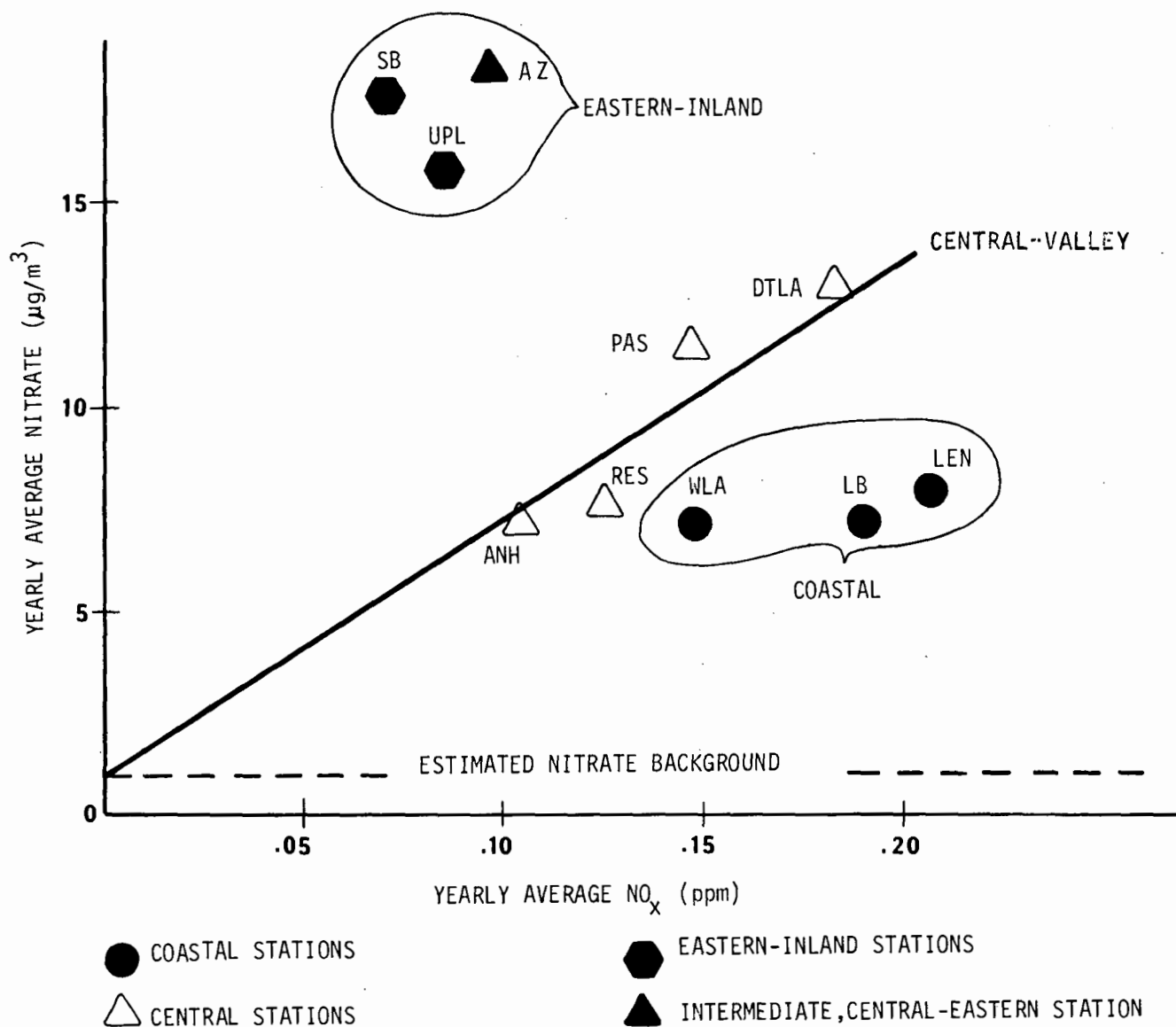
\*\* Possibly this is because  $\text{NO}_x$  data are not available for a  $\text{NO}_3^-/\text{NO}_x$  study. The federal NASN data summaries for 1967 and 1968 report only  $\text{NO}_2$ , (not  $\text{NO}$ ), for nearly all the monitoring sites, [11], [43].

An attempt was made in the present study to perform an empirical analysis of the nitrate --  $\text{NO}_x$  relationship based on data from the Los Angeles Region. Figure 3-8 presents the results of plotting yearly average  $\text{NO}_3^-$  vs yearly average  $\text{NO}_x$  at ten locations. Figure 3-8 reveals that for given  $\text{NO}_x$ , nitrate increases considerably from coast to inland. This apparently reflects the continuous conversion of  $\text{NO}_x$  to  $\text{NO}_3^-$  as the air mass moves inland under the typical sea breeze dominated wind pattern. As to the dependence of  $\text{NO}_3^-$  on  $\text{NO}_x$ , Figure 3-8 is inconclusive. For the coastal and eastern-inland data, the spread in  $\text{NO}_x$  concentrations is not wide enough to justify inferences about the  $\text{NO}_3^-$  --  $\text{NO}_x$  relationship. For the central-valley stations, a straight line to the estimated  $\text{NO}_3^-$  background level fits well; however, four data points are not sufficient to make a firm conclusion concerning linearity.

In summary, existing knowledge concerning the dependence of  $\text{NO}_3^-$  concentrations on  $\text{NO}_x$  emissions is very poor. Neither theoretical nor empirical analysis can presently justify sound conclusions as to the form of the  $\text{NO}_3^-$  --  $\text{NO}_x$  relationship. In this study, the simplest relationship will be assumed: non-background nitrate (total nitrate minus  $1 \mu\text{g}/\text{m}^3$  background\*) will be taken as directly proportional to total  $\text{NO}_x$  emission levels. It should be emphasized that there is considerable uncertainty in the use of this linear rollback formula for nitrate --  $\text{NO}_x$ . The principal justification is that there is no firm evidence to support the use of any specific nonlinear relationship.

Another caveat that should be kept in mind is that the above relationship between nitrate and  $\text{NO}_x$  neglects possible effects on

\* See Section 2.2 for a discussion of the background value.



DATA SOURCE:

WLA	- West Los Angeles	(LA APCD, 1969-72)
LB	- Long Beach	(LA APCD - NO <sub>x</sub> , NASN-NO <sub>3</sub> <sup>-</sup> , 1969-70)
LEN	- Lennox	(LA APCD, 1969-72)
DTLA	- Downtown Los Angeles	(LA APCD, 1969-72)
PAS	- Pasadena	(LA APCD, 1972)
RES	- Reseda	(LA APCD, 1969-72)
ANA	- Anaheim	(Orange APCD-NO <sub>x</sub> , NASN-NO <sub>3</sub> <sup>-</sup> , 1969-70)
AZ	- Azusa	(LA APCD, 1972)
SB	- San Bernardino	(San Ben., APCD, 1972-73)
UPL	- Upland	(San Ben., APCD, 1972-73)

Figure 3-8 Aerometric Relationship Between Nitrate and NO<sub>x</sub> in the Metropolitan Los Angeles AQCR

nitrate formation from hydrocarbon (HC) emission level changes. Since photochemical processes seem to be important in nitrate formation, hydrocarbon levels may indirectly impact on nitrate levels by governing the amount of photochemical activity. Since HC emissions will be undergoing reductions in the future, the neglect of HC effects would appear to yield conservative results, e.g. actual nitrate levels may be lower than predicted due to decreased HC emissions and correspondingly decreased photochemical activity. Whether or not the HC effect will be significant is uncertain.

### 3.4 AMMONIUM AIR QUALITY RELATIONSHIP

Ammonium ion ( $\text{NH}_4^+$ ) constitutes a small fraction of total suspended particulate levels in the Los Angeles Region, (about 1%). Non-background ammonium was estimated to be around  $1 \mu\text{g}/\text{m}^3$  in the origin characterization, (Table 2-17). Here by non-background, we do not imply that the ammonia ( $\text{NH}_3$ ) precursor was necessarily man-made. Rather, non-background ammonium is defined as that which is associated with non-background sulfate and nitrate.

The air quality relationship for non-background ammonium will be taken as simple linear rollback based on non-background sulfate and nitrate control. That is, the fractional reduction in non-background  $\text{NH}_4^+$  will be assumed proportional to the molar fractional reduction of non-background  $\text{SO}_4^{=}$  and  $\text{NO}_3^-$ .\* Since ammonium ion is such a small fractional of total suspended particulate levels, the prediction of total particulate levels should be highly insensitive to errors in the above assumption for the  $\text{NH}_4^+$  air quality relationship

---

\*Actually, since two  $\text{NH}_4^+$  would be associated with one  $\text{SO}_4^{=}$  and only one  $\text{NH}_4^+$  would be associated with a  $\text{NO}_3^-$ , sulfate reductions are given twice the weight in the total molar fraction.

### 3.5 SECONDARY ORGANIC AIR QUALITY RELATIONSHIP

Secondary organic aerosol is one of the products of the photochemical smog reactions that occur in the Los Angeles atmosphere. The composition of secondary organic aerosol has not been definitely established, but there appears to be a general dominance of highly oxygenated compounds [22],[10], [44]. Likewise, the importance of various hydrocarbons as precursors of secondary organic aerosol is not fully understood. However, higher molecular weight aromatics and olefins, particularly the latter, are evidently most important, [22],[45], [46], [47], [34].

The purpose here is to determine how secondary organic aerosol levels will depend on reactive hydrocarbon (RHC) emissions in the Los Angeles Region. Actually, in this task, we begin at a disadvantage. The hydrocarbon reactivity scale used to define RHC emissions in this study is based on the oxidant forming potential of hydrocarbon emissions, (See Support Document #2, [18]). However, recent research has indicated that reactivity ratings based on aerosol formation can be significantly different from oxidant reactivity ratings [47]. To reformulate the hydrocarbon emission inventory with a new aerosol reactivity scale was beyond the scope of the present study. Thus, the use of an inappropriate reactivity scale will be an error inherent in the present analysis.

The relationship between secondary organic aerosol levels and RHC emission levels cannot presently be established from a theoretical analysis of the chemical reactions involved in the transformation because the chemical reactions are not well understood. One specific reaction that has been implicated is the combination of

olefins with ozone, [10], [22]. However the total basic system of reactions for secondary organic aerosol formation is still unknown.

The relationship between secondary organic aerosol levels and RHC emissions also cannot presently be determined from empirical models based on atmospheric monitoring data. Existing aerometric data is inadequate for both the precursor (reactive hydrocarbons) and the end product (secondary organic aerosol). The inadequacies of ambient monitoring data for reactive hydrocarbons have been previously discussed [48], [49]. Most measurements of organic aerosol in the Los Angeles Region consist of data on benzene solubles. Primary organic aerosol is rather soluble in benzene, but secondary organic aerosol is highly insoluble, [7], [9]. Thus, benzene soluble data provide a poor indication of secondary aerosol levels in Los Angeles and are inappropriate for use in an empirical model for secondary organics.

Recent smog chamber experiments are shedding some light on the relationship between secondary aerosol levels and RHC input. These experiments show that changing HC mixture has an extremely complex effect on aerosol formation [47]. However, for a given HC mixture, preliminary results seem to indicate a linear-proportional relationship between total HC input and total aerosol formation, [50]. Although these results pertain to total aerosol produced, it appears reasonable to assume that they also pertain to the organic fraction of the aerosol (which is of interest here).

In this study, a linear-proportional relationship will be assumed for the dependence of non-background secondary aerosol levels on total RHC emissions. Although this assumption is in qualitative agreement with

some recent smog chamber results, its applicability is nonetheless very uncertain. There are no firm theoretical or atmospheric - empirical results which support the proportional formula for secondary organics. The main justification for the linear rollback formula is that it is the simplest and most obvious one to assume until more evidence is gathered.

#### 4.0 BASELINE PARTICULATE AIR QUALITY PROJECTIONS FOR THE METROPOLITAN LOS ANGELES REGION

Chapter 2 characterized the origins of annual average particulate levels at 12 locations in the Metropolitan Los Angeles Region. Chapter 3 provided (linear) relationships linking the contributions from controllable origin categories to contaminant emission levels. By combining these results, we obtain a model that yields annual average particulate levels at each location as functions of total emission levels in the Los Angeles Region.

##### Illustration of the Completed Model

Table 4-1 illustrates the application of the air quality/emission level model. The left side of Table 4-1 presents the 1972 origin classification for an example location, Downtown Los Angeles. The center column of the table describes a hypothetical control strategy for primary particulates,  $\text{SO}_2$ ,  $\text{NO}_x$ , and RHC. The right side of the table gives the predicted impact of the control strategy. In this hypothetical case, the  $140 \mu\text{g}/\text{m}^3$  AAM in 1972 would be reduced to  $78 \mu\text{g}/\text{m}^3$  AAM by the control strategy.

##### A Special Case: Chino

In this study, the model will be applied as illustrated above to each location with one exception. The exception involves the primary particulate and sulfate contributions at Chino. For the other eleven locations and other origin categories, the origin contribution will be factored (rolled-back) according to total emissions in the Four-County Sub-Area. However, for non-background primary particulates and sulfate at Chino, an allowance will be made for localized emissions.



TABLE 4-1 HYPOTHETICAL ILLUSTRATION OF  
THE MODEL FOR PREDICTING CONTROL  
STRATEGY IMPACT ON PARTICULATE  
AIR QUALITY LEVELS

Origin Categories	1972 Base Year Origin Character- ization for Down- town Los Angeles $\mu\text{g}/\text{m}^3$	Hypothetical Control Strategy (% Reduction from the 1972 Base Year Level)	Air Quality Resulting from the Control Strategy ( $\mu\text{g}/\text{m}^3$ )
BACKGROUND CONTRIBUTIONS (Sea Salt, Soil Dust, Man-Made Sources exterior to the L.A. Region, and Background $\text{SO}_4$ , $\text{NO}_3$ , and Secondary Organics)	44		44
NON-BACKGROUND CONTRIBUTIONS			
PRIMARY-----	54	67% Reduction in Primary Particulate Emissions →	18
SECONDARY:			
$\text{SO}_4$ -----	10	50% Reduction in $\text{SO}_2$ Emissions →	5
$\text{NO}_3$ -----	11	50% Reduction in $\text{NO}_x$ Emissions →	$5\frac{1}{2}$
$\text{NH}_4$ -----	1	50% Reduction in $\text{SO}_2$ & $\text{NO}_x$ →	$\frac{1}{2}$
Secondary Organics	20	75% Reduction in RHC Emissions →	5
TOTAL AAM	140 $\mu\text{g}/\text{m}^3$	→	78 $\mu\text{g}/\text{m}^3$

As explained in Section 2.4.2, the Chino monitoring site appears to experience a particularly strong influence from a localized source. This source, evidently the Kaiser Steel/Edison Electric complex, leads to abnormally high primary particulate and sulfate levels at Chino. Estimates of the contributions from the localized source are presented in Table 2-2. The model will be applied in a special way to Chino by rolling back the localized origin contributions (column III in Table 2-19) according to emissions from the localized source and by rolling back the remainder (column II in Table 2-19) according to total emissions in the Four-County Sub-Area. Appendix A summarizes the techniques used to forecast emissions for the localized source.

TABLE 4-2

BREAKDOWN OF PRIMARY PARTICULATE AND  
SULFATE CONTRIBUTIONS AT CHINO

	COLUMN I Total 1972 non-background level*  ( $\mu\text{g}/\text{m}^3$ )	COLUMN II Typical value for similar stations not strongly influenced by the localized source*  ( $\mu\text{g}/\text{m}^3$ )	COLUMN III Contribution from the localized source  (II Minus I) ( $\mu\text{g}/\text{m}^3$ )
Primary Suspended Particulates	89	30	59
Sulfates	18	9	9

\* See Table 2-17.

The present chapter will illustrate the application of the air quality/emission level model by forecasting air quality levels for the baseline emission projections given in Support Document #2 of this project [18]. These results will be presented in Section 4.2.

Section 4.1 resolves a preliminary issue. The air quality/emission level model gives predicted particulate air quality in terms of annual arithmetic means. However, the federal annual air quality standards for particulates are stated as geometric means. Section 4.1 derives target annual arithmetic mean levels for the Los Angeles Region which approximate the geometric mean standards.

#### 4.1 ARITHMETIC MEAN TARGET LEVELS CORRESPONDING TO THE GEOMETRIC MEAN STANDARDS

National air quality standards for suspended particulates have been established for both long term (annual) and short term (24 hour) concentrations. As explained in Section 3.1, the present study will address only the long term standards. These standards are expressed in terms of annual geometric means:

Primary Standard .....  $75 \mu\text{g}/\text{m}^3$  (AGM)  
Secondary Standard ...  $60 \mu\text{g}/\text{m}^3$  (AGM).

In order to preserve overall linearity, the aerosol origin characterization was carried out in terms of annual arithmetic means, and the resulting model of the relationship between suspended particulate levels and emission levels is appropriate to arithmetic means. A method is required to reconcile the outputs of the air quality model, (arithmetic means), with the form of the air quality standards, (geometric means). The method used here will be to approximate the geometric mean standards by equivalent arithmetic mean levels.

Table 4-3 gives the ratio of arithmetic mean (AM) to geometric mean (GM) for log normal distributions with various geometric standard deviations, ( $S_g$ ). In the Los Angeles Region, suspended particulate distributions

TABLE 4-3 RATIO OF ARITHMETIC MEAN TO GEOMETRIC MEAN VS. GEOMETRIC STANDARD DEVIATION FOR LOG NORMAL DISTRIBUTIONS

GEOMETRIC STANDARD DEVIATION $S_g$	RATIO OF ARITHMETIC MEAN TO GEOMETRIC MEAN AM/GM
1.3	1.035
1.4	1.06
1.5	1.09
1.6	1.12
1.7	1.15
1.8	1.19
1.9	1.23
2.0	1.27

typically have values of  $S_g$  in the range 1.4 to 1.7, (See Support Document #1, [1]). Thus, arithmetic means tend to fall approximately 6 to 15% higher than geometric means.

It is not obvious whether the implementation of control strategies will significantly alter  $S_g$  values in the Los Angeles Region. Since there now appears to be no significant correlation between  $S_g$  and total suspended particulate levels at various locations in the Los Angeles Region, [1], one might expect that the values for  $S_g$  would not change much with control strategy implementation. Assuming that  $S_g$  values remain the same, the arithmetic means would remain about 6 to 15% higher than the geometric means. This implies that the federal primary annual standard ( $75 \mu\text{g}/\text{m}^3$  AGM) is equivalent to around  $80\text{--}86 \mu\text{g}/\text{m}^3$  AAM, and that the federal secondary annual standard ( $60 \mu\text{g}/\text{m}^3$  AGM) is equivalent to around  $64\text{--}69 \mu\text{g}/\text{m}^3$  AAM.

For the purposes of this study, it will be assumed that the federal primary annual standard for particulates is equivalent to a target AAM level of  $80 \mu\text{g}/\text{m}^3$  and that the federal secondary annual standard is equivalent to a target AAM of  $65 \mu\text{g}/\text{m}^3$ . These target arithmetic mean levels are on the "conservative" side of the estimates made above, i.e., achieving these target AAM levels will likely result in air quality slightly better than the federal standards.

#### 4.2 AIR QUALITY FORECASTS FOR THE BASELINE EMISSION PROJECTIONS

Table 4-4 summarizes the emission projections for primary particulates,  $\text{SO}_2$ ,  $\text{NO}_x$ , and RHC that were derived in Support Document #2 of this project,[18]. Projections are given for two scenarios: (1) "present controls", (controls presently scheduled to go into effect by the local APCD's plus the California ARB and federal new car control programs); and (2) "EPA oxidant plan", (the present controls plus the controls called for in the EPA-promulgated plan for oxidant in the Los Angeles Region, [51]). The values are for the 4 County Sub-Area, (Los Angeles, Orange, Riverside, and San Bernardino),

TABLE 4-4 SUMMARY OF EMISSION PROJECTIONS FOR THE  
4 COUNTY SUB-AREA OF THE LOS ANGELES REGION

Pollutant	1972 Base Year Emissions	--Tons/Day--		EPA Oxidant Plan	
		Present Controls		1977	1980
		1977	1980		
Primary Suspended Particulates	178	233	240	223	233
$\text{SO}_2$	444	530	540	524	535
$\text{NO}_x$	1345	1614	1434	1614	1434
RHC	1095	741	567	547	410

which experiences particulate levels well in excess of the air quality standards and in which the 12 sites of the aerosol characterization are located.

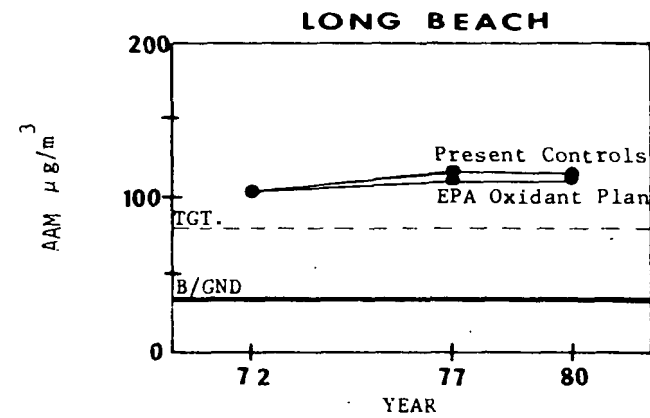
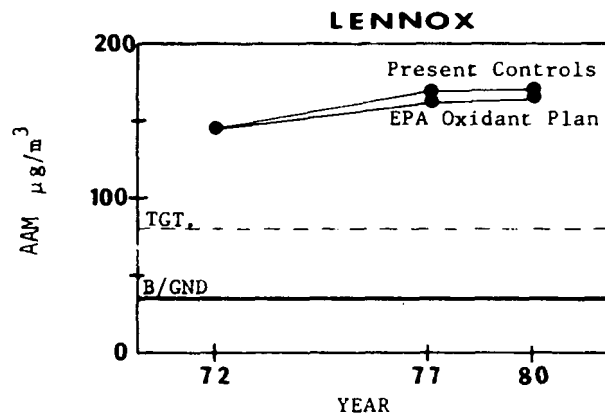
As demonstrated in Table 4-4, primary suspended particulate and  $\text{SO}_2$  emissions are forecasted to increase through 1977 and 1980. This is the result of source growth and of projected switches from natural gas to fuel oil; these factors will outstrip the presently planned controls for primary particulates and  $\text{SO}_2$ . Basically due to the same two factors,  $\text{NO}_x$  emissions are also predicted to increase from 1972 base year levels. However, in the late 1970's, the new car controls should reverse the upward trend in  $\text{NO}_x$  emissions. RHC emissions will decrease due to the new and used car control programs. The EPA oxidant plan brings about even greater reductions in RHC emissions. For details on these projections, the reader is referred to Support Document #2, [18].

Figure 4-1 presents forecasted air quality levels at eight locations for the two baseline emission scenarios. The air quality projections have been derived from the emission projections by using the model outlined in Section 4.0 with the data in Tables 2-17 and 4-4. As noted in Section 4.0, the model is applied in a special way to the Chino monitoring site. The methods of emission projection for the localized Chino source are outlined in Appendix A.\*

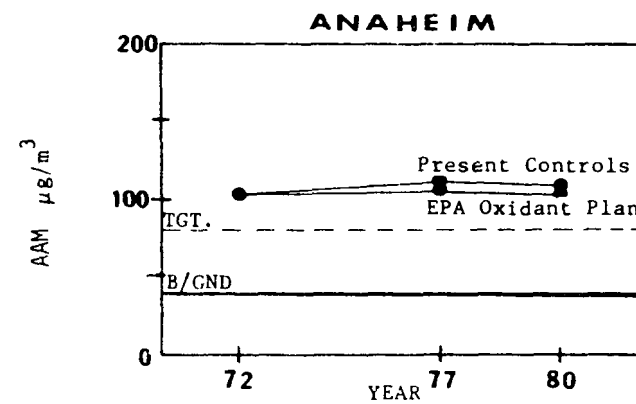
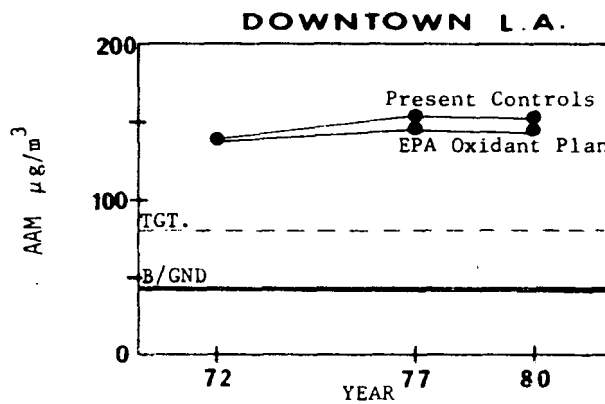
\* The projected primary particulate and  $\text{SO}_2$  levels for the local Chino source (assuming no further controls) are as follows:

(Kaiser/Edison Complex)		
Emissions as % of 1972 level		
	<u>1977</u>	<u>1980</u>
Primary Particulates	150%	147%
$\text{SO}_2$	166%	163%

## COASTAL AREA



## CENTRAL — VALLEY AREA

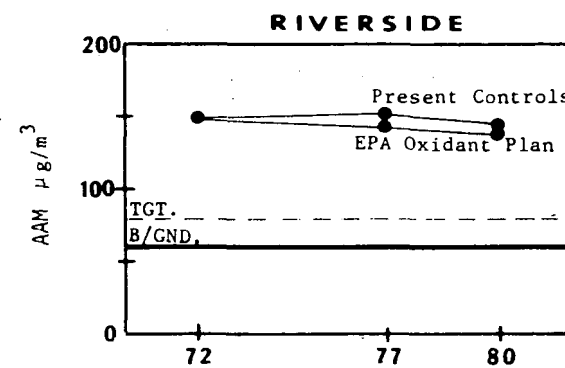
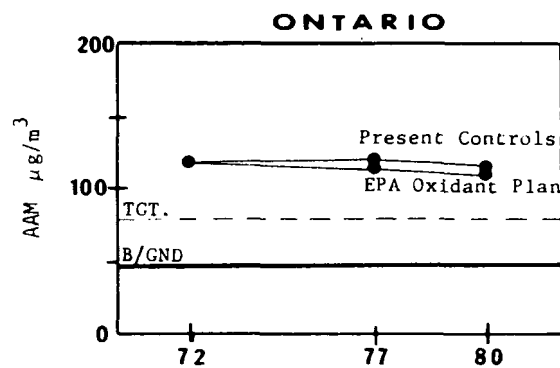
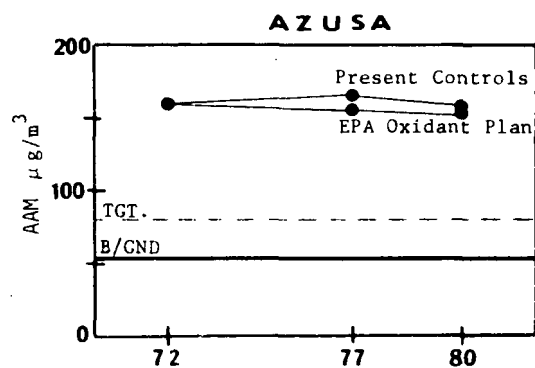


LEGEND:

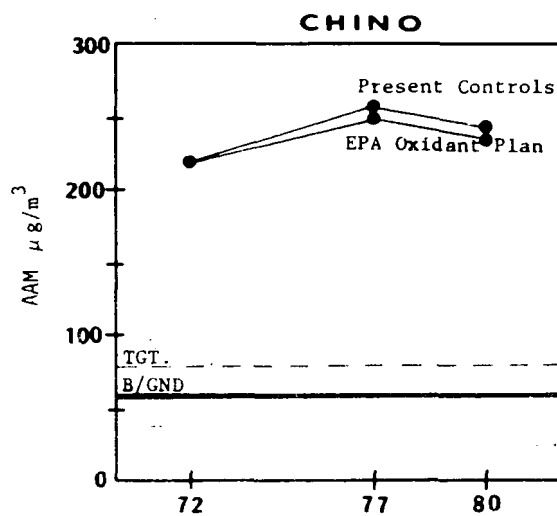
TGT. --- TARGET FOR PRIMARY STANDARD  
 B/GND — ESTIMATED BACKGROUND

Figure 4-1 Suspended Particulate Air Quality Forecasts for the Baseline Emission Projections

## EASTERN-INLAND AREA



## WESTERN SAN BERNARDINO COUNTY HOT-SPOT



## LEGEND:

TGT. --- TARGET FOR  
PRIMARY STANDARD

B/GND — ESTIMATED BACKGROUND

Figure 4-1 Suspended Particulate Air Quality Forecasts for the Baseline Emission Projections (continued)



It is apparent that the projected increases in primary particulate,  $\text{SO}_2$ , and  $\text{NO}_x$  emissions will lead to a deterioration of suspended particulate air quality at most locations. Reductions in secondary organics (due to decreases in RHC emissions) are sufficient to keep particulate levels about constant in the eastern-inland area where secondary organics are particularly important. The deterioration of air quality is especially pronounced at Chino; with no further controls, the forecasted increase in primary particulates and  $\text{SO}_2$  from the Kaiser Steel/Edison Electric complex will result in considerable worsening of an already severe particulate problem.\*

In the final report of this study, an implementation plan is formulated to achieve decreases in primary particulate,  $\text{SO}_2$ ,  $\text{NO}_x$ , and RHC emissions by 1977 and 1980. The effect of these emission reductions will again be calculated using the simple linear model of Section 4.0. The goal will be to select control strategies that will be sufficient to attain the federal standards for total suspended particulates in the Los Angeles Region.

---

\* Actually, some significant emission controls are planned for the Kaiser/Edison complex. They have not been included in the above projections because the expected emission reductions have not yet been documented. These controls may be similar to the controls proposed in the final report of this study.

## REFERENCES

1. TRW Environmental Services, The Development of a Particulate Implementation Plan for the Los Angeles Region, Support Document #1, Analysis of Air Monitoring Data, (Preliminary), Prepared for the Environmental Protection Agency under Contract #68-02-1384, Redondo Beach, California, May 1974.
2. White, W., Post Doctoral Research Assistant, Environmental Health Engineering Department, Caltech, Pasadena, California. Personal Communication of data from Phase II of the California Aerosol Characterization Study (ACHEX) performed by Rockwell International for the California Air Resources Board under Contract #358, July 1974.
3. Lundgren, D. A., "Atmospheric Aerosol Composition and Concentration as a Function of Particle Size and of Time", Journal of the Air Pollution Control Association, Vol. 20, #9, September 1970.
4. Duckworth, S., Meteorologist, California Air Resources Board, Sacramento, California. Personal Communication, May 1974.
5. San Bernardino Air Pollution Control District, Final Report ... Suspended Dust Study, ~1969.
6. White, W., Post Doctoral Research Assistant, Environmental Health Engineering Department, Caltech, Pasadena, California. Personal Communication, July 1974.
7. Miller, M. S., Friedlander, S. K., and Hidy, G. M., "A Chemical Element Balance for the Pasadena Aerosol", Journal of Colloid and Interface Science, Vol. 39, No. 1, April 1972.
8. Hidy, G. M., et al., "Observations of Aerosols Over Southern California Coastal Waters", Submitted to Journal of Applied Meteorology, May 1973.
9. Holzworth, G. C., "Atmospheric Contamination at Remote California Sites", J. Meteorol, 16, #68, February 1959.
10. Hidy, G. M., et al, Characterization of Aerosols in California, Interim Report for Phase I, Prepared for the California Air Resources Board by Rockwell International Under ARB Contract #358, December 1973.
11. U.S. Environmental Protection Agency, Air Quality Data for 1967 from the National Air Surveillance Networks, APTD-0978, August 1972.
12. Hidy, G. M., and Friedlander, S. K., "The Nature of the Los Angeles Aerosol", Proceedings of the Second International Clean Air Congress, Academic Press, p. 391-404, 1971.

13. Friedlander, S. K., "Chemical Element Balances and Identification of Air Pollution Sources", Environmental Science & Technology, Vol. 7, #3, March 1973.
14. Gartrell, G., and Friedlander, S. K., "Relating Particulate Pollution to Sources: The 1972 California Aerosol Characterization Study", Working Paper, W. M. Keck Laboratory of Environmental Engineering, Caltech, Pasadena, California.
15. California Air Resources Board, "California Air Quality Data", Quarterly Reports, 1972-1973.
16. Gordon, R. J. and Bryan, R. J., "Ammonium Nitrate in Airborne Particles in Los Angeles", Environmental Science and Technology, Vol. 7, July 1973.
17. Grosjean, Daniel, Research Associate, Environmental Health Engineering, Caltech, Pasadena, California, Personal Communication, June 1974.
18. TRW Environmental Sources, The Development of a Particulate Implementation Plan for the Los Angeles Region, Support Document #2, Emission Inventories and Projections (Preliminary), Prepared for the Environmental Protection Agency under Contract #68-02-1384, June 1974.
19. Holmes, J., Spectroscopist, California Air Resources Board, El Monte, California. Personal Communication, July 1974.
20. Ter Haar, G. L., Lenane, D. L., and Brandt, M., "Composition, Size and Control of Automotive Exhaust Particulates", J. of the Air Poll. Control Assoc., Vol. 22, #1, January 1972.
21. Habibi, K., "Characterization of Particulate Matter in Vehicle Exhaust", Environmental Science and Technology, Vol. 7, #3, March 1973.
22. O'Brien, R. J., Holmes, J. R., and Bockian, A. H., "Photochemical Aerosol Formation in the Atmosphere and in an Environmental Chamber", Presentation before the Division of Environmental Chemistry, American Chemical Society, Los Angeles, April 1974.
23. Los Angeles County Air Pollution Control District, Air Monitoring Logs, 434 So. San Pedro St., Los Angeles.
24. Zeldin, M., Meteorologist, San Bernardino County Air Pollution Control District. Personal Communication, May 1974.
25. U.S. Department of Health, Education, and Welfare, Air Quality Criteria for Sulfur Oxides, AP-50, April 1970.
26. Bufalini, M., "Oxidation of Sulfur Dioxide in Polluted Atmospheres - A Review", Environmental Science and Technology, Vol. 5, #8, August 1971.
27. Altshuller, A. P., "Atmospheric Sulfur Dioxide and Sulfate", Environmental Science and Technology, Vol. 7, #8, August 1973.

28. Appel, B., "Sulfate and Nitrate Chemistry in Photochemical Smog", Presentation before the Division of Environmental Chemistry, American Chemical Society, Los Angeles, April 1974.
29. Roberts, Paul, Graduate Student, Environmental Health Engineering, Caltech, Pasadena, California, Personal Communication, June 1974.
30. Appel, B., Air and Industrial Hygiene Laboratory, California Department of Public Health, Berkeley, California, Personal Communication, June 1974.
31. Gerhard, E. R. and Johnstone, E. F., "Photo Chemical Oxidation of Sulfur Dioxide in Air", Ind. Eng. Chem., Vol. 47, May 1955.
32. Urone, P., Lutsep, H., Nozes, C. M., and Parcher, J. F., "Static Studies of Sulfur Dioxide Reactions in Air", Environmental Science and Technology, Vol. 2, 1968.
33. Hall, T. C., Jr., Ph.D. Thesis, University of California at Los Angeles, 1953.
34. Renzetti, N. A. and Doyle, G. J., "Photochemical Aerosol Formation in Sulfur Dioxide - Hydrocarbon Systems". International Journal of Air Pollution, Vol. 2, June 1960.
35. Wilson, W. E. Jr. and Levy, A., "Studies of Sulfur Dioxide in Photochemical Smog", American Petroleum Institute, Project S-11, Batelle Memorial Institute, 1968.
36. Leighton, P. A., Photochemistry of Air Pollution, Academic Press, New York, 1961.
37. Junge, C. E. and Ryan, T., "Study of the SO<sub>2</sub> Oxidation in Solution and its Role in Atmospheric Chemistry", Quart. J. Roy. Meteorol. Soc., Vol. 84, January 1958.
38. Smith, B. M., Wagman, J., and Foh, B. R., "Interaction of Airborne Particles with Gases", Environmental Science and Technology, Vol. 3, 1969.
39. Cox, R.A. and Penkett, S.A., "Aerosol Formulation from Sulfur Dioxide in the Presence of Ozone and Olefinic Hydrocarbons", Journal of the Chemical Society, Faraday Transactions, 1, Vol.68, 1972.
40. Wadley, M., Chief Chemist, Los Angeles County Air Pollution Control District. Personal Communication, July 1974.
41. Los Angeles County Air Pollution Control District, Profile in Air Pollution Control, 1971.
42. Environmental Protection Agency, Air Quality Criteria for Nitrogen Oxides, AP-84, January 1971.

43. Environmental Protection Agency, Air Quality Data for 1968 from the National Air Surveillance Networks, APTD-0978, August 1972.
44. Renzetti, N. A. and Doyle, G. J., "The Chemical Nature of the Particulate in Irradiated Automobile Exhaust", Journal of the Air Pollution Control Association, Vol. 8, 1959.
45. Wilson, W. E., Merryman, E. L., and Levy, A., A Literature Survey of Aerosol Formation and Visibility Reduction in Photochemical Smog, American Petroleum Institute, Project EF-2, Battelle Memorial Institute, August 1969.
46. Prager, M. J., Stephens, E. R., and Scott, W. E., "Aerosol Formation from Gaseous Air Pollutants", Int. Journal of Air and Water Pollution, Vol. 9, 1965.
47. Miller, D. F., Levy, A., and Wilson, W. E. Jr., A Study of Motor-Fuel Composition Effects on Aerosol Formation, Part II. Aerosol Reactivity Study of Hydrocarbons, American Petroleum Institute, Project EF-2, Battelle Memorial Institute, February 1972.
48. U.S. Department of Health, Education, and Welfare, Air Quality Criteria for Hydrocarbons, AP-64, March 1970.
49. Dimitriadis, B., "Application of Reactivity Criteria in Development of Control Strategies", EPA Working Paper, Chemistry and Physics Laboratory, June 1973.
50. Miller, D. F., Battelle Memorial Institute, Columbus, Ohio. Personal Communication, May 1974.
51. Federal Register, Vol. 38, No. 217, Nov. 12, 1973

## APPENDIX A

### A METHOD FOR PROJECTING EMISSIONS AND CALCULATING CONTROL IMPACTS FOR THE KAISER/EDISON COMPLEX

As noted in the text, (Section 4.0), the air quality/emission level model developed here is applied to the Chino monitoring site in a specialized way. The effect of primary particulate and sulfate emissions from the Kaiser Steel/Edison Electric complex is treated individually. This Appendix outlines the method that will be used in this study to project emissions for the Kaiser/Edison complex and to calculate the impact of control measures on those emissions.

Table A-1 gives a breakdown of suspended particulate and SO<sub>2</sub> emissions from the Kaiser/Edison complex. There are three main categories, metallurgical processes at Kaiser, oil/gas combustion at Kaiser, and oil/gas combustion at Edison. To project primary suspended particulate

TABLE A-1

BREAKDOWN OF PRIMARY SUSPENDED PARTICULATE  
AND SO<sub>2</sub> EMISSIONS AT THE KAISER/EDISON COMPLEX

	EMISSIONS -- (TONS/DAY)			
	KAISER STEEL		EDISON ELECTRIC ETIWANDA PLANT)	TOTAL
	Metallurgical Processes	Oil and Gas Combustion		
Primary Suspended Particulates	4.1	1.0	1.1	6.2
SO <sub>2</sub>	14.8	5.4	12.2	32.4

#### REFERENCES

Emission Data: [A1]  
Particulate Suspension Assumptions: [A2]

and SO<sub>2</sub> emissions from this complex and to calculate reductions from various control strategies, the following procedures will be used:

- The emissions from metallurgical processes at Kaiser Steel will be projected proportional to total metallurgical emissions in the 4 County Sub-Area.
- The emissions from oil and gas combustion at Kaiser Steel will be projected proportionate to total industrial fuel combustion emissions in the 4 County Sub-Area.
- The emissions at the Edison Etiwanda Plant will be projected proportional to total power plant emissions in the 4 County Sub-Area.

#### REFERENCES - APPENDIX A

- A-1. Hilovsky, R., Engineering Department, San Bernardino County Air Pollution Control District, personal communication, September 1974.
- A-2. TRW Environmental Services, "The Development of a Particulate Implementation Plan for the Los Angeles Region, Support Document #2, Emission Inventories and Projections", prepared for the Environmental Protection Agency under contract #68-02-1384, June 1974

AN IMPLEMENTATION PLAN FOR SUSPENDED  
PARTICULATE MATTER IN THE LOS ANGELES REGION

TECHNICAL SUPPORT DOCUMENT #4

ALTERNATIVE EMISSION CONTROL MEASURES

By: G. Richard

Prepared for  
Environmental Protection Agency  
Region IX - San Francisco, California

**TRW** / TRANSPORTATION AND  
ENVIRONMENTAL ENGINEERING  
OPERATIONS

ALTERNATIVE EMISSION  
CONTROL MEASURES



AN IMPLEMENTATION PLAN FOR SUSPENDED  
PARTICULATE MATTER IN THE LOS ANGELES REGION

TECHNICAL SUPPORT DOCUMENT #4

ALTERNATIVE EMISSION CONTROL MEASURES

By: G. Richard

Prepared for  
Environmental Protection Agency  
Region IX - San Francisco, California

**TRW** / TRANSPORTATION AND  
ENVIRONMENTAL ENGINEERING  
OPERATIONS

## DISCLAIMER

This report was furnished to the Environmental Protection Agency by TRW Transportation and Environmental Engineering Operations in fulfillment of Contract Number 68-02-1384. The contents of this report are reproduced herein as received from the contractor. The opinions, findings, and conclusions are those of TRW and not necessarily those of the Environmental Protection Agency. Mention of company or product names does not constitute endorsement by the Environmental Protection Agency.

## TABLE OF CONTENTS

	<u>Page</u>
1.0 INTRODUCTION	1
2.0 SUMMARY	3
2.1 Emission Control Region - The Four-County Area	3
2.2 The Major Pollution Sources	4
2.3 Existing Air Pollution Control	6
2.4 Alternative and Additional Candidate Controls	8
2.4.1 Identification of Candidate Control Measures	8
2.4.2 Effectiveness of the Candidate Control Measures	10
2.4.3 Cost of the Candidate Control Measures	13
2.5 Limitations of the Analysis	15
2.6 Conclusions and Recommendations	17
3.0 GENERAL CONTROL METHODS	21
3.1 Controls for Primary Particulates	21
3.1.1 Mechanical Collectors	23
3.1.2 Wet Scrubbers	27
3.1.3 Electrostatic Precipitators	28
3.2 Controls for Gaseous Precursors	37
3.2.1 Desulfurization of Petroleum Products	37
3.2.2 SO <sub>2</sub> Removal Technology	46
3.3 Alternative Fuels - A Control for Particulates, SO <sub>2</sub> , and NO <sub>x</sub>	50
3.4 Non Technological Controls	64
3.4.1 Growth Restrictions	65
3.4.2 Relocation	65
3.4.3 Source Usage	66
4.0 PETROLEUM INDUSTRY	69
4.1 Baseline Characterization	69
4.1.1 Emissions	69
4.1.2 Emission Control	73

## TABLE OF CONTENTS (Continued)

	<u>Page</u>
4.2 Alternative Control Measures	75
4.2.1 Particulate - Electrical Precipitators	75
4.2.2 Gaseous Precursors	77
5.0 STATIONARY FUEL COMBUSTION	85
5.1 Baseline Emissions	85
5.2 Current Emission Controls	89
5-3 Alternative Control Measures	91
5.3.1 Control of Particulates	91
5.3.2 NO <sub>x</sub> Control	95
5.3.3 Control of SO <sub>2</sub>	101
6.0 MINERALS INDUSTRY	113
6.1 Baseline Emissions and Controls	113
6.2 Alternative Control Measures	119
7.0 AIRCRAFT OPERATIONS	123
7.1 Baseline Characterization	123
7.1.1 Aircraft Emissions	123
7.1.2 Emission Controls	126
7.2 Alternative Control Measures	128
7.2.1 Retrofit Alternatives: Turbine Engines	128
7.2.2 Modification of Ground Operations	141
7.2.3 Fuel Alternatives	144
7.2.4 Retrofits for Piston Aircraft	145
8.0 MOTOR VEHICLE	149
8.1 Baseline Emissions and Emission Controls	149
8.2 Alternative Control Measures	155
8.2.1 Fuel Composition	155
8.2.2 Particulate Trap Devices	167
8.2.3 SO <sub>2</sub> Scrubbers	171
8.2.4 Fuel Substitution	174
8.2.5 Tire Options	175

## TABLE OF CONTENTS (Continued)

	<u>Page</u>
9.0 ORGANIC SOLVENTS	181
9.1 Baseline Emissions and Controls	181
9.2 Alternative Controls	185
10.0 METALLURGICAL OPERATIONS	187
10.1 Baseline Emissions	187
10.2 Emissions Controls	188
10.3 Alternative Controls	190
11.0 CHEMICAL PROCESSING INDUSTRY	197
11.1 Baseline Emissions	197
11.2 Emission Controls	198
11.3 Alternative Controls	198

## LIST OF TABLES

		<u>Page</u>
2-1	Major Emission Sources of the Four-County Area, For Baseyear (1972) and Future Years Under the EPA Implementation Plan	5
2-2	Summary of Emission Preventions Attainable With Implementation of the Most Effective Emission Control Options, Four-County Area, 1977	11
2-3	Summary of Cost for Implementation of Most Effective Emission Control Options, Four County Area, 1977	14
3-1	Cyclone Efficiency Versus Particle Size Range	25
3-2	Scrubber Capabilities	28
3-3	Control Mechanism for Particle Size Collection	33
3-4	Sulfur Content of Refinery Products for Different Crudes	38
3-5	Onplot Investment for Alternative Desulfurization Schemes	44
3-6	Direct Manufacturing Costs for Alternate Desulfurization Systems	45
3-7	Process for Desulfurization of Effluent Gas Streams Processed Principally in the Gas Phase	47
3-8	Lime-Limestone SO <sub>x</sub> Scrubbing Large-Scale Projects	51
3-9	Processes Used for Sulfur Removal From Claus Tail Gas	55
3-10	SO <sub>2</sub> Removal Processes Currently in Test	56
3-11	Capital Cost of Retrofitting SO <sub>2</sub> Cleanup Technology In Existing Power Generating Plants	58
3-12	Production Cost of Energy in Fuels, September 1972	61
3-13	Economics of Synthesis of 20,000 Tons/Day of Methanol (MeOH) From Coal	62
4-1	Emissions from the Petroleum Industry, Present and Future Four-County Area	70
4-2	Particulate Emissions From Petroleum Industry Operations, Four-County Area, 1972	71
4-3	SO <sub>2</sub> Emissions from Operations of the Petroleum Industry Four-County Area	72
4-4	NO <sub>x</sub> Emissions From Operations of the Petroleum Industry, Four-County Area	72

## LIST OF TABLES (Continued)

		<u>Page</u>
4-5	Characterization of Control Methods Currently Utilized In Petroleum Industry for Control of Major Particulate Emission Sources, Four-County Area, 1972	74
4-6	Impact of Alternative Controls on Emissions From Petroleum Refineries, 1977	81
4-7	Cost Effectiveness of Alternative Controls for Refinery Major Emission Sources in Four-County Area, 1977	82
5-1	Emissions of Fuel Combustion, Four-County Area	86
5-2	Summary of Fuel Burning Equipment	87
5-3	Comparison of Pollutants Emitted From Power Plants When Burning Natural Gas and Fuel Oil	87
5-4	Proportion of Fuel Usage (Percent) as Natural Gas For Basic Combustion Categories in South Coast Basin	88
5-5	Pollutant Emissions by Fuel Type Consumed for Basic Combustion Categories in Four-County Area	88
5-6	Summary of NO <sub>x</sub> Emission Rate Reductions Achieved at Edison Company Utility Boilers when Burning Gas Fuel	90
5-7	Particle Size Distribution of Typical Material Collected From a Steam Generator Stack During the Burning of Residual Fuel Oil	92
5-8	The Effect of Particulate Controls on Oil-Burning Combustion Equipment, 1977	93
5-9	Cost of Particulate Emission Control for Oil-Burning Combustion Equipment, 1977	94
5-10	The Effect of NO <sub>x</sub> Emission Controls on Fuel Combustion Equipment, Four-County Area	99
5-11	Impact of Candidate Controls on SO <sub>2</sub> Emissions From Fuel Combustion Units in Four-County Area, 1977	104
5-12	Cost of Controls for SO <sub>2</sub> Emissions From Fuel Combustion Units in Four-County Area	106
5-13	Impact of Conversion to Methyl-Fuel in Combustion Units in Four-County Area	108
5-14	Cost of Conversion to Burning to Methyl-Fuel in Combustion Equipment	108

## LIST OF TABLES (Continued)

		<u>Page</u>
6-1	Particulate Emissions from Major Mineral Process and Product Industries in the Four-County Area	114
6-2	Summary of Emission Controls Currently Utilized in Minerals Industry of Los Angeles County	115
7-1	Emissions From Aircraft, Present and Projected, Four-County Area	124
7-2	Jumbo Jet Emission Characteristics	125
7-3	General Aviation Piston Emission Characteristics	125
7-4	Aircraft Emissions, Present and Projected Piston and Jet	126
7-5	Effect of Smoke Combustor Retrofit On Emissions in Los Angeles County	126
7-6	Aircraft Emission Standards	127
7-7	Engine Modifications for Emission Control for Existing And Future Turbine Engines	128
7-8	Effectiveness of Engine Modification in Control of Emissions from Turbine Engines, By Operating Mode	130
7-9	Basis for Control Method Effectiveness Estimates For Turbine Engines	132
7-10	Turbine Engine Classification	133
7-11	Average Annual Tons of Air Contaminants Emitted in Los Angeles County By Gas Turbine Aircraft Engines Operated At LAX in 1970	134
7-12	Modal Emissions Distribution for Principal Jet Engines In use	136
7-13	Impact of Alternative Control on Overall Jet Aircraft Emissions	137
7-14	Time and Costs for Modification of Current Civil Aviation Engines	138
7-15	Cost Results for Turbine Engine Population by Separate Use Categories	139
7-16	Cost Effectiveness for Turbine Retrofit Measures, 1977, Four-County Area	140



# LIST OF TABLES (Continued)

	<u>Page</u>
7-17 Comparative Reductions Resulting From Control Methods Applied at Los Angeles International Airport	143
7-18 Impact of Ground Operation Modifications on Turbine Aircraft Emissions of Four-County Area	144
7-19 Engine Modifications for Emission Control for Existing and Future Piston Engines	147
8-1 Role of Motor Vehicle Emissions in Atmospheric Pollution of Four-County Area	149
8-2 Sulfuric Acid Emissions From Pelletized Oxidation Catalyst Equipped Vehicle, 1975 Federal Test Procedure	152
8-3 Sulfuric Acid Emissions From Monolithic Oxidation Catalyst Equipped Vehicles, 1972 Federal Test Procedure	152
8-4 Suspended Particulate Emissions From Motor Vehicles Using Leaded And Unleaded Fuel	156
8-5 The Effect of Lead Removal in Motor Fuels on Motor Vehicle Particulate Exhaust Emissions in Four-County Area	160
8-6 Cost of Removing all Lead From Motor Vehicle Fuel Pool (As Opposed to the EPA Plan Requiring Partial Removal by 1977)	161
8-7 The Effect of Automotive Fuel Desulfurization (100 ppm) on Motor Vehicle Emissions in Four County Area	164
8-8 Cost of Desulfurization of Vehicle Fuels for Control of Exhaust Emissions	165
8-9 Impact of Particulate Traps on Particulate Emissions From Motor Vehicles in Four-County Area	169
8-10 Cost of Implementing Particulate Emission Control From Motor Vehicles with Particulate Traps, Four-County Area	170
8-11 Impact of Scrubber on SO <sub>2</sub> and Particulate Emissions From Motor Vehicles in Four County Area	172
8-12 Cost of Equipping Vehicle Population With Scrubber Device For Control of SO <sub>2</sub> and Particulate Emissions, Four-County Area, 1977	173
8-13 Emissions From a 1972 Gremlin Converted for Methanol Consumption	175
9-1 Role of Organic Solvent Emissions in Atmospheric Pollution of Four-County Area	181

## LIST OF TABLES (Continued)

9-2	Emissions From Organic Solvent Operations In Four-County Area	182
9-3	Characterization of Emission Sources Arising From Organic Solvent Operations in Los Angeles County, 1972	183
9-4	Emissions From Paint Spray Booths and "Other" Organic Solvent Operations, Four-County Area, 1972	184
9-5	Effect of Retrofit Water Wash Control on Emissions From Paint Spray Booths	185
10-1	Role of Metallurgical Industry Emissions in Atmospheric Pollution of Four-County Area	187
10-2	Emissions From Metallurgical Operations in Four-County Area	188
10-3	Characterization of Furnace Control Effectiveness, Four-County Area	189
10-4	Characterization of Emission Sources Arising From Metallurgical Operations in Los Angeles County, 1972	191
10-5	Effect of Baghouse Retrofit on Uncontrolled Particulate Emissions from Furnaces in Four-County Area	193
10-6	Effect of Retrofitting SO <sub>2</sub> Cleanup Systems to Lead Refining Furnace Effluents in Four-County Area	193
10-7	Cost of Retrofit Control Alternatives for Metallurgical Furnace Emissions, Four-County Area, 1977	194
11-1	Role of Chemical Processing Industry in Atmospheric Pollution of Four-County Area	197
11-2	Emissions From Chemical Processing Operations in Four-County Area, Tons/Day	198
11-3	Characterization of Particulate Emission Sources Associated With Chemical Processing Operations in Los Angeles County	200

	LIST OF FIGURES	<u>Page</u>
2-1	Degree of Emission Control Effectiveness Required To Maintain a Given Air Quality When Emission Sources Are Increasing	12
3-1	Increasing Market Demand for Air Pollution Equipment in United States	22
3-2	Baffled Settling Chamber	23
3-3	Reverse Flow Cyclone	24
3-4	Purchase and Installation Cost of Centrifugal Collectors	26
3-5	Annualized Cost of Operation of Centrifugal Collectors	26
3-6	Purchase and Installation Cost of Wet Collectors	29
3-7	Annualized Cost of Wet Collectors	29
3-8	Cross Sectional View of Tubular Blast Furnace Electrical Precipitator	31
3-9	Cost of Purchase and Installation of High-Voltage Electrical Precipitator	32
3-10	Annualized Cost of Operation of High-Voltage Electrostatic Precipitator	32
3-11	Schematic of Basic Three Baghouse Designs	35
3-12	Cost of Purchase and Installation of Baghouse Particulate Collector	36
3-13	Annualized Cost of Operation of Baghouse Particulate Collectors	36
3-14	Continued Improvement in VGO Isomax Process	39
3-15	Cost to Desulfurize Arabian Heavy Crude Oil with VGO Isomax	40
3-16	Effect of Feed Desulfurization on Fluid Catalytic Cracker Product Sulfur Contents at Constant Cracking Severity	41
3-17	Cost of Effectiveness for SO <sub>2</sub> Removal Systems	57
3-18	The Investment for Desulfurization Facilities at Sulfur Recovery Plants	59
3-19	Operating Costs for Removing the Residual Sulfur from Conventional Claus Units	59

## LIST OF FIGURES (Continued)

		<u>Page</u>
4-1	Role of Petroleum Industry in Atmospheric Pollution of Four-County Area, 1972	70
4-2	Control of Particulates and Carbon Monoxide in Catalytic Regeneration Systems	75
4-3	Effect of Sulfur Content on Cracker Feed Stock on Regeneration Unit Stack SO <sub>2</sub> Emissions	80
5-1	Role of Fuel Combustion in Atmospheric Pollution of Four-County Area	85
5-2	Effect of Combustion Air Quantity on NO Formation	96
5-3	Effect of Combustion Air Preheat Temperature on NO Formation	97
7-1	Role of Aircraft Emissions in Atmospheric Pollution of Four-County Area	123
7-2	Gaseous Emission Characteristics of a JT8D Turbine Engine	142
7-3	Emission Characteristics for Piston Engine	145
8-1	The Effect of Exhaust Emission Standards on Pollutant Emissions from Various Vehicle Categories	151
8-2	Effect of Lab Sulfur Charging on CO Reactivity of a Cu-CR Catalyst	154
8-3	Effect of Lab Sulfur Charging on HC Reactivity of a Cu-Cr Catalyst	154
8-4	Typical "Blending" Properties of Southern California Motor Gasoline	159

## 1.0 INTRODUCTION

Under contract to the Environmental Protection Agency, TRW Environmental Services has developed a particulate implementation plan for the Metropolitan Los Angeles Air Quality Control Region. Specifically, TRW has investigated strategies for approaching and achieving the National Ambient Air Quality Standards for suspended particulate matter in the Los Angeles Region. This report, the fourth of four technical support documents associated with the project, provides a characterization of alternative emission control measures applicable to the Los Angeles Region.

The objective of the study described in this report was to identify and characterize the various alternative emission control measures which might be employed to achieve the Ambient Air Quality Standards for particulate matter in the Los Angeles Region. Recognizing that several types of emissions are related to pollution by airborne particles, the study included an identification of emission control options for the management of gaseous precursors of secondary particulates, namely sulfur dioxide and nitrogen oxides. The omission in the study of the consideration of emission controls for reactive hydrocarbon precursors was justified on the basis that the control of this pollutant species was the principal subject of extensive investigation in the preparation of the State Air Program Implementation plan. Consequently it was considered unlikely that this study could provide additional insights to this already well studied issue.

The study deals with the control of emissions from the eight dominant emission source categories. The investigation of alternative emission control measures which may be used to prevent emission of particulates,  $\text{SO}_2$ , and  $\text{NO}_x$  from each of the eight source categories is compiled in eight corresponding sections of the report. Each of the sections is a self-contained chapter containing 1) a characterization of the baseyear and projected baseline (assuming implementation of EPA air programs) emissions for the category, 2) a description of existing emission control methods,

and 3) an identification and description of candidate emission control measures, and an analysis of the impact and cost of these controls. Section 3.0 provides an overview of the more significant emission control measures relevant to the study, and Section 2.0 contains a summary of some of the more significant findings.

The investigation was carried out through reliance on several different data sources. The Los Angeles Air Pollution Control District cooperated in supplying TRW with a printout of the District's Computer Emission Inventory File, which provides a description of each individual emission source permit in terms of the process equipment, emission control equipment, and emissions and preventions estimates. This file was utilized primarily to help determine the current status of controls in the different source categories. Numerous consultations with APCD officials were arranged to augment and clarify the District's data. Candidate emission control alternatives were identified by a search of the public domain, by contact with numerous manufacturers of the eight process categories, by contact with developers and manufacturers of the candidate control systems, and by communication with cognizant researchers studying in the subject area.

It is hoped that the individual chapters of this report will help provide a basis for the formulation of an emission control strategy which may be implemented to attain the National Ambient Air Quality Standards in the Los Angeles Region.

## 2.0 SUMMARY

This chapter provides a brief summary of the more significant findings of the study on alternative emission control measures. It is necessarily selective with regard to certain aspects of the study, hence the reader is encouraged not to constrain his scope solely within the summary framework. Section 2.1 describes the basis for the emission control study region definition; Section 2.2 includes a delineation of the major emission source categories of the study; Section 2.3 is a characterization of current emission controls; Section 2.4 provides a discussion of candidate emission controls; Section 2.5 is a statement of limitations affecting the study, and Section 2.6 provides recommendations based on the study findings.

### 2.1 EMISSION CONTROL STUDY REGION - THE FOUR-COUNTY AREA

Air monitoring data has consistently shown that there are substantial variations in air quality among various portions of the South Coast Air Basin. One of the most definitive regional differences is the contrast of air quality characteristics in Santa Barbara and Ventura Counties with those in the remainder of the Basin (Los Angeles, Orange, San Bernardino, and Riverside Counties). The air resources of Santa Barbara and Ventura are relatively remote from the remaining "Four-County Area" in a meteorological sense, and consequently the air pollution problems of these two portions of the Basin are distinctly separate. Moreover, the character and quantity of pollution sources of each of the two regions are substantially different. These factors would suggest the sensibility of developing separate air resources management techniques for each of the two portions.

Air monitoring data for Santa Barbara and Ventura demonstrate that the National Ambient Air Quality Standards for particulate concentrations are seldom exceeded. By contrast, the remaining Four-County Area of the Basin frequently experiences dramatic violations of the particulate standard. Except for minor differences, the air pollution regulations governing pollution sources in both Basin segments are essentially the same. In view of these factors, it appears plausible to direct the substantial effort of this study to develop pollution control alternatives for the worst case of the Basin, (the Four-County Area) with the reasonable

assumption that this effort would adapt to the construction of candidate control plans applicable to the two northern counties of the Basin.

## 2.2 THE MAJOR AIR POLLUTION SOURCES

In Los Angeles, formidable reductions in air pollution emissions must be obtained if air quality is to be upgraded to the National Ambient Air Standards. A successful air pollution control implementation plan will depend greatly on the effectiveness of controls proposed for the major pollution sources. Clearly the control of the largest sources is a prerequisite to any further action. If it can be shown that effective emission controls can be feasibly applied to large pollution sources, the justification exists to develop further an equitable plan for control of smaller, less significant sources.

It was established early in this study that the greater portion of the effort should be directed to investigating the feasibility of controlling emissions from large sources. Large sources were identified in terms of those process categories which are the most significant generators of particulate emissions, including the gaseous precursors  $\text{NO}_x$  and  $\text{SO}_2$ . Examination of the 1972 baseyear for the Four-County Area revealed the dominance of eight major process categories in the role of significant pollution. Table 2-1 provides an identification of the eight categories, and their role in atmospheric emissions. The eight process categories are responsible for all but about 3% of the particulate,  $\text{SO}_2$ , or  $\text{NO}_x$  emissions generated about the Four-County Area. This status of this relationship is maintained for the next several years. The remaining 3% of the Four-County emission inventory is comprised of sources such as ships and railroads, agriculture, and incineration operations.

Of the eight major process categories, four warrant special attention. These are fuel combustion, motor vehicles, petroleum refining, and aircraft. In 1977 these four process categories themselves are projected to account for 79% of all  $\text{SO}_2$  emitted from sources in the Four-County Area, 93% of all  $\text{SO}_2$  emitted, and 98% of all  $\text{NO}_x$  generated. It is clear that effective control of these four major sources must be achieved for attainment of ambient air quality federal standards.



TABLE 2-1. MAJOR EMISSION SOURCES OF THE FOUR-COUNTY AREA, FOR BASEYEAR (1972)  
AND FUTURE YEARS UNDER THE EPA IMPLEMENTATION PLAN

Process Category	Total Particulates			SO <sub>2</sub>			NO <sub>x</sub>		
	1972	1977	1980	1972	1977	1980	1972	1977	1980
1. Fuel Combustion	44.9	83.5	86.1	208	374	380	282	672	629
2. Motor Vehicles <sup>a</sup>	85.4	71.4	69.2	48.9	46.1	47.0	950	815	665
3. Petroleum	3.0	3.0	3.0	60.0	60.0	60.0	67.5	67.5	67.5
4. Aircraft	15.0	26.8	38.3	3.6	6.5	9.6	18.6	32.2	45.4
5. Chemical	9.2	9.7	10.1	97.0	10.0	10.1	.4	.5	.5
6. Metallurgical	12.3	13.4	14.0	13.0	15.0	15.9	.5	.6	.5
7. Organic Solvent	8.0	8.5	8.7	-	-	-	-	-	-
8. Mineral	12.3	12.5	12.8	1.4	1.7	1.8	-	-	-
SUBTOTAL FOR 8 CATEGORIES	190	229	242	432	515	524	1319	1588	1408
TOTAL EMISSIONS, FOUR-COUNTY AREA	196	235	249	444	525	536	1345	1614	1434
PERCENTAGE OF ALL EMISSIONS GENERATED BY 8 CATEGORIES	97.0	97.4	97.2	97.2	97.7	97.8	98.1	98.3	98.2

<sup>a</sup>Motor Vehicle emissions include airborne particulates arising from tire wear.

Source: data: Reference (1).

### 2.3 EXISTING POLLUTION CONTROL

The enactment of definitive and extensive air pollution regulations in the South Coast Air Basin has given rise to an immense system of methods and equipment for control of various emissions of air contaminants from stationary sources. The Los Angeles County Air Pollution Control District credits the District's regulations and permit system for the control and prevention of 95% of all potential emissions of particulate matter in the Basin, 88% of the emissions of  $\text{SO}_2$ , 59% of the  $\text{NO}_x$ , and 86% of the reactive hydrocarbons.<sup>2</sup> Emissions from virtually all stationary emission sources are restricted within allowable limits as specified by the numerous rules applicable in each of the six Basin counties. Strict construction of the rules and an enforcement program have caused a high degree of compliance with the emission regulations, according to local APCD officials. However, despite an indicated capacity for local agencies to manage air programs effectively, it is also evident at the same time that the current air programs themselves cannot provide the degree of emission control which is needed for attainment of federal ambient air standards.

The current state air program implementation plan is constructed with the aim of preventing hydrocarbon and  $\text{NO}_x$  emissions, and therefore does not address the problem of increasing loadings of particulates and  $\text{SO}_2$  to the atmosphere in future years. The effect of the implementation plan on contaminant emissions related to atmospheric particulate matter is indicated in Table 2-1. Only two of the eight major process categories will claim reductions in particulate and  $\text{SO}_2$  emissions by 1980: 1)  $\text{SO}_2$  emissions from sulfur recovery plants are being drastically reduced due to the local District's new Rule #53.2, and 2) particulate emissions from motor vehicles will be reduced slightly due to catalytic muffler retrofits under the state air program. Due to economic growth and subsequent increased activity in the eight process categories, particulate emissions in the Four-County Area will increase by 27% from 1972 to 1980, and  $\text{SO}_2$  emissions are anticipated to increase by 21% in the same period. The projections indicate the need for stricter emission controls for all the process categories.

Control regulations for emissions of particulate matter from stationary sources are currently satisfied by utilization of standard air pollution control devices such as mechanical separators, scrubbers, electrical precipitators, and baghouses. Baghouses and electrical precipitators are employed extensively to obtain high efficiency particulate collection in the final treatment of effluent gases for all the major stationary sources except fuel combustion equipment. Emission of particulates from fuel combustion units are regulated only by Rule 52, which allows .3 grain of particulate matter per cubic foot of stack effluent gas. Particulate emissions from combustion units are maintained within the allowable limit by means of special combustion techniques, and by use of fuels with low ash content. The utilization of increasing proportions of fuel oil anticipated in future combustion operations accounts for the substantial projected increase of particulate emissions from this source category.

Control regulations limiting  $\text{SO}_2$  emissions from stationary sources have been formulated to address two principal sources: power plants (fuel combustion) and sulfur recovery units (chemical operations). The other major process categories (Table 2-1) are not affected by the  $\text{SO}_2$  emissions rules (Rule 53) inasmuch as the concentration of  $\text{SO}_2$  arising from the equipment of these source categories is within the prescribed allowable limits. Power plant stack emissions are managed within the allowable 2000 ppm level by burning fuels of low sulfur content. New  $\text{SO}_2$  cleanup systems have been recently installed at sulfur recovery plants to comply with the strict new emission standard of Rule 53.2. The  $\text{SO}_2$  removal systems exemplify a new state of the art in emission control technology. This technology is applicable to other  $\text{SO}_2$  emission sources, as discussed in Section 3.2.2.

Regulations governing allowable emissions of  $\text{NO}_x$  from stationary sources are practically non-existent, except for those governing fuel combustion sources. These control requirements have been met with the incorporation of burner design modifications and by modification of operating conditions (discussed in Section 5.0).

Emission control rules limiting hydrocarbon emissions from stationary sources are generally met by incorporating equipment to prevent evaporation

of organic vapors (such as closure seals on storage tanks, or closed vapor recovery systems used during transfer of volatile organic liquids), or sometimes by combustion in afterburners. As previously explained in Section 1.0, the control of hydrocarbon emission is a problem which was extensively examined in the preparation of the State Air Program Implementation Plan, and consequently was not reconsidered again in this study.

Control regulations affecting mobile emission sources are enacted and enforced by the State of California or the federal government, and are not a responsibility of the local air pollution control districts. Legislation of motor vehicle regulations has resulted in an evolution of motor vehicle emission standards and emission control retrofits which are constructed primarily for the control of hydrocarbon, CO, and NO<sub>x</sub> emissions. The implementation of additional retrofits and more stringent motor vehicle emission standards is scheduled to continue in the next few years. The enactment of these controls is presently forcing the development of emission control technology, and these demands are currently scheduled to be satisfied by utilization of catalytic exhaust devices. In the Four-County Area these exhaust devices will be employed as retrofits for a large segment of the motor vehicle population. Reductions of hydrocarbon and CO are the specific goals of these controls. No specific controls are proposed for the purpose of reducing emissions of SO<sub>2</sub> and particulates.

## 2.4 ALTERNATIVE AND ADDITIONAL CANDIDATE CONTROLS

Various air pollution control techniques were identified in the study as candidates to improve the control of emissions from the major eight source categories. The following sections provide a brief summary characterizing these candidate control options.

### 2.4.1 Identification of Candidate Controls

The most significant emission control options identified in the study are: 1) desulfurization of petroleum products to very low sulfur levels, 2) alternative fuels, 3) SO<sub>2</sub> removal processes, 4) motor vehicle particulate traps, 5) fabric filters or baghouses, and 6) electrical precipitators.

The first three control options listed above each represent a relatively new state of the art in emission control technology. Desulfurization of

petroleum products to very low sulfur content has been practiced commercially in very few applications. However, the technology has been proven, and it appears to be suitable for the production of very low sulfur fuel oils, and for motor vehicle fuels with sulfur contents below 100 ppm. Conversion to synthetic, clean-burning fuels is another possible air pollution control option in which new technology must be consolidated into commercial production systems. Various studies have demonstrated the adaptability of current fuel systems to methanol fuel, and confirmed its effectiveness in reducing polluting emissions from fuel burning operations. Construction of several large methanol producing plants is now being considered as an economic route to fuel supply needed by the electric utilities.  $\text{SO}_2$  cleanup systems represent an established emission control technology, but one which has been employed in a limited number of applications. Still there are several  $\text{SO}_2$  removal systems commercially available for removal of  $\text{SO}_2$  gases from stack effluents. In each of these systems the objective is to produce a sulfur product (elemental sulfur, sulfuric acid, or sulfates) which may be removed mechanically from the system.

The most promising equipment which has been developed to be responsive to the problem of sulfate emissions from vehicles equipped with catalytic exhaust control devices is an  $\text{SO}_2$  scrubber-muffler system. The unit operates on the basis that lead and sulfur will react with an alkaline molten carbonate placed in the scrubber. The unit also is highly effective for collection of total particulates. Limited testing has been performed with the scrubber-muffler device, and there are no immediate plans by its manufacturer to commit the concept to a production effort.

The other significant emission control options identified in the study include the standard air pollution control equipment now used extensively in many emission-control applications. Both baghouses and electrical precipitators may be incorporated as emission controls in cases where 1) sources are currently uncontrolled by either of these two devices, or 2) when the efficiency of the existing precipitator or baghouse may be improved. In the latter case, improving the collection efficiency may involve the replacement of an older, or less efficient unit, or the retrofit of an existing unit with additional equipment.

Control options classified as non-technological controls were addressed only very briefly in this study. The implementation of shutdowns, partial or total, or relocation of process categories to locations where their generation of pollution is tolerable, is generally unfeasible from an economic standpoint. The actual disruption and socio-economic impact of this control option was not assessed quantitatively. It was assumed this approach would be considered as a last resort only, or possibly as an option allowed the manufacturer in lieu of compliance with local emission regulations.

#### 2.4.2 EFFECTIVENESS OF THE CANDIDATE CONTROLS

Table 2-2 provides a summary of the most effective (in terms of emission reductions) control options identified in the study, including the projected prevention of emissions attributable to their implementation in the Four-County Area. Implementation of the control measures will reduce the 1972 baseyear source emission totals by 54% for particulate matter, 82% for  $\text{SO}_2$ , and -6% for  $\text{NO}_x$  (the state air program implementation plan for hydrocarbon control will reduce baseyear reactive organic emissions by 49%).

An important factor mitigating the potential effectiveness of any of the alternative control measures is community growth. As the community grows, both economically and physically, air polluting emissions increase proportionately. It is evident that pollution control measures must become increasingly more effective if the total tonnage of all source emissions is to remain constant. Hence air pollution controls which provide attainment of the ambient air standards in 1977 may not be sufficient for the same goal in 1980. The emission control regulations must be continually modified to reflect a higher degree of pollution control needed for each individual emission source throughout the ambient air region. The hypothetical curve of Figure 2-1 illustrates the gains in emission control which must be affected to maintain air quality at a prescribed level. As pollution control becomes increasingly more efficient, additional small gains in efficiency can manage greater increases in emission levels. However, it should be noted that emission control becomes exceedingly difficult to obtain at efficiencies over 90% (in Los Angeles, regulations have effected control of most particulate emission sources with a collection efficiency greater than 90%).

Table 2-2. Summary of Emission Preventions Attainable with Implementation of the Most Effective Emission Control Options, Four-County Area, 1977

Source Category	Control Option	Emission Preventions, Tons/Day		
		Particulates	SO <sub>2</sub>	NO <sub>x</sub>
Petroleum	1) Improve electrical precipitator 2) Desulfurization (to .05% S) of feed to catalytic cracker	1.8	51.4	
Fuel Combustion	1) SO <sub>2</sub> cleanup systems 2) Combination of NO <sub>x</sub> controls 3) Baghouse		336	334
Motor Vehicles	SO <sub>2</sub> Scrubber-muffler	67.9		
Aircraft	1) Major combustion chamber redesign and modification of ground operations 2) Water injection and modification of ground operations	46.8	43.8	
Chemical	None	13.6	1.4	
Metallurgical	1) SO <sub>2</sub> cleanup systems 2) Baghouses			14.8
Organic Solvent	Water wash control on paint spray booths	7.5	13.5	
Minerals	None	6.5		
Total Preventions		144	446	349
1977 Total Emission Projected Inventory		235	525	1614
1977 Emission Inventory After Control Options		91	79	1265
1972 Total Emission Base Year Inventory		196	444	1345
Level of Emission Total Obtained by Control Options, Percent Reduction of Baseyear Emissions.		54%	82%	-6%

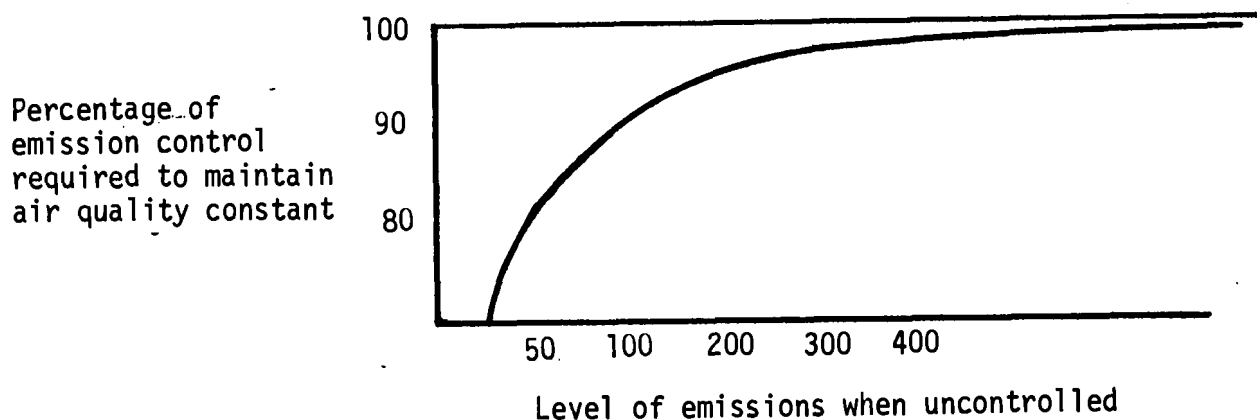


Figure 2-1. Degree of Emission Control Effectiveness Required to Maintain a Given Air Quality When Emission Sources Are Increasing.

Within each process category there are unique air pollution problems which lend to treatment by the various alternative control measures in distinctly separate ways. Table 2-2 shows that each of the significant control measures identified in the study is the most effective control approach available for at least one of the major source categories. In some cases, there are only minor advantages to be gained in emission control by using one control in preference to another. For example, desulfurization of petroleum products to very low sulfur content can result in effective emission control for  $\text{SO}_2$  emissions from motor vehicle travel, fuel combustion, and petroleum refining operations. Slightly greater  $\text{SO}_2$  control can be achieved for the former categories by utilizing other options, since they provide slightly greater removal efficiency for a given source ( $\text{SO}_2$  muffler-scrubber for motor vehicles), or they enable control of a larger portion of the sources within the process category ( $\text{SO}_2$  cleanup systems can effect emissions from refinery heaters as well as from boilers).

Clearly there are a great number of factors which must be examined to determine which of the emission control options are, in a true sense, the



"most effective." First it is evident that emission controls for the Four largest source categories cannot be evaluated on a mutually exclusive basis. If a single control method can be utilized throughout the source categories, its effectiveness would have to be judged according to its overall benefits, as well as the singular effects on each process category. Another factor in the fair appraisal of the candidate emission control methods involves technical feasibility. Some of the measures are in a higher state of technical refinement than others, and may therefore be more feasible in terms of immediate implementability. Another consideration in candidate appraisals must be the long term potential it possesses for meeting emission standards which become increasingly more stringent with time. Several other factors are significant in the true appraisal of an emission prevention system. Identification of these factors, and their relative significance, is integral to final control strategy development, which is accomplished in a succeeding report of this study. The separate chapters of this report provide the basis by which the various candidate control methods may be appraised.

#### 2.4.3 COST OF THE CANDIDATE CONTROL MEASURES

The cost of implementing the "most effective" (in terms of emission control only) control options in the Four County Area is shown in Table 2-3. A scan of the cost effectiveness column shows that these control options may be implemented for as low as \$118 per ton of emission controlled to a cost of \$3200 per ton of emissions controlled. It is clear that those controls which obtain the maximum emission reductions in each of the process categories are also usually the most cost effective. The overall cost effectiveness of the combined control measures is estimated to be \$1069 per ton of combined emissions of  $\text{SO}_2$ ,  $\text{NO}_x$ , and particulates prevented. This corresponds to a daily air pollution control expenditure of \$1.1 million in the Four County Area. If this amount was to be assessed as a tax on automobile gasoline cost in the Four County Area, it would amount to an 8¢ per gallon price increase.

The cost effectiveness figures must be judged with some reservation. For example, the desulfurization control option may not be fairly represented in the summary (Table 2-3) in the sense that its implementation in

TABLE 2-3. SUMMARY OF COST FOR IMPLEMENTATION OF MOST EFFECTIVE  
EMISSION CONTROL OPTIONS, FOUR COUNTY AREA, 1977

Source Category	Control Option	Annualized Cost, Millions of Dollars	Cost Effectiveness \$ Per Ton of Particulates, SO <sub>2</sub> , or NO <sub>x</sub> Prevented	Range of Cost Effectiveness (All Measures Investigated)
Petroleum	1) Improve electrical precipitator	19.0	\$ 512	\$ 193 - 964
	2) Desulfurization (to .05% S) of feed to catalytic cracker			
Fuel Combustion	1) SO <sub>2</sub> cleanup systems	192	\$1540	\$1030 - 1590
	2) Combination of NO <sub>x</sub> controls	53.5	\$ 440	\$ 18 - 1190
	3) Baghouse	42.5	\$1530	\$ 904 - 1863
Motor Vehicles	SO <sub>2</sub> scrubber-muffler	79.1	\$2380 <sup>a</sup>	\$ 231 - 3070 <sup>a</sup>
Aircraft	1) Major combustion chamber redesign and modification of ground operations	15.9	\$2930	\$ 300 - 4100
	2) Water injection and modification of ground operations	4.3	\$ 890	\$ 820 - 1100
Chemical	None	-	-	-
Metallurgical	1) SO <sub>2</sub> Cleanup systems	.5	\$ 101	-
	2) Baghouses	3.4	\$1242	-
Organic Solvent	Water wash control on paint spray booths	1.6	\$ 724	-
Minerals	None			

<sup>a</sup>Cost effectiveness for this measure is expressed in terms of the combined emissions of SO<sub>2</sub> and particulates prevented.

the petroleum industry produces reductions in  $\text{SO}_2$  emissions whenever the associated petroleum products are used, and these reductions have not been credited to this control in Table 2-3. Instead, other controls have been utilized to obtain more complete emission control from operations (motor vehicle) using the low sulfur fuel. If desulfurization was adopted as a universal emission control method for the petroleum, fuel combustion, motor vehicle, and aircraft emissions source categories, its cost effectiveness would be superior to all other control alternatives identified in this study.

The cost of controlling aircraft particulate emissions is greater than the control cost for any of the other control options. However it should be realized that these cost figures may be high, since the emission reductions attributed to the major combustion chamber redesign and ground operation modifications were conservative estimates, calculated to a baseline turbine engine which emits at "best emission rate" levels.

Obviously, the cost effectiveness of a given control option will vary accordingly to the degree of pollution which is available for cleanup. For example,  $\text{SO}_2$  removal systems are shown to cost \$101 per ton of  $\text{SO}_2$  removed when installed to manage emissions of metallurgical furnaces, but cost \$1540 per ton of  $\text{SO}_2$  removed when treating effluent gases from stationary fuel combustion units. The difference in cost effectiveness is due in large part to the more concentrated emissions of  $\text{SO}_2$  which are available for control from lead melting furnace effluents.

In general, the cost effectiveness of the various controls for the mobile emission sources appears least impressive. These controls involve the incorporation of retrofit technology to individual engines. Traditionally this type of control has been more expensive than those which are associated with stationary industrial process operations. The source emissions from the individual engines are relatively small, and there is therefore only minimal control potential available.

## 2.5 LIMITATIONS OF THE ANALYSIS

Due to the open-ended nature of the study problem, there were several judgements to be made regarding the study approach which would be utilized. It was clear that it would not be feasible to provide a strictly rigorous analysis of the study topic when the possibilities for research were

practically endless and the budget for execution discretely finite. Accordingly the first major adjustment to these dilemma involved the decision to concentrate the study on identifying candidate air pollution control measures which would have major and long term impact on control of emissions from existing and projected emission sources within the Four County Area. This decision was plausible in view of the fact that air quality standards are violated in dramatic fashion in the study area, and only major emission reductions will be effective toward the attainment of the ambient air standards. Hence the numerous devices, process changes, and operation modifications which can be employed to effect minor reductions in air pollution were not investigated in this study.

It is recognized that the evaluation of various control options is a difficult matter when the technology concerning their use is complex, and in most cases represents a complete study in itself. Most of the control alternatives consist of carefully engineered systems customized to a specific application. Hence the cost and effectiveness of a given type of control method may vary substantially depending on the particular circumstances of the installation and operating conditions. The scope of the study would not permit a detailed itemization of individual emission sources contained in the study area. There are over 30,000 emission sources registered through the permit system of the Los Angeles APCD alone. Hence it was necessary to aggregate emission sources into categories, and to assume these aggregated emission sources representative of the entire lot. Moreover it is assumed that efficiency characteristics and cost figures may be applied to the aggregated equipment categories in a consistent fashion, based on simplified estimative data presented in the literature, and on documented costs of existing installations which are similar to those proposed in this study.

One of the most serious shortcomings of the control measures analysis concerns the accuracy of the particulate emission inventory for the study area. Reliable methods of measuring and quantifying existing emission rates are not yet developed. Many of the emission estimates published by the local air pollution control districts are based on theoretical calculations or outdated or insufficient field measurement data. Estimates of emissions derived by different studies are frequently substantially

different, and often there is little basis upon which one analysis may be assumed more correct than another.

There are also many uncertainties regarding the quantification of emission preventions claimed by the APCD for existing air pollution control equipment. Data obtained from the computer emission inventory file of the APCD contained many apparent defects. Emission totals from the file are not in accord with information contained in official publications by the APCD. This is because the estimating procedures for each of these data is derivative of a distinctly separate methodology. These two systems are targeted to evolve into a single coordinated methodology, but this final development has been projected appreciably to the future. In the interim, the computer emission inventory is the most complete tabulation available in terms of a source by source identification of process equipment, pollution control, source emissions, and current control preventions. The data from the file was used sparingly in the study, mainly to determine distribution of emissions within a process category for the purpose of disaggregating emissions by equipment type.

Another problem encountered in the study concerns the use of proprietary information. Information regarding feasible new control methods is somewhat proprietary since the manufacturers have only engaged in limited production of the controls to date. Hence it was difficult to assess the comparative benefits of alternative controls when the basis for most performance information are figures released by the various manufacturers of the control equipment. It was found however, in most cases, that the effectiveness and cost for the candidate control measures were less optimistically represented by the manufacturers than by governmental publications. The analysis of this study included incorporation of less optimistic estimates, both in terms of cost and control efficiency.

## 2.6 CONCLUSIONS AND RECOMMENDATIONS

This section provides a brief summary of conclusions and recommendations evolving during the performance of the study to identify and characterize alternative emission control measures applicable to the Los Angeles Region.

## Conclusions

- Eight process categories are the major candidates for control in the Los Angeles Region. These are stationary source fuel combustion, motor vehicles, the petroleum industry, aircraft, the chemical industry, metallurgical processes, organic solvent use, and the mineral industry. Together these categories account for more than 97 percent of the emissions of primary particulates,  $\text{SO}_2$ ,  $\text{NO}_x$ , and RHC in the Los Angeles Region. Especially significant are the fuel combustion, motor vehicle, petroleum, and aircraft categories.
- The federal and state motor vehicle control programs and the county APCD stationary source control programs have achieved substantial overall control for primary particulates and gaseous precursors of secondary aerosol in the Los Angeles Region. However, additional control options can be identified to bring significant further reductions in emissions.
- The most significant additional control alternatives for primary suspended particulates in the Los Angeles Region are motor vehicle particulate traps, fabric filters, and electrostatic precipitators. For  $\text{SO}_2$ , the major options are desulfurization of petroleum products to very low sulfur levels,  $\text{SO}_2$  removal processes for exit gases, and alternative fuels. For  $\text{NO}_x$  control, various modifications of combustion processes and alternative fuels are the principal control possibilities. No major new options for RHC control, other than those contained in the EPA oxidant implementation plan, have been identified.
- Application of the most effective control options which have been identified will attain overall reductions of 61%, 85%, and 22% for total primary particulates,  $\text{SO}_2$  and  $\text{NO}_x$  respectively, from projected 1977 levels. Since emissions of each pollutant are forecasted to increase from 1972 to 1977, the overall reductions in 1977 from the 1972 levels are only 34%, 82%, and -6% respectively. The EPA oxidant plan will achieve a 51% reduction in RHC levels from 1972 to 1977.

- The total annualized cost associated with a major new control program to achieve substantial emission reductions such as that noted above would be around \$400 million per year. The initial capital cost would be around \$1 billion. These costs would be in addition to the costs of present controls and the costs associated with the EPA oxidant plan.
- The various control measures for each pollutant demonstrate a wide range of cost-effectiveness. Most of the particulate emission controls yield cost effectiveness ratios around \$1,000 to 4,000 per ton. The majority of the SO<sub>2</sub> controls considered here had cost-effectiveness values of around \$500 to \$1500 per ton. Most NO<sub>x</sub> measures tended to demonstrate ratios of around \$500-\$1200 per ton controlled.
- Many of the potential control measures will entail significant implementation difficulties. These will include problems of technical development, engineering application, enforcement, and administration.

#### Recommendations

- As control strategy planning efforts proceed, more in-depth analysis should be performed on the effectiveness and cost of the control measures studied in this report. Due to limitations on time and level of effort, the present study estimated control efficiency and costs on a simplified basis, aggregating over many emission sources in a given process category. The cost and effectiveness of the measures will likely vary substantially among individual sources within a given process category. Some of these variations can have significant implications for control policy.
- As part of the implementation procedure, proposed control measures should undergo an intensive evaluation as to real applicability. This evaluation should be carried out by a task force of industrial, academic, and governmental experts who would consider the specific engineering, enforcement, and legal problems involved with the control measure. A carefully planned and executed implementation procedure should help to reduce technical difficulties as well as

public and private resistance.

- Further attention should be given to a long term view of the various control measures. A strategy based on long run considerations may be considerably different from one designed to achieve short run control. Short run controls should be evaluated as to their compatibility with likely long run controls.



### 3.0 GENERAL CONTROL METHODS AVAILABLE

This Chapter provides a general characterization of alternative control methods which are applicable for prevention of emissions leading to the suspension of particulate matter in the atmosphere. Section 3.1 is a summary of the traditional control devices available to manage emissions of primary particulates. Section 3.2 includes an identification of alternative controls now available or in development to prevent emissions of gaseous precursors. Section 3.3. deals with simultaneous control of primary particulates and gaseous precursors via alternative fuels, and Section 3.4 provides a discussion of emissions control by the route of non-technological control measures (growth restrictions, relocation and source usage control).

#### 3.1 CONTROLS FOR PRIMARY PARTICULATES

Feasible control devices for emissions of primary particulates include mechanical collectors, wet scrubbers, electrostatic precipitators, and filters. The application of these various gas cleaning devices is based on consideration of particulate characteristics in the gas stream, and process, operating, construction, and economic factors. The technology of each of the above controls is well developed, and many equipment manufacturers have provided several generations of reliable control devices to the industry. The impact of the Clean Air Act has been to increase the need for these devices throughout the industry. Figure 3-1 illustrates the growing demand for particulate controls in this country, and the apparent lag in manufacturing capability to make the equipment available.

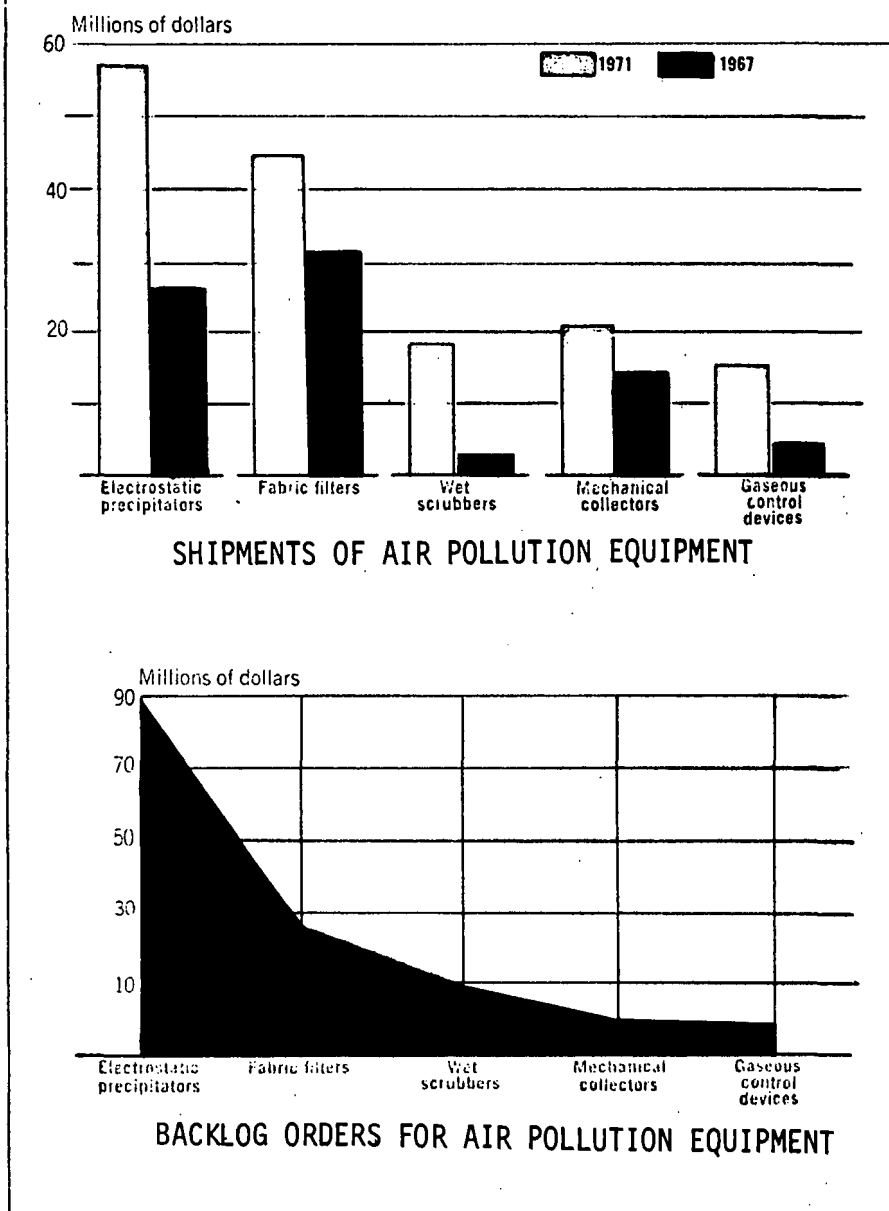


Figure 3-1. Increasing Market Demand For Air Pollution Equipment in United States

Source: Reference (5)

The following sections provide a brief discussion of each of the standard gas cleaning devices in terms of operating characteristics, applications, and cost.

### Mechanical Collectors

Mechanical collectors include settling chambers and cyclones. The settling chamber is the simplest particulate collector, typically consisting of a baffle chamber in which the velocity of the polluted gas is diminished to a level where particles settle out by gravity (Figure 3-2). Its applications are limited as it is effective only in removing relatively large particles. They are usually employed as pre-cleaners to remove large particles (greater than 43 microns) before the gas is treated by other more efficient removal equipment.

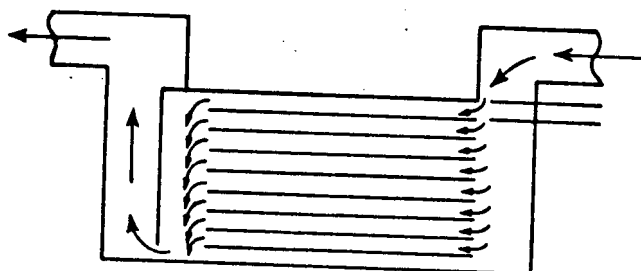


Figure 3-2. Baffled Settling Chamber

As one of the earliest approaches to collector designs, the cyclone provides a configuration in which the polluted gas is introduced tangentially into a conically shaped vessel that directs it along a spiral path. Centrifugal forces push particulates of the gas stream toward the wall, where they fall by gravity to the bottom of the device. The inner flow of clean air travels up the center of the cyclone and exits out the top.

Development of the cyclone device has produced several different commercial designs: 1) reverse flow cyclones, 2) straight through flow, and 3) impeller collectors. Figure 3 illustrates the principle of the reverse flow cyclone. In this version the polluted gas enters the tangential inlet and flows in a helical vortex path that reverses at the base of the cyclone to form an inner cone of flow which emits out the top.

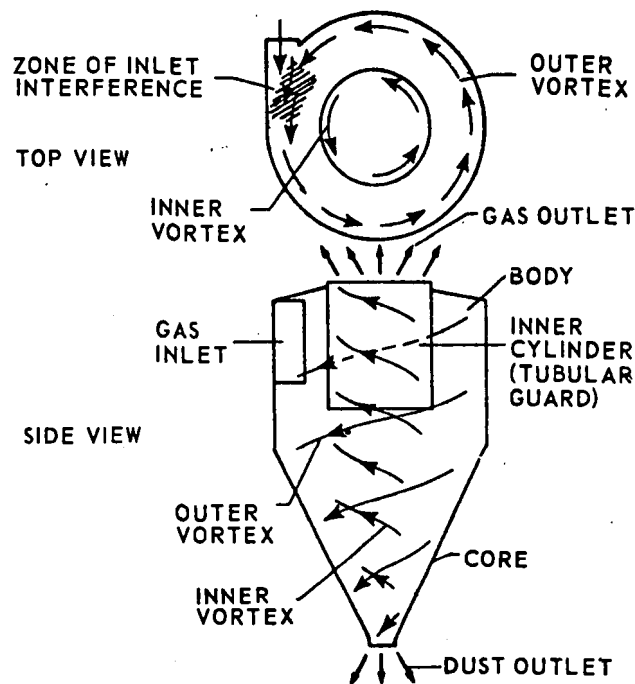


Figure 3-3. Reverse Flow Cyclone

In the impeller cyclone the polluted gas enters the impeller and passes through a fan blade which throws dust into an annular slot leading to a collection hopper.

Cyclone efficiencies vary widely depending on the spatial configuration and design. The collection efficiency of a "high efficiency" cyclone and a conventional efficiency cyclone are given below.

TABLE 3-1. CYCLONE EFFICIENCY VERSUS PARTICLE SIZE RANGE

Particle Size (Microns)	Actual Efficiency, % of Particles Removed	
	Conventional Cyclone	"High Efficiency Cyclone"
< 5	-	50 - 80
5 to 20	50 - 80	80 - 95
15 to 50	80 - 95	95 - 99
> 40	95 - 99	95 - 99

Source: Reference (2).

Cyclones are widely employed in various industrial applications for both pre-treatment or secondary gas cleaning operations. They are used in fertilizer plants, petroleum refineries, mineral processing, metallurgical operations, chemicals, metals manufacturing, and so forth.

The approximate cost of purchase and installation, and operation of cyclone collectors is given in Figure 3-4 and 3-5. The cost curves reflect efficiencies of 50, 70 and 95 percent for typical commercial application.

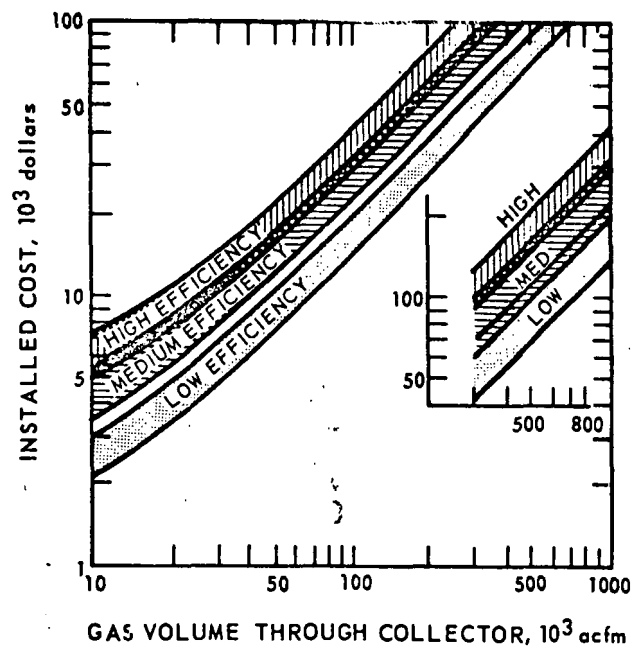


Figure 3-4. Purchase and Installation Cost of Centrifugal Collectors<sup>2</sup>

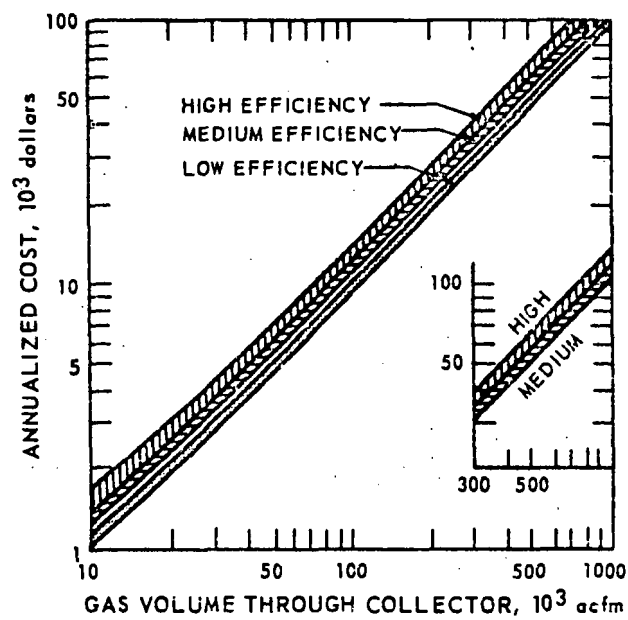


Figure 3-5. Annualized Cost of Operation of Centrifugal Collectors<sup>2</sup>

## Wet Scrubbers

Wet collectors are devices which employ liquids to remove particles by 1) increasing the effective size of the particles to enable efficient collection, and 2) trapping and washing away particles in a liquid film. This particulate-liquid interface occurs through the physical processes of interception, gravitation, impingement, diffusion, electrostatic forces, and thermal gradients.

There are principally two classes of wet scrubbers: the low energy type and the high energy type. The low energy type includes:

- Open spray towers.
- Packed towers, in which the polluted gas and liquid pass cross flow through a contact bed.
- Wet cyclone, in which water spray and centrifugal forces work in combination to collect particles
- Flooded bed scrubbers, in which baffle grids cooperate in aiding contact between particles and water spray.
- Orifice type, in which the polluted gas is directed through an orifice restricted by liquid spray.
- Wet dynamic, which consists of a liquid spray in an impeller cyclone.

The high energy wet collectors are commonly known as Venturi scrubbers. In a Venturi scrubber high collection efficiency is obtained by high velocity impingement of the gas particles with the scrubbing liquid spray in the throat of a Venturi. The liquid is injected into the throat of the Venturi where the velocity of the gases causes the disintegration of the liquid to fine droplets, This disintegration enhances the probability of contact with particulates of the gas stream.

The collection efficiency of scrubbers varies with the power input. Table 3-2 summarizes the efficiency of the various types of scrubbers discussed above.

TABLE 3-2. SCRUBBER CAPABILITIES

Type of Scrubber	Usual Range of Particle Sizes, Microns	Normal Draft Loss, In Water	Maximum Efficiency %
Open spray tower	> 10.0	3/4-2	85
Packed tower	> 10.0	1-6	85
Wet centrifugal	> 2.5	2-6	95
Flooded bed	> 2.5	2-8	95
Orifice	> 2.5	To 6	95
Wet dynamic	> 2.0	None	98
Venturi	> 0.5	6-80	99+
Flooded disk	> 0.5	6-70	99+

Source: Reference (1)

The costs of purchase and installation, and operation of wet collectors are given in Figures 3-6 and 3-7. The efficiencies of the different curves reflect removal rates of 75, 90, and 99 percent in typical commercial applications.

#### Electrostatic Precipitators

The electrostatic precipitator is most frequently used to process large volumes of gas (50,000 to 2,000,000 CFM) at large industrial installations. In many applications the precipitator is the only proven high-efficiency (up to 99.9% removal) particulate control device available today. They are used extensively to process polluted effluent gases from smelters, furnaces petroleum refineries, acid plants, boilers, and other process operations.

The electrostatic precipitator collects suspended particulates by directing the polluted gas through an electrical field. The field is established between an electrode maintained at high voltage and a grounded collection surface. Particles passing through the field become charged immediately and are attracted to the grounded collecting surface. The particulate matter is dislodged from the collecting surface by mechanical means such as vibrating with rappers or by flushing with liquids.



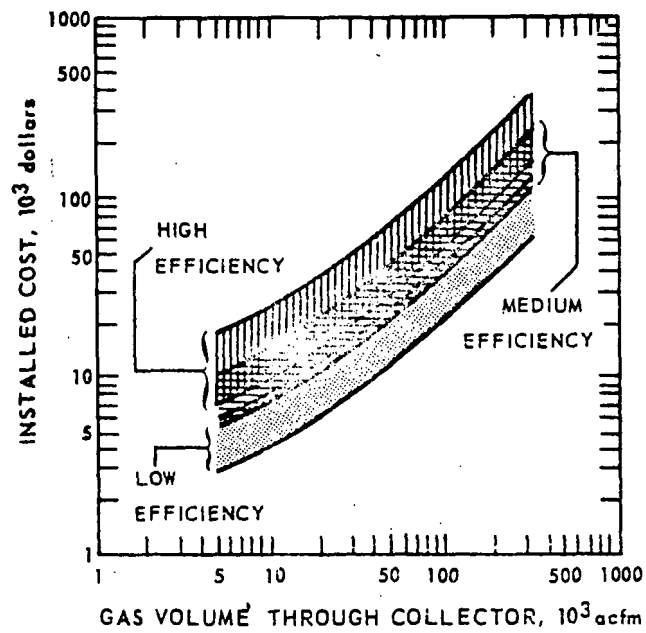


Figure 3-6. Purchase and Installation Cost of Wet Collectors<sup>2</sup>

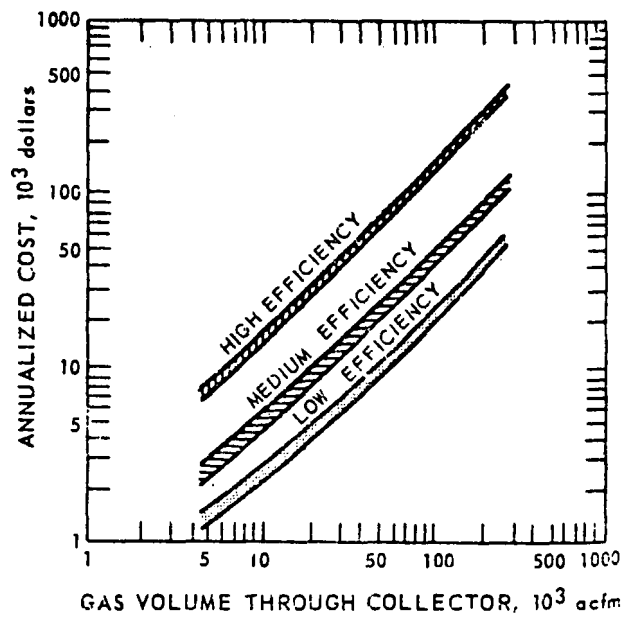


Figure 3-7. Annualized Cost of Wet Collectors<sup>2</sup>

There are basically two configurations utilized in the electrostatic precipitator: flat surface and tube types. In the flat surface version, particles are collected on parallel grounded plates spaced between rod discharge electrodes. In the tubular collector configuration, the rod electrode is centered in a tube causing the particulate matter to be collected on the surface of the grounded tube. A precipitator unit consists of many plates or tubes, as shown in Figure 3-8. A distinct advantage of the configuration of either type of precipitator is the low pressure drop associated with the gas flow path, permitting immense volumes of gas to be handled with relatively low level of power required.

The electrostatic precipitator is a versatile approach to particulate collection in that it may handle a variety of applications at very high efficiencies. It is capable of operation at temperatures exceeding 1000°F, for collection of particles in the submicron range, for dry dust and mists, and at pressures up to 150 psi. Because the design of the precipitator requires considerable experience for a given application, the industry relies heavily on the air pollution control device manufacturer to develop equipment specifications and provide guarantees of performance.

The approximate cost of purchase and installation and operation of electrostatic precipitators is shown in Figures 3-9 and 3-10. The cost curves reflect efficiencies of 90, 95, and 97.5 percent in a typical commercial application.

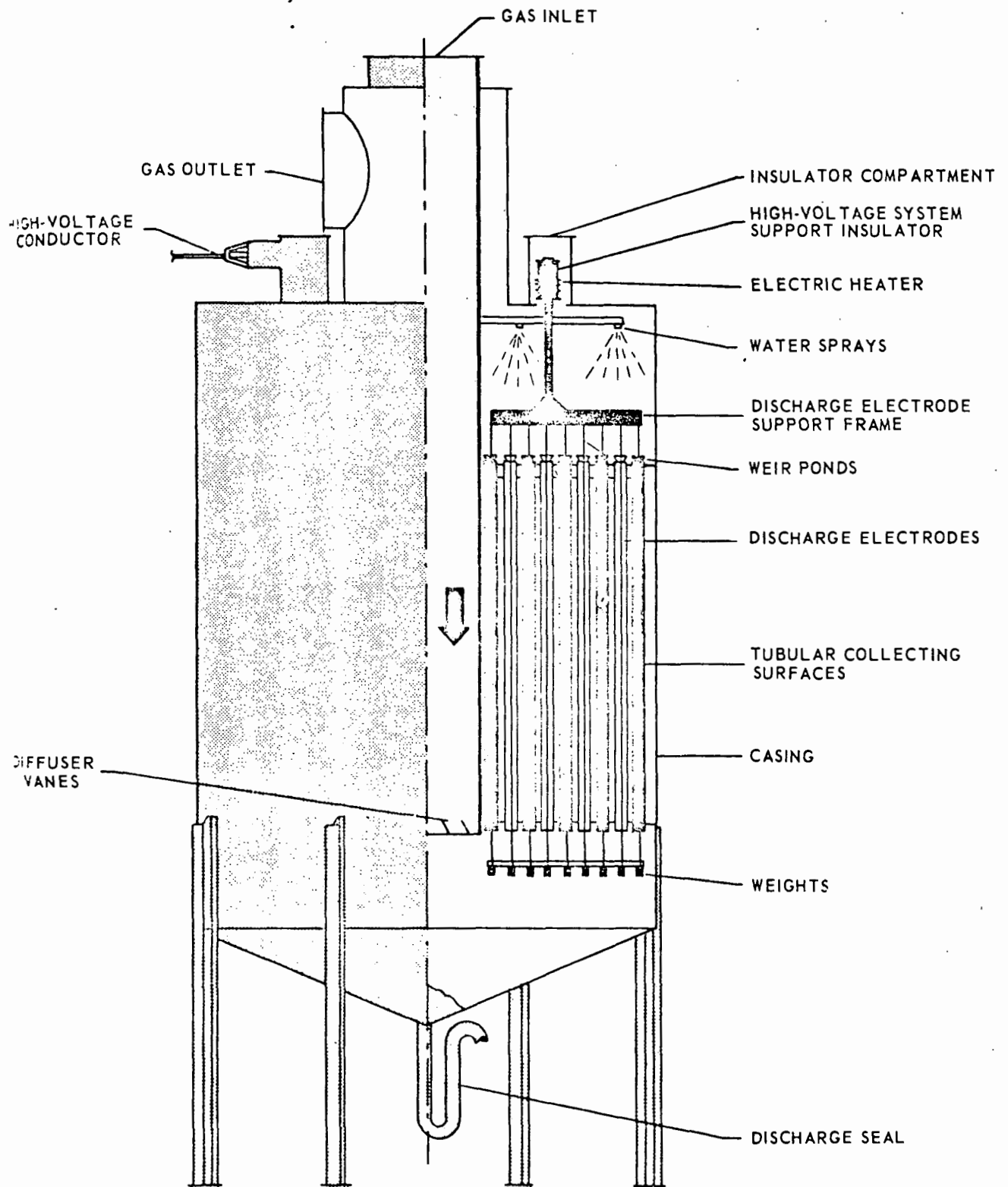


Figure 3-8. Cross Sectional View of Tubular Blast Furnace Electrical Precipitator

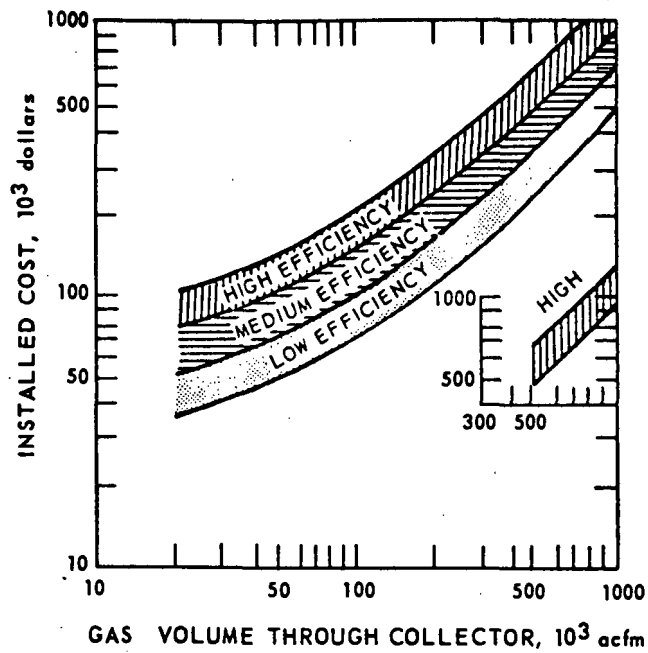


Figure 3-9. Cost of Purchase and Installation of High-Voltage Electrical Precipitator<sup>2</sup>

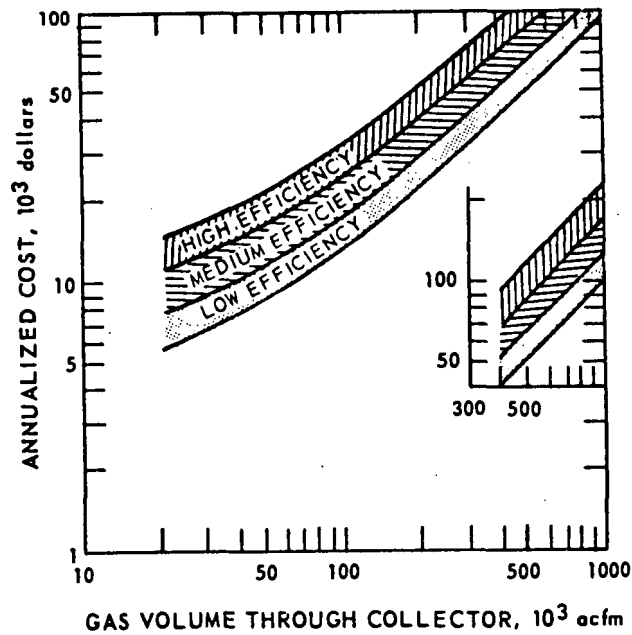


Figure 3-10. Annualized Cost of Operation of High-Voltage Electrostatic Precipitator<sup>2</sup>

### Filter Collectors

Collecting devices based on fabric are among the oldest means of removing material from gas streams. In fabric filtration, the particulate matter is removed from the gas stream by impinging or adhering to fibers of the fabric. The physical mechanism for particle collection includes interception, inertial impaction, diffusion, electrostatic attraction, sieving, and gravitational settling. The effect of each of these physical processes in the overall collection of particle sizes is illustrated below in Table 3-3. As can be seen, fabric filtration is an effective device for removal of particles

TABLE 3-3. CONTROL MECHANISM FOR PARTICLE SIZE COLLECTION

Primary collection mechanism	Diameter of particle, microns
Direct interception .....	>1
Impingement .....	>1
Diffusion .....	0.001 to 0.5
Electrostatic .....	0.01 to 5
Gravity .....	>1

Source: Reference (2)

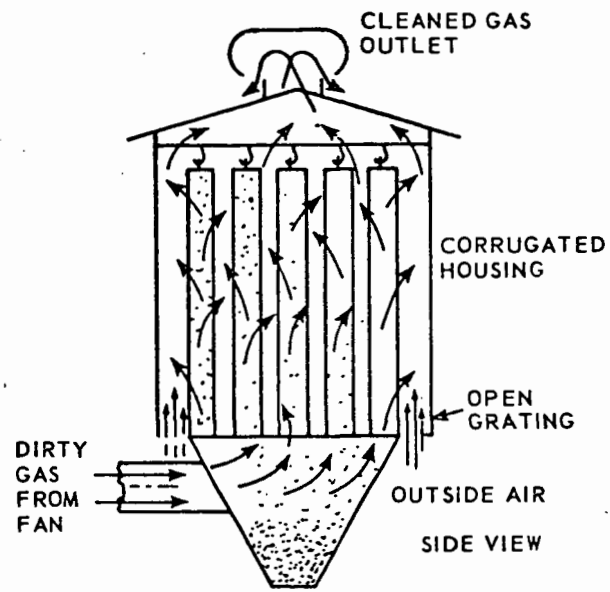
as small as .5 micron and will remove a substantial quantity of particles as small as .01 micron.

Fabric filtration is typically accomplished by directing the pollutant-bearing gas through flat or tubular fabric bags hanging in an enclosure called a baghouse. The particulate material is retained on the upstream side of the fabric while the cleaned air which passes through the fabric is discharged to the atmosphere. The collected material is removed from the bags by mechanical means, such as manual shaking or air shaking.

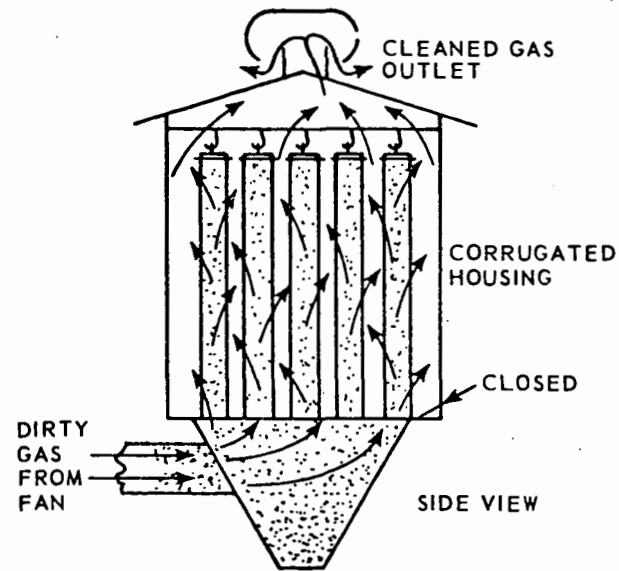
The selection of the fabric is probably the most critical aspect of the equipment design. Determining the resistance of the filter to gas flow for the clean fabric, and for dust laden fabric are important prerequisites to intake and exhaust system design. Optimal air flow ratio through the fabric is another important consideration. Experience in numerous applications (cement kilns, foundry cupolas, furnaces, grain operations) have provided the baghouse device manufacturers with detailed performance characteristics of the many different bag fabrics and baghouse systems. These data allow the manufacturer to guarantee high efficiency baghouse installations in varied applications.

Selection of suitable baghouse configurations is based primarily on the amount of moisture in the waste gas. Higher moisture content increases the probability of filter damage and corrosion of hardware. Three systems are used (Figure 3-11) corresponding to the various moisture conditions: The open pressure type, the closed pressure type, and the closed suction version. In the open pressure baghouse, the air fans are located on the upstream side of the filter bags, and the bags are exposed to the atmosphere. The open baghouse is capable of treating high temperature gas streams as cooling is facilitated by the open design. In the closed pressure baghouse, filter bags are closed off from ambient exposure. This configuration is utilized when the effluent gas contains toxic pollutants and the cleaned discharge must be conducted away from the area. The closed suction baghouse operates with the fans on the downstream side of the filter bags in an insulated airtight structure. This unit is used for cleaning gases with high dew points to prevent condensation on the filter fabric.

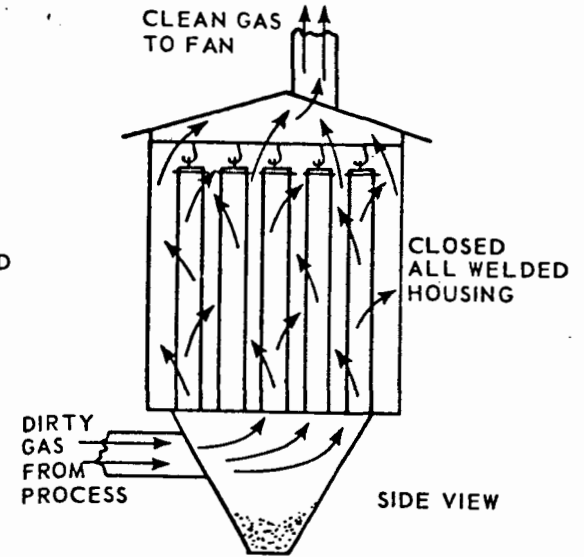
Figure 3-12 and 3-13 provide cost estimates for the purchase and installation, and operation of fabric filter devices (baghouses). The cost curves all reflect a 99.9 percent efficiency for the various types of fabrics indicated.



Open pressure baghouse.

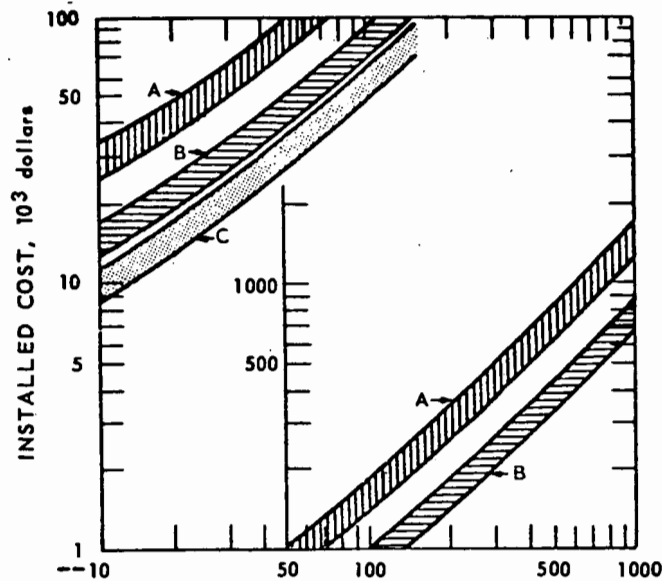


Closed pressure baghouse.



Closed suction baghouse.

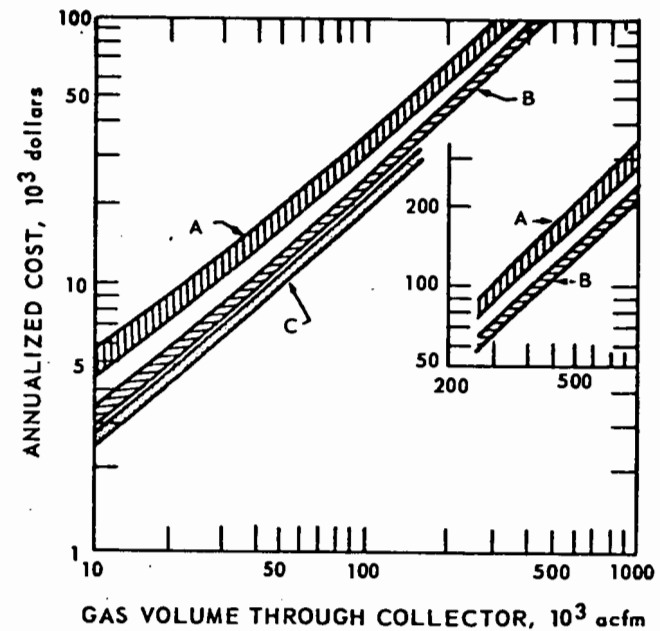
Figure 3-11. Schematic of Basic Three Baghouse Designs<sup>3</sup>



GAS VOLUME THROUGH COLLECTOR,  $10^3$  acfm

- A - HIGH-TEMPERATURE SYNTHETICS, WOVEN AND FELT. CONTINUOUS AUTOMATIC CLEANING.
- B - MEDIUM-TEMPERATURE SYNTHETICS, WOVEN AND FELT. CONTINUOUS AUTOMATIC CLEANING.
- C - WOVEN NATURAL FIBERS. INTERMITTENTLY CLEANED - SINGLE COMPARTMENT.

Figure 3-12. Cost of Purchase and Installation of Baghouse Particulate Collector<sup>2</sup>



- A - HIGH-TEMPERATURE SYNTHETICS, WOVEN AND FELT. CONTINUOUS AUTOMATIC CLEANING.
- B - MEDIUM-TEMPERATURE SYNTHETICS, WOVEN AND FELT. CONTINUOUS AUTOMATIC CLEANING.
- C - WOVEN NATURAL FIBERS. INTERMITTENTLY CLEANED - SINGLE COMPARTMENT.

Figure 3-13. Annualized Cost of Operation of Baghouse Particulate Collectors<sup>2</sup>



### 3.2 CONTROLS FOR GASEOUS PRECURSORS

Gaseous emissions which play a major role as precursors to particulate formation in the atmosphere are  $\text{NO}_x$ ,  $\text{SO}_2$ , and hydrocarbons. The technology to control emissions of these gases is not yet in a high state of refinement. While there are control devices commercially available for preventing emissions of  $\text{NO}_x$ ,  $\text{SO}_2$ , and hydrocarbons, many of these are sold without substantial guarantees of performance. Nevertheless, regulations stemming from the Clean Air Act are accelerating the development of the control equipment, and numerous installations have now been tested and are operating continuously and effectively. The following sections provide a brief description of the most promising control methods which are applicable to prevention of  $\text{SO}_2$ ,  $\text{NO}_x$ , and hydrocarbon emissions.

#### 3.2.1 Desulfurization of Petroleum Products

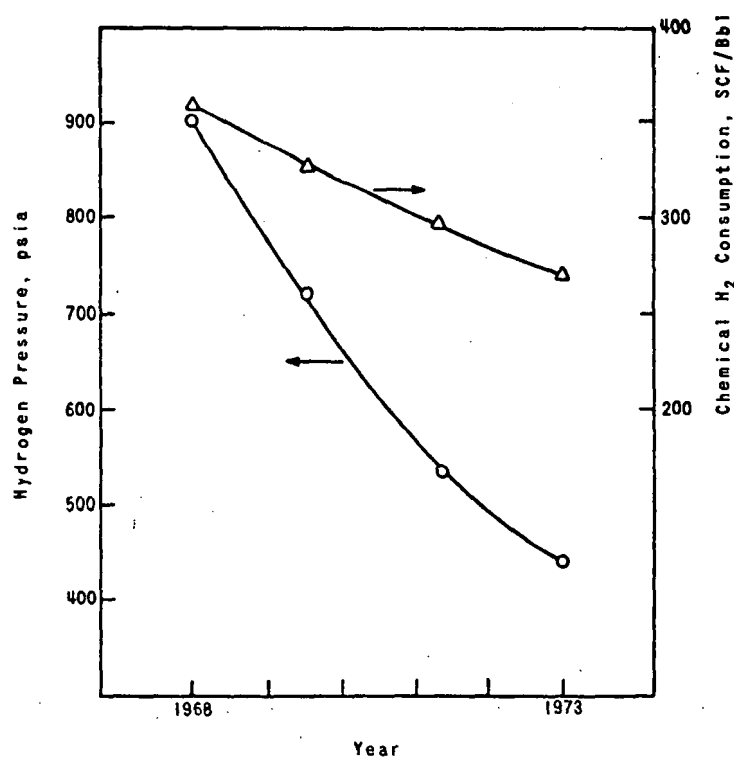
The trend toward the processing of higher sulfur crude oils coincides with the trend of increasingly stringent emission regulations, which are causing restrictions on the sulfur content of refinery products, as well as on the sulfur level of refinery process emissions. These concurrent trends (demonstrated by Table 3-4) obviate the need to develop additional sulfur removal facilities in U.S. oil refineries.

Desulfurization of the heavier fractions of crudes (from diesel/No. 2 oil to heavy fuel oils) has not been extensively practiced in the U.S. to date. The production of low sulfur products in the heavier fractions of the crude will require catalytic hydrodesulfurization of the heavy distillates and residuum fuel oil stocks. Extensive processing of this type has been employed in foreign countries, especially Japan. In many cases, improved technology in desulfurization of the heavy distillates to produce very low sulfur blend stocks has deferred the need for facilities to desulfurize the residuum portion of the barrel. The residuum portion is blended with the low sulfur blend stocks to obtain low sulfur fuel oils meeting the standards.

TABLE 3-4. SULFUR CONTENT OF REFINERY PRODUCTS  
FOR DIFFERENT CRUDES.<sup>3</sup>

SULFUR LEVEL, WT %				
Product	Typical U.S. Refinery Feeding Gulf Coast Crude	Same Refinery Running Arabian Light	Present Specifi- cations	Possible 1975 Specifi- cations
Motor Gasoline	0.03	0.08	0.1	0.01-0.03
Kero Jet	0.04	0.15	0.12	0.05
Diesel No. 2 Oil	0.10	0.6	0.25	0.2
Heavy F/O	0.65	3.2	0.5- 2	0.3 - 1.0

While many of the initial desulfurization facilities were designed to reduce sulfur levels to prevailing standards, the technology is now available for desulfurization of vacuum gas oils to levels of a few parts per million sulfur. Chevron claims their VGO Isomax Process, which was first operated in Japan five years ago, is capable of sulfur levels as low as 100-200 ppm with only moderate increases in operating severity (high pressure and temperature) over the conditions which produce products with sulfur contents of .1-.2 percent sulfur. Figure 3-14 illustrates progress made in the last five years in terms of the operating pressure required to remove 92% of the sulfur from a Middle East vacuum gas oil.



Basis: Middle-East VGO  
Desulfurized to  
0.2% Sulfur

Figure 3-14. Continued Improvement in VGO Isomax Process<sup>3</sup>

Technical improvements in desulfurization processes have had dramatic effects on processing costs. Figure 3-15 summarizes the trend to lower costs. At current levels of technology, the Chevron Isomax Process can produce .05% sulfur fuel oil blend stock at less cost than required to produce .2% sulfur fuel oil blend a few years ago.

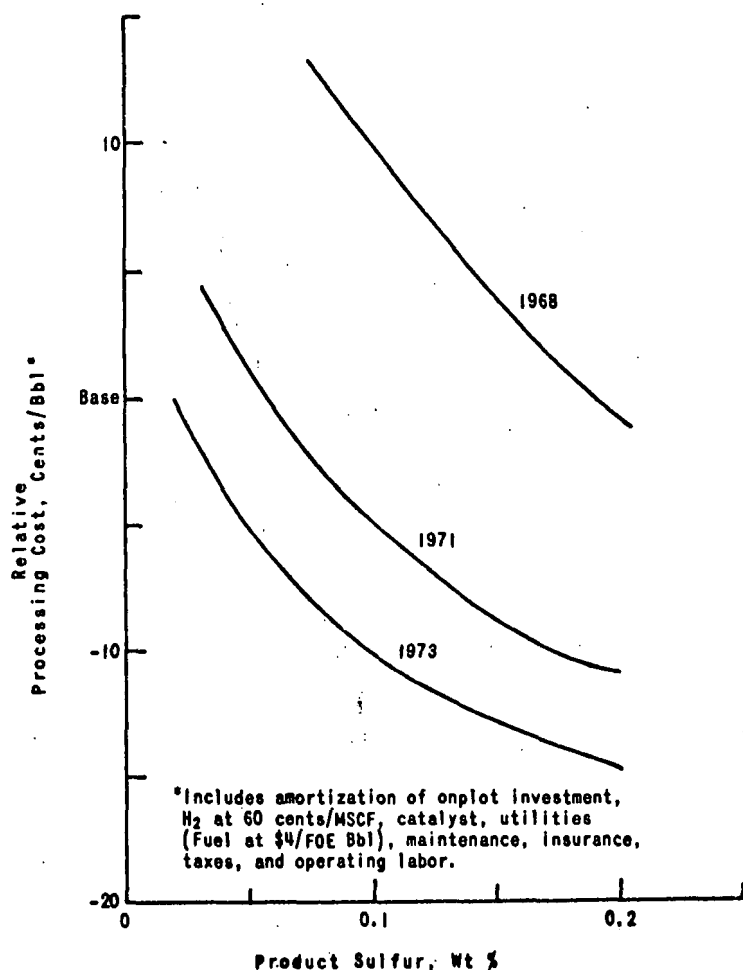


Figure 3-15. Cost to Desulfurize Arabian Heavy Crude Oil with VGO Isomax<sup>3</sup>

The Isomax can be used to achieve essentially complete desulfurization of a wide variety of feed stocks. A very wide boiling range of distillates, from diesel up to 1100°F end point vacuum gas oil, can be economically processed in the unit. The Isomax is also suitable for desulfurization of feed stock to the catalytic cracker unit. Figure 3-16 illustrates the effect of desulfurization of the cracker feed stock on the sulfur content of the cracked products.

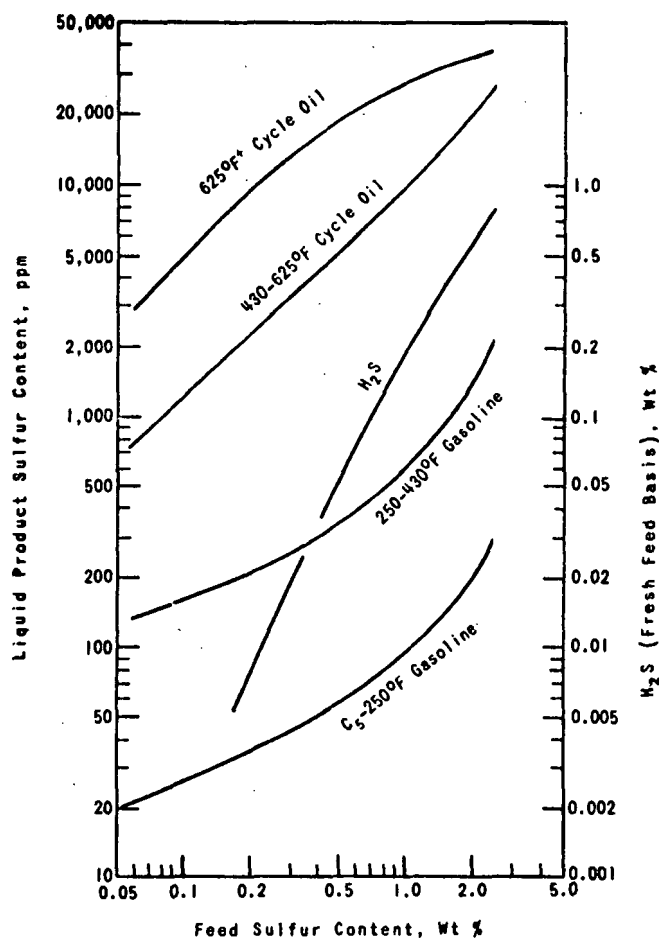


Figure 3-16. Effect of Feed Desulfurization on Fluid Catalytic Cracker Product Sulfur Contents at Constant Cracking Severity

Typically the VGO Isomax Process has not been utilized to produce very low sulfur content products as the standards do not generally require this degree of operation. In fact, because of the ability of the VGO Isomax to process low sulfur fuels far below standards, a VRDS Isomax process has been designed to complement the VGO Isomax process by providing for moderate sulfur content fuels which may be blended with VGO Isomax fuels to reach the higher limits of the sulfur content standards. The VRDS Isomax is a moderate pressure, vacuum residuum desulfurization process which will process a wide variety of high sulfur content residual to produce low sulfur products in the range of .5 to 1% sulfur content. Blending of VRDS Isomax products with products of the Isomax unit provides the most economic route for manufacturing low sulfur fuel oils meeting the current sulfur content standards.

The VGO Isomax is an efficient tool to remove sulfur from the vacuum gas oils of the fuel oil barrel. However it is becoming evident that low sulfur processing of both vacuum residuum as well as the vacuum gas oil will be needed to meet lower sulfur fuel oil requirements. There are several processing schemes being studied as possible routes to very low sulfur fuels (such as .05 to 1% sulfur). Chevron Research has identified two of the most feasible methods as:

- 1) Solvent-deasphalting and gasification of the by product high sulfur SDA tar, and
- 2) VRDS Isomax followed by delayed coking of the VRDS bottoms product.

In the first of the two methods, the vacuum residuum is solvent deasphalted and then combined with the vacuum gas oil for desulfurization in the VGO Isomax process to give a 93% yield of low sulfur fuel oil. Gasification facilities are included to convert high sulfur by-product tar to a useful high BTU content synthetic field gas.

The solvent-deasphalted oil is more difficult to desulfurize in the VGO Isomax Unit than the straight run vacuum gas oil above. However the blend of the two oils does not require appreciably different processing conditions than those which are used in existing commercial VGO Isomax Units. The VGO Isomax Plus solvent-deasphalting process is well established and has been operative at the Standard Richmond Refinery over the past eight years. Experience has shown that high yields of low sulfur fuel oils can be obtained.

In the second of the two methods above, vacuum residuum is processed in a VRDS Isomax Unit and the higher boiling products are sent to a delayed coker. The lower boiling fractions (975°F-) are combined with the vacuum gas oil for desulfurization in the VGO Isomax to result in the desired low sulfur fuel oil. This process provides a 93% yield of fuel oil from high sulfur Arabian residuum. Metallurgical quality coke is removed as a useful by-product from the delayer coker.

Chevron Research has demonstrated the two processes above with pilot plant studies using difficult high sulfur feed stocks such as Arabian Heavy. Results of test runs show that refineries can process high sulfur crude while maintaining product quality and meeting environmental standards. The implications of this new technology for air quality are evident. If very low sulfur fuels were to be utilized for the various combustion processes throughout the Four-County Area, SO<sub>2</sub> emissions from combustion equipment would be substantially reduced, perhaps by as much as 80% or 90%. The impact of low sulfur fuels on SO<sub>2</sub> pollution from the various fuel burning sources (aircraft motor vehicles, industrial boilers, and heaters) is quantified in the different sections of this report.

Both processes lend to stepwise construction at the refinery. The VRDS Isomax and the VGO Isomax can be integrated into existing refineries with delayed coking and catalytic cracking facilities.

#### Economics of Desulfurization

Cost comparisons reveal that initial capital investment is similar for the two low sulfur processing approaches. In terms of processing costs, the Isomax VGO/VRDS plus delayed coker method is superior by about 36 cents/barrel of low sulfur product over the Isomax VGO/Solvent-Deasphalting plus gasification process plan. Process costs depend somewhat on the market demand for the by-products of the two approaches, which tend to fluctuate greatly. Tables 3-5 and 3-6 provide a summary of the initial investment and manufacturing costs for the two desulfurization schemes when 50,000 barrels per day of Arabian residuum are processed.

TABLE 3-5. ONPLOT INVESTMENT FOR ALTERNATIVE  
DESULFURIZATION SCHEMES

<u>Onplot Investment, \$M<sup>1</sup></u>	<u>VGO Isomax Plus SDA Plus Gasification</u>	<u>VGO/VRDS Isomax Plus Delayed Coking</u>
Vacuum Flasher	5.7	5.7
VGO Isomax	9.9	8.7
VRDS Isomax	-	12.6
H <sub>2</sub> Plant	6.7	8.4
SDA Unit	6.0	-
Gasification	15.3	-
Coker (Incl. Fractionator)	-	5.5
WWT, Gas and Sulfur Recovery	<u>7.8</u>	<u>7.9</u>
Total Investment	51.4	48.8
Catalyst	1.0	1.8
Royalties	1.8	2.7
Total Onplot	<u>54.2</u>	<u>53.3</u>

<sup>1</sup> Gulf Coast USA, Early 1973 Costs

Source:      Reference (4)



TABLE 3-6. DIRECT MANUFACTURING COSTS FOR  
ALTERNATE DESULFURIZATION SYSTEMS

	VGO Isomax Plus SDA Plus Gasification	VGO/VRDS Isomax Plus Delayed Coking
Feed Costs, \$M/Yr		
650°F+Resid at \$2.50/Bbl	41.0	41.0
H <sub>2</sub> Plant Naphtha, \$3.50/Bbl	<u>1.4</u>	<u>1.9</u>
Total	42.4	42.9
Investment Amortization, \$M/Yr <sup>1</sup>	13.6	13.3
Operating Costs, \$M/Yr <sup>2</sup>	<u>11.8</u>	<u>10.0</u>
Subtotal	67.8	66.2
By-Product Credits, \$M/Yr		
SNG/Fuel Gas \$6.50/Bbl EFO	(4.4)	(3.0)
Naphtha, \$3.50/Bbl	(0.4)	(3.7)
Metallurgical Coke, \$20/ST	-	(2.0)
Sulfur, Zero Value	-	-
Total	<u>(4.8)</u>	<u>(8.7)</u>
Net Fuel Oil Cost		
\$M/Yr	63.0	57.5
Incremental Cost Over Base, \$/Bbl of 0.05% S F/O	+ 0.36	Base

<sup>1</sup>Onplot Only - 25% per year

<sup>2</sup>Includes Utilities, Labor and Super., Maintenance, Taxes and Ins.

<sup>3</sup>0.90 Operating Factor

Source: Reference (4)

### 3.2.2 SO<sub>2</sub> Removal Technology

Commercial methods for desulfurization of tail gas from sulfur plants, stack gases, and other effluent gas streams amount to some 20 techniques which are representative of more than 50 identifiable processes. These SO<sub>2</sub> removal systems are in various phases of development and the number of actual applications have been limited to date. Because of performance uncertainties associated with the infant SO<sub>2</sub> control systems, industry is not rushing to purchase these expensive systems, despite the approaching clean air deadlines.

Virtually every desulfurization control process has its own chemical, engineering, economic, and operating peculiarities. Some processes are particularly suited to meet one set of plant effluent conditions, while another SO<sub>2</sub> removal process may be best adapted to an entirely different set of plant parameters. Since there are probably as many different plant effluent-gas-stream types as there are plants emitting gases, the combinations of effluent stream and desulfurization techniques are practically unlimited.

In the long term, radical new technologies may lead to entirely different process systems which are compatible with the ambient air quality goals. However until such new technology is available, "add on" control systems are a more likely candidate method for achieving the imminent and stringent future SO<sub>2</sub> emission regulations. Table 3-7 provides a description of 14 of the principle techniques now being adapted or considered for SO<sub>2</sub> removal in different process effluent streams. The choice of technique in any application depends on the nature of the gas stream being treated and a variety of engineering and economic factors related to each situation.

Sulfur can exist in a large number of oxidation states. The common oxidation states of sulfur found in process effluent gas streams are those typified by H<sub>2</sub>S (-2), elemental sulfur (zero), SO<sub>2</sub> (+4) and SO<sub>3</sub> (+6). The reduction-oxidation interconversion of sulfur between the oxidation states -2, 0, +4, and +6 is an essential feature of current and proposed desulfurization processes. In each of the processes the objective is to produce a sulfur product which may be removed mechanically from the system. This corresponds

TABLE 3-7. PROCESS FOR DESULFURIZATION OF EFFLUENT GAS STREAMS  
PROCESSED PRINCIPALLY IN THE GAS PHASE

Process (Developer)	Comments	Process Chemistry
YIELDING SULFURIC ACID OR SULFATE (S = + 6)		
1. Dry limestone (TVA)	Simultaneous reaction of SO <sub>2</sub> with lime and air oxidation of resulting sulfite to sulfate. End product slag requires suitable disposal. Swedish Bahco Process uses hydrated lime slurry. Lignite ash also used as absorber (Carl Still, W. Germany).	$\text{CaCO}_3 \longrightarrow \text{CaO} \xrightarrow[\text{+ CO}_2 \text{ (TO ATMOSPHERE)}]{\text{SO}_2, \text{SO}_3, \text{AIR}} \text{CaSO}_4$
2. Manganese dioxide (Mitsubishi)	Initial concentration and oxidation of SO <sub>2</sub> to metal sulfate with air regeneration of MnO <sub>2</sub> , oxygen carrier and ammonium sulfate (fertilizer) production.	$\text{SO}_2 \xrightarrow{\text{MnO}_2} \text{MnSO}_4 \xrightarrow[\text{AIR}]{\text{NH}_4\text{OH}} (\text{NH}_4)_2\text{SO}_4 + \text{H}_2\text{O}$ <p style="text-align: center;">↑ REGENERATION</p>
3. Active magnesia (Showa Hatsuden) (Chemico)	Essentially a concentration process using MgO as a "collector" followed by regeneration of concentrated SO <sub>2</sub> stream for sulfuric acid plant feed.	$\text{SO}_2 \xrightarrow[\text{MgO}]{200^\circ\text{--}300^\circ\text{F}} \text{MgSO}_3 \xrightarrow{1400^\circ\text{F}} 15\% \text{ SO}_2 \text{ GAS}$ <p style="text-align: center;">↑ REGENERATION</p> <p style="text-align: right;">↓ CONTACT PROCESS H<sub>2</sub>SO<sub>4</sub></p>
4. Modified contact	Essential Contact Process yield acid (Monsanto) or ammonium sulfate (Tokyo) but accepts hot dilute SO <sub>2</sub> gas stream rather than high SO <sub>2</sub> acid plant feed.	$\text{AIR} + \text{SO}_2 \xrightarrow[\text{V}_2\text{O}_5]{900^\circ\text{F}} \text{SO}_3 \xrightarrow{\text{H}_2\text{O}} \text{H}_2\text{SO}_4$ <p style="text-align: right;">↓ 2NH<sub>4</sub>OH (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> + H<sub>2</sub>O</p>
5. Activated carbon	All methods depend on absorptive powers of various forms active carbon to first concentrate and then catalyze oxidation SO <sub>2</sub> to SO <sub>3</sub> for acid or sulfate production. Fluidized, fixed and plugged flow beds variously employed	$\text{SO}_2 \xrightarrow[\text{ACTIVE CARBON}]{\text{AIR, H}_2\text{O}} \text{H}_2\text{SO}_4$

TABLE 3-7. PROCESS FOR DESULFURIZATION OF EFFLUENT GAS STREAMS (Continued)

Process (Developer)	Comments	Process Chemistry
YIELDING SULFUR (S = ZERO)		
6. Sulfreen (SNPA-Lurgi)	Catalytic use of active carbon for high efficiency Claus redox reaction to yield sulfur rather than oxidation of SO <sub>2</sub> to SO <sub>4</sub> <sup>=</sup> . Requires both H <sub>2</sub> S and SO <sub>2</sub> in stream.	$\text{H}_2\text{S} + \text{SO}_2 \xrightarrow{\text{ACTIVE CARBON}} \text{H}_2\text{O} + \text{S}$
7. Alkalized alumina (U.S.Bur.of Mines Alk/alumina and in situ catalytic reduction to H <sub>2</sub> S using reformer Hb, H <sub>2</sub> S then to Claus with regenerated SO <sub>2</sub> . Cent. Elec.Board	Concentration of dilute SO <sub>2</sub> stream on Alk/alumina and in situ catalytic reduction to H <sub>2</sub> S using reformer Hb, H <sub>2</sub> S then to Claus with regenerated SO <sub>2</sub> .	$\text{SO}_2 \xrightarrow[56\%]{\text{Al}_2\text{O}_3/\text{Na}_2\text{O}} \text{ABSORBED SO}_2 \xrightarrow{37\%}$ <p>REGENERATION</p> $\text{H}_2\text{S} + \text{CO}_2 \rightarrow \text{H}_2 + \text{CO} \xrightarrow{\text{REFORMED}}$ <p>CLAU</p> $\text{S} \xrightarrow{\text{SO}_2}$
Processes With At Least One Principal Solution Stage		
8. Molten salt (Atoms,Intn'l) (Garrett, Res.& Dev.)	Dilute SO <sub>2</sub> concentrated by absorption in molten salt as sulfite and reduced by H <sub>2</sub> (Atoms) or coke roasting (Garrett) to sulfide and hence H <sub>2</sub> S. Both processes feed Claus.	$\text{SO}_2 + \text{M}_2\text{CO}_3(\text{L}) \xrightarrow{430^\circ\text{C}} \text{M}_2\text{SO}_3 + \text{CO}$ <p>CLAU</p> $\text{H}_2\text{S} + \text{M}_2\text{CO}_3(\text{L}) \rightarrow \text{M}_2\text{S} + \text{H}_2\text{O} + \text{CO}_2$ <p>STEAM + CO<sub>2</sub></p> <p>NATURAL GAS REFORMATE OR COKE ROASTING</p>
9. Solution Claus (Inst. Francais du Petrole)	Essentially Claus redox in solution with or without added catalyst. High boiling solvents preferred to accept hot gases without extensive cooling.	$\text{H}_2\text{S} + \text{SO}_2 \xrightarrow[\text{POLYGLYCOL SOLVENT (M.W. ~400)}]{\text{METAL SALT CATALYST}} \text{S} + \text{H}_2\text{O}$
10. Giammarco- Vetrocoke	Solution oxidation of H <sub>2</sub> S absorbed as thioarsenite with arsenate/arsenite air regeneratable redox couple as oxygen carrier. Several similar systems involving inorganic redox couples (thylox, manchester, lacykeller exist.	$3\text{H}_2\text{S} + \text{KH}_2\text{AsO}_3 \rightarrow \text{KH}_2\text{AsS}_3 + 3\text{H}_2\text{O}$ $\text{KH}_2\text{AsS}_3 + 3\text{KH}_2\text{AsO}_3 \rightarrow 3\text{KH}_2\text{AsO}_4 + 3\text{S}$ <p>1,5 O<sub>2</sub> (AIR)</p>

TABLE 3- 7 PROCESS FOR DESULFURIZATION OF EFFLUENT GAS STREAMS (Continued)

Process (Developer)	Comments	Process Chemistry
YIELDING SULFUR (S = ZERO) (Continued)		
11. Stretford U.K. North W. Gas Board)	Solution oxidation of H <sub>2</sub> S absorbed as Bisulfide by two stage redox couple involving vanadate and anthraquinone disulfonic acid as oxygen carriers. Takahax uses napthaquinone.	$\begin{array}{c} \text{H}_2\text{S} + \text{Na}_2\text{CO}_3 \longrightarrow \boxed{\text{NaHS} + \text{NaHCO}_3} \\ \text{S} + \text{Na}_2\text{V}_2\text{O}_5 + \text{Na}_2\text{CO}_3 + \text{H}_2\text{O} \longleftarrow \boxed{\text{NaVO}_3} \\ \text{REDOX} \\ \text{AQDSA}(\text{O}_2) \longleftarrow \text{AIR O}_2 \longrightarrow \text{AQDSA} \end{array}$
12. Wellman-Lord	A solution method for concentrating dilute SO <sub>2</sub> steam to rich feed for Claus by bisulfite formation, crystallization and thermal regeneration. No reduction or oxidation in solution step.	$\begin{array}{c} \text{SO}_2 + \text{H}_2\text{O} + \text{M}_2\text{SO}_3 \longrightarrow 2\text{MHSO}_3 (\text{SOLN}) \\ \text{SO}_2 + \text{H}_2\text{O} + \text{M}_2\text{SO}_3 \xrightarrow[\text{HEAT}]{\text{REDISSOLVE}} 2\text{MHSO}_3 \text{O}(\text{XSTL}) \\ \text{H}_2\text{S} \xrightarrow[\text{FEED TO}]{\text{RICH}} \text{CLAUS} \longrightarrow \text{S} \end{array}$
13. Beavon (Parsons Co.)	Preliminary gas phase catalytic hydrogenation all sulfur compounds to H <sub>2</sub> S for feed to Stretford. In particular COS and CS <sub>2</sub> reduced.	$\begin{array}{c} (\text{H}_2), \text{SO}_2, \text{COS}, \text{CS}_2 \xrightarrow{\text{Co/Mo CAT}} \text{H}_2\text{S} \\ \text{REFORMER H}_2/\text{CO} \longrightarrow \text{H}_2\text{S} \\ \text{S} \longleftarrow \text{STRETFORD} \end{array}$
14. Cleanair (Pritchard) (IGS)	H <sub>2</sub> S rich tail gas water cooled to continue Claus and hydrolyze COS and CS <sub>2</sub> ; final H <sub>2</sub> S to Stretford.	$\begin{array}{c} \text{H}_2\text{S}(\text{HIGH}), \text{SO}_2, \text{COS}, \text{CS}_2 \xrightarrow[\text{COOLING}]{\text{H}_2\text{O}} \text{H}_2\text{S} + \text{CO}_2 + \text{S} \\ \text{FURTHER CLAUS} \\ \text{S} \longleftarrow \text{STRETFORD} \end{array}$

Source: Reference (6)

to an oxidation state of either zero (elemental sulfur) or +6 (sulfuric acid and sulfates). To convert the various oxidation states of sulfur existing in an effluent gas, a wide range of oxidizing and reducing agents is used. The conversion route may involve an indirect pathway, such as +4 to -2 to zero as in the Beavon Process, +4 to +6 in the Mitsubishi Process, and other variations as shown in Table 3-7.

Characterization of the effluent stream is the first step in selection of an appropriate desulfurization process. Effluents from combustion sources such as power generating stations are rich in  $\text{SO}_2$  with little or no  $\text{H}_2\text{S}$  content due to prior oxidation incineration. These conditions would tend to encourage the use of processes that handle  $\text{SO}_2$  directly and alone. On the other hand, in processes where effluents consist principally of hydrogen sulfide, such as from oil refinery sour gas processing, those desulfurization processes designed to treat  $\text{H}_2\text{S}$  alone or  $\text{H}_2\text{S}$  and  $\text{SO}_2$  may be preferred. Of course the  $\text{H}_2\text{S}$  may be incinerated to  $\text{SO}_2$  alone, but this leads to dilution of the effluent and complicates the control process by introducing larger processing volume requirements.

#### Description of the Processes

The bulk of the research and development effort has been applied to processes with throwaway products using lime or limestone as an absorbent for  $\text{SO}_2$ . Table 3-8 lists some of the more significant projects now under way which employ this popular process. In the limestone process the +4 sulfur of  $\text{SO}_2$  is oxidized to +6 in sulfate. A major unresolved problem for both lime and limestone scrubbing processes is sludge (sulfates) disposal. The solids do not compact well, and large throwaway volumes are produced. In an EPA sponsored project at TVA's Shawnee Station, the problems of both lime and limestone  $\text{SO}_2$  cleanup systems will be investigated.

The Manganese dioxide, or Mitsubishi Process, is similar to the limestone process, but yields instead ammonium sulfate which can be used as a fertilizer.

**TABLE 3-8. LIME-LIMESTONE SO<sub>x</sub> SCRUBBING LARGE-SCALE PROJECTS**

Company	Developer	Status	Unit type and size	Absorbent
<b>FULL SCALE</b>				
Arizona Public Service	Research-Cottrell	Under construction	Coal-fired, 115 MW	CaCO <sub>3</sub>
Commonwealth Edison	B & W	Operating	Coal-fired, 175 MW	CaCO <sub>3</sub>
Detroit Edison		Planned	Coal-fired, 160 MW	CaCO <sub>3</sub>
Duquesne Light	Chemico	Under construction	Coal-fired, 150 MW	CaO
Kansas City Power and Light	Combustion Engineering	Operating	Coal-fired, 2 X 120 MW	CaO
Kansas City Power and Light	B & W	Operating	Coal-fired, 117 MW	CaCO <sub>3</sub>
Kansas City Power and Light	Combustion Engineering	Operating	Coal-fired, 125, 430 MW	CaO
Key West	Zurn	Operating	Oil-fired, 37 MW	CaCO <sub>3</sub>
Louisville Gas and Electric	Combustion Engineering	Under construction	Coal-fired, 70 MW	Ca(OH) <sub>2</sub>
Northern States	Combustion Engineering	Under construction	Coal-fired, 2 X 700 MW	CaCO <sub>3</sub>
Ohio Edison		Planned	Coal-fired, 2 X 880 MW	CaO
TVA	TVA	Under construction	Coal-fired, 550 MW	CaCO <sub>3</sub>
Union Electric	Combustion Engineering	Abandoned	Coal-fired, 120 MW	CaO
USSR (state-operated)	NIIOGAZ	Operating	Smelter, 900 MW equiv	CaCO <sub>3</sub>
Nippon Kokan KK (Japan)	Mitsubishi	Operating	H <sub>2</sub> SO <sub>4</sub> plant, about 20 MW equiv	CaO
Kansai Electric (Japan)	Mitsubishi	Operating	Oil-fired, 30 MW	CaO
Tomakomai Chemical (Japan)	Mitsubishi	Planned	Smelter, 15 MW equiv	CaO
Mitsui Aluminum (Japan)	Chemico	Operating	Coal-fired, 165 MW	CaO
Sodersjukhuset (Sweden)	Bahco	Operating	Oil-fired, 3 X 6 MW	CaO
Egypt (state-operated)	Chemiebau	Abandoned	H <sub>2</sub> SO <sub>4</sub> plant, small	CaO
Public Service of Indiana	Combustion Engineering	Planned	Coal-fired, 650 MW	CaCO <sub>3</sub>
Southern California Electric	SCE	Planned	Coal-fired, 2x150 MW	CaO/CaCO <sub>3</sub>
<b>PROTOTYPE</b>				
EPA-TVA	Bechtel, EPA, TVA	Operating	Coal-fired, 3 X 10 MW	CaCO <sub>3</sub> , CaO
STEAG (Germany)	Bischoff	Operating	Coal-fired, 35 MW	CaO
Ontario Hydro (Canada)	Ontario Hydro	Planned	Coal-fired, 30 MW	CaCO <sub>3</sub>

Source: Reference (6).

The Chemical Magnesia system serves to concentrate the dilute  $\text{SO}_2$  gas stream to provide a feedstock for sulfur recovery in an established conversion process to sulfuric acid. The magnesium oxide absorbs the  $\text{SO}_2$  as  $\text{MgSO}_3$ , after which the  $\text{MgSO}_3$  is regenerated to produce the concentrated  $\text{SO}_2$  gas.

The Monsanto and Hitachi  $\text{SO}_2$  removal methods are one step catalytic oxidations of  $\text{SO}_2$  to  $\text{SO}_3$  and sulfuric acid. In the Monsanto approach, hot dilute  $\text{SO}_2$  in the gas stream is oxidized by the catalyst at a high temperature. Sulfur trioxide condenses with moisture to form  $\text{H}_2\text{SO}_4$ . This process is being tested in an EPA sponsored project at the 100 MW Wood River Station of Illinois Power.

The processes above are all considered to be desulfurization techniques for combustion effluents.  $\text{SO}_2$  is the required feed for these processes. Hence any of these cleanup methods could be installed as "add on" equipment with no other plant modifications required.

The Sulfreen system is a reduction process in that it produces the end product of elemental sulfur. The Sulfreen process was developed specifically for sulfur plant tail-gas cleanup. Activated carbon is utilized to provide adsorption of  $\text{SO}_2$  and subsequent reaction with  $\text{H}_2\text{S}$  (reduction) to produce sulfur. The Sulfreen process requires both  $\text{H}_2\text{S}$  and  $\text{SO}_2$  in the effluent gas.

The alkalized alumina Process, developed by the U. S. Bureau of Mines, removes sulfur oxides from the stack by dry absorption on alkalized alumina ( $\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3$ ). The spent absorption agent is regenerated at 1200F by contact with a reducing gas (CO), which forms  $\text{H}_2\text{S}$ . The  $\text{H}_2\text{S}$  is then converted to elemental sulfur in a conventional Claus Unit.

The molten carbonate system (Atomics International) involves the absorption of the effluent  $\text{SO}_2$  in the molten salt as a sulfite. The sulfite is reduced by  $\text{H}_2$  and CO to hydrogen sulfide. The molten carbonate is regenerated for reuse, and the  $\text{H}_2\text{S}$  is converted to sulfur in a conventional sulfur plant.

The IFP sulfur recovery process utilizes a metal salt-type catalyst to convert  $\text{H}_2\text{S}/\text{SO}_2$  to a gaseous mixture of ammonia, sulfur dioxide, and water. This mixture is then treated in a Claus unit to reduce the  $\text{SO}_2$  to sulfur by reaction with hydrogen sulfide.



The Vetrocope and Stretford processes have had widespread application in Europe. Only recently has the Stretford process been incorporated into the overall desulfurization procedures known as the Beavon and Cleanair. Both the Vetrocope and Stretford method include the use of an oxygen carrier into a multiple coupled redox reaction in solution. In the process,  $H_2S$  in the stack is converted to elemental sulfur.

The Wellman Lord process scrubs  $SO_2$  from the stack gas with a solution of sodium sulfite. The solution absorbs the sulfur dioxide, converting the sodium sulfite to sodium bisulfite. The sodium bisulfite solution is regenerated by steam stripping producing a concentrated  $SO_2$  stream for recovery to sulfur in a sulfur recovery plant. The Wellman-Lord process is used on Claus and sulfuric acid plants as well as the electric utilities industry. Sodium sulfate disposal is a main drawback to this system. The process will undergo careful examination in an EPA sponsored project at the 125 MW Northern Indiana Public Service power plant.

The Beavon and Cleanair processes are combinations of other basic techniques. In the Beavon process the  $SO_2$  of the stack gas is initially reduced to  $H_2S$  and then fed to a Stretford Unit. In the Cleanair system both a Claus unit and the Stretford unit are used simultaneously.

#### End Products of Desulfurization Systems

All desulfurization processes yield an end product. In some of the processes the product is marketable. Sulfur is the end product in many of the cleanup processes, particularly those applied to sulfur recovery tail gas at oil refineries, and finds wide use as a base chemical. Its marketability fluctuates, and its low dollar-per-ton cost does not begin to enable the cleanup system to pay for itself. However because of its marketability and relative ease of handling, sulfur as an end product may be disposed of conveniently.

The disposal of sulfuric acid as an end product is complicated by storage problems. Large tonnage storage or long distance hauling is not feasible. Selection of desulfurization clean up systems yielding sulfuric acid as an end product depends on the presence of a consumer near the process.

Disposal of ammonium sulfate (the end product in processes such as the ammoniacal solution and manganese dioxide technique) may be costly when moisture protection during storage is required. It can then find immediate use as a fertilizer. Calcium sulfate, an end product of the dry-limestone process, is a waste requiring land fill disposal.

Water wastes are a disposal problem with all of the large-volume aqueous solution processes. Large volumes of contaminated water must be repurified before recycling or discharging as effluent.

The Wellman Lord cleanup process yields a sodium sulfate which is nonregenerable. Its handling does not pose a problem, but the current market for this product is limited.

#### Process Efficiency

Performance data for the various desulfurization processes is rather limited, except as each of the processes relates to particular applications now prevalent in the field. In this respect a number of the cleanup processes have proven suitable for  $\text{SO}_2$  removal down to concentrations of less than 500 ppm. Initially, desulfurization processes were applied successfully to the tail gas of Claus units at oil refineries. Several units have been operating successfully at various refineries for the past few years (Table 3-9).  $\text{SO}_2$  cleanup processes have also been installed in Los Angeles, reducing emissions from refinery tail gas to less than 500 ppm as required by new regulations imposed by the APCD. Among those processes capable of reducing  $\text{SO}_2$  levels well below 500 ppm in effluent gas streams are the Vetrocoke, Stretford, and Wellman-Lord process. These processes have operated in various tail-gas applications to reduce  $\text{SO}_2$  concentrations to less than 200 ppm.

Motivated by imminent new  $\text{SO}_2$  emission standards targeted for the electric utilities, several power plants have now been equipped with desulfurization systems which are providing continuous operation at 90% plus  $\text{SO}_2$  removal rates. Table 3-10 provides a summary of nine different cleanup processes now under test at various utilities.

Numerous equipment difficulties have been encountered during the brief operating histories of these infant systems. For example, at the Four Corners power plant in Arizona, massive  $\text{SO}_2$  scrubber units installed in 1971

TABLE 3-9. PROCESSES USED FOR SULFUR REMOVAL FROM CLAUS TAIL GAS

Name	Developer	Operation	Sulfur Removal	Product
Beavon Sulfur Removal Process	Ralph M. Parsons & Union Oil Co. of California	Los Angeles refinery. Union Oil Co. of Ca.	Removal to 250 ppm SO <sub>2</sub> or less	Sulfur
CleanAir Sulfur Process	J.F. Pritchard & Co. and Texas Gulf Sulfur Co.	Pilot plant work. Okotoks plant, Texas Gulf Sulfur Co.	Removal to 250 ppm SO <sub>2</sub> or less	Sulfur
IFP Sulfur Recovery Process	Institut Francais du Petrole	Demonstration plant, Lone Pine Creek plant, Hudson's Bay Oil & Gas. Nippon Petroleum Refining Co., Japan Idemitsu Oil Co. Japan Kyokutoh Oil Co. Japan Showa Oil Co. Japan	SO <sub>2</sub> removal to 1,000 ppm	Sulfur
Shell's Flue Gas Desulfurization Process	Koninklijke/Shell Laboratorium, the Netherlands	Pilot plant work, Pernis, the Netherlands	90% SO <sub>2</sub> removal	SO <sub>2</sub> formed is recycled through a Claus unit
Sulfreen Process	SNPA and Lurgi Gesellschaften	SNPA sulfur plant, Lacq field Aquitaine's Ram River sulfur plant, Rocky Mountain House, Alberta	75% of sulfur in the Claus Plant tail gas	Sulfur
Wellman-SO <sub>2</sub> Recovery Process	Wellman Power Gas	Olin Chemical Co. Paulsboro, N.J. Japanese Synthetic Rubber Co. Chiba, Japan Toa Nenryo Kogyo Refinery, Kanagawa, Japan Standard Oil Refinery, El Segundo, California Allied Chemical Co. sulfuric acid plant, Chicago. Olin Corp. sulfuric acid plant, Curtis Bay, Md.	SO <sub>2</sub> Removal to 100 ppm	60% SO <sub>2</sub> and 40% water vapor

Source: Reference (7).

TABLE 3-10. SO<sub>2</sub> REMOVAL PROCESSES CURRENTLY IN TEST

Process	Approx. test unit size, Mw	Developer	Utility
Lime scrubbing (boiler injection)	120	Combustion Engineering	Kansas City Power and Light
Lime scrubbing (scrubber introduction)	120	Chemico	Mitsui Aluminum (Japan) <sup>a</sup>
Limestone scrubbing	117	Babcock & Wilcox	Kansas City Power and Light
Magnesia scrubbing	150	Chemico-Basic	Boston Edison <sup>a,b</sup>
Catalytic oxidation	100	Monsanto	Illinois Power <sup>b</sup>
Sodium salt scrubbing (thermal regeneration)	125	Wellman-Power Gas	Northern Indiana Public Service <sup>a, b</sup>
Sodium salt scrubbing (throwaway)	125	Combustion Equipment Associates	Nevada Power
Manganese oxide absorption	110	Mitsubishi	Chubu Electric Power (Japan)
Carbon adsorption	150	Hitachi	Tokyo Electric Power (Japan)

**Footnotes**

a. Example of typical installation for this system. Other companies also have units under construction or in operation.

b. EAP sponsored.

There are 50 or more significant projects in the United States at this time.

Source: Reference (8).

have been plagued by numerous problems which have created unscheduled outages, and have cost several million dollars in repair costs.<sup>9</sup> Many of the problems already experienced by cleanup systems now in operation have been engineered out of succeeding installations, with the result that a number of suppliers now are able to give performance guarantees with new installations.

In Los Angeles, APCD SO<sub>2</sub> emission regulations are met by the electric utilities burning low sulfur fuels of less than .5% sulfur content (Rule 62, Sulfur Content of Fuels). By burning the low sulfur fuels, stack emissions are kept under the permissible 2000 ppm SO<sub>2</sub> emission level (Rule 53, Sulfur Compounds Concentration). This control procedure permits relatively low sulfur emissions to be achieved without the need of costly add-on desulfurization systems. However unless desulfurization of fuels is extended to lower limits, the sulfur removal effected by this strategy may not be satisfactory

to meet the moving clean air targets. Add-on desulfurization equipment may then become a candidate control measure for power utilities located in the Four-County Area.

### Cost

Desulfurization of industrial effluent gas streams involves expenditures which generate benefits entirely in terms of air quality improvement, and not in terms of process improvement. The fact that there are no cost benefits from implementing desulfurization controls emphasizes the need for minimizing costs to be incurred by installation and operation of the prospective clean-up systems.

Quantitative analysis of the comparative cost of available desulfurization processes is possible only when the precise nature of the gas stream to be treated is known. Even when the effluent stream specifications are identified, comparative operating data of the candidate systems is generally insufficient to appraise which methods are most economical and effective. Figure 3-17 is a qualitative summary of cost versus effectiveness for the typical clean-up systems of Table 3-7. All the systems are not capable of the higher levels of effectiveness shown in the figure, and generally those which are most efficient are available at the higher costs.

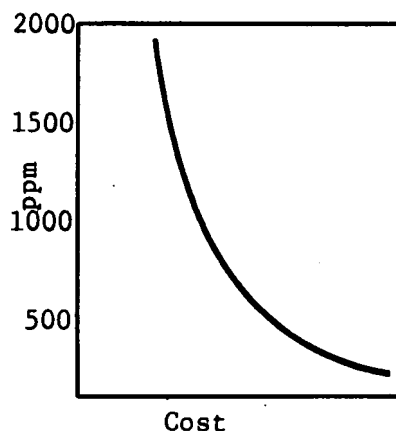


Figure 3-17. Cost of Effectiveness for  $\text{SO}_2$  Removal Systems

Under the new federal regulations, electric utilities are the main target for SO<sub>2</sub> and control systems. The Sulfur Oxide Control Technology Assessment Panel has estimated that the cost of SO<sub>2</sub> stack cleaning for power utilities could increase consumer cost for electricity by 17%. Several utilities have affirmed that SO<sub>2</sub> cleanup technology will increase consumer rates by 20%.<sup>8</sup> The Louisville Gas and Electric Co. has stated that the cost of its announced SO<sub>2</sub> compliance program for its eight existing units will amount to a rate increase of 30%. Some examples of the capital cost of retrofitting SO<sub>2</sub> cleanup technology in existing power generating plants are shown below:

Size of Plant (MW)	Initial Capital	\$ per KW	Developer & Utility
800	150	60	Penn Power, Bruce Manifold Station (2 units)
550	42	80	TVA, Widows Creek
65	3.1	50	Louisville Gas & Electric
1650	100	60	Louisville Gas & Electric (8 units)

Although numerous cost estimates have been made for cleaning stack gases, most of the published information is not definitive. It is difficult to evaluate and compare the cost of cleanup processes when there are still many problems to be identified during development. This situation will be remedied as current projects are completed and more operating data has been obtained. In addition, costs will vary widely depending on factors such as plant size and location, cost of raw materials, difficulty of product disposal, and whether the installation is new or retrofit. The present indication is that for power plants investment can be as high as \$80/KW with an annual operating cost as high as \$2.5/KW.

The costing of desulfurization cleanup systems used to control emissions from the tail gas of Claus sulfur recovery plants involves less guess work than other applications. SO<sub>2</sub> removal processes have operated continuously with high efficiency at several sulfur recovery plants for the past few years. The capital and operating cost of a high efficiency SO<sub>2</sub> cleanup process when applied to a Claus plant operating at 95% recovery are shown in Figures 3-18 and 3-19. A high efficiency cleanup system for a

typical Claus unit processing 1000 tons/day of sulfur with a tail gas  $\text{SO}_2$  concentration of 10,000 ppm would incur a capital cost of \$3.5 million.

The problem of high cost for stack desulfurization is compounded by the limited availability of the  $\text{SO}_2$  cleanup systems. The Sulfur Oxide Control Technology Assessment Panel has stated that processes may not be readily available for the next few years. Currently there are several scheduled process installations, and if emission control standards do not become more lenient in the next few years, commercial demand for the cleanup systems will far exceed the industry's limited manufacturing capacity.

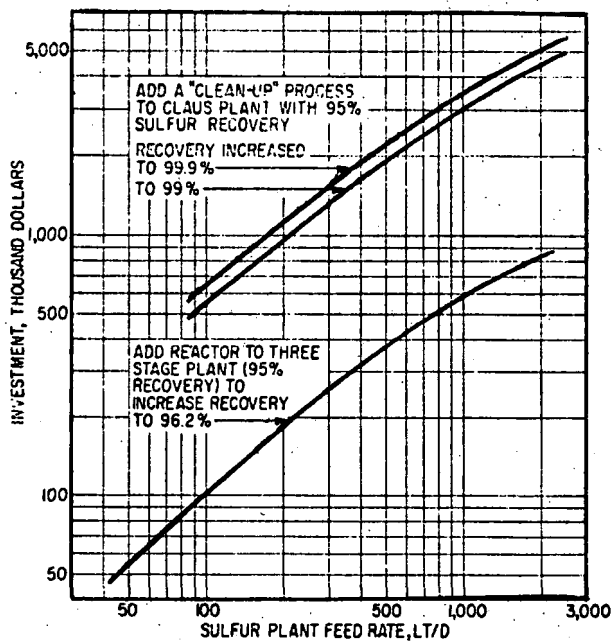


Figure 3-18. The Investment for Desulfurization Facilities at Sulfur Recovery Plants.

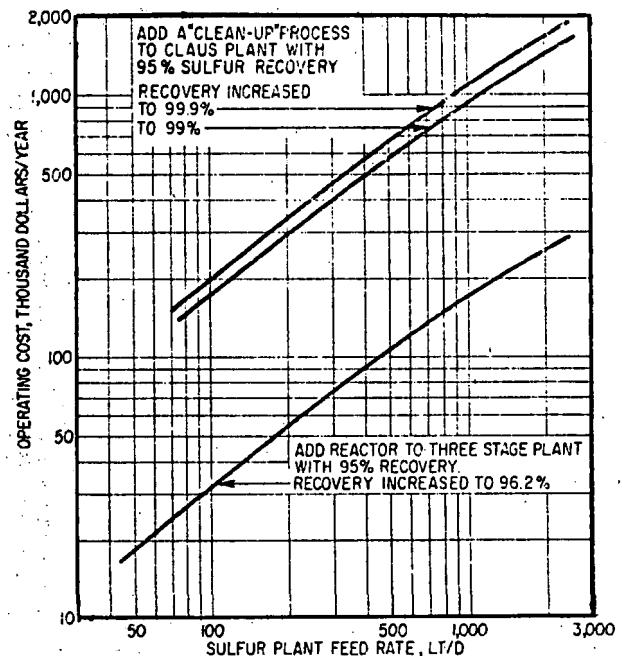


Figure 3-19. Operating Costs for Removing the Residual Sulfur from Conventional Claus Units.

Source: Reference (7).

### 3.3 ALTERNATIVE FUELS - A CONTROL FOR PARTICULATES, SO<sub>2</sub> AND NO<sub>x</sub>

Today's energy needs are served primarily by direct use of fossil fuels. The disappearing reserves of these fuels for low cost energy, and the concern over long-term energy supply, has recently given rise to investigation of alternative energy systems by various energy planning agencies. Synthetic fuels from non-fossil sources are now being advocated as the most suitable alternative for supplying the long term needs for gaseous and liquid fuels. However, in the near term, until technology is more advanced, even synthetic fuels will require fossil sources such as coal and oil shale.

A conversion to synthetic fuel systems would have dramatic impact on air quality problems. Consumption of synthetic fuels in these systems results in very little air pollution, and would eliminate the immense effort now targeted for control of air pollutant emissions from fossil energy use.

Among the comprehensive studies of potential fuels, methanol is described as the most desirable of the alternatives in many ways. Hydrogen, which has been suggested as a universal, nonpolluting fuel, is expensive, difficult to store and transport, unadaptable to current fuel-using equipment, and hazardous; the use of methanol does not pose these problems.

Methyl-fuel can serve as a substitute in many current fuel systems. In full scale boiler combustion tests, methyl-fuel has proven itself an effective air pollution control measure. The burning of methyl-fuel produced virtually no unburned hydrocarbons, SO<sub>2</sub>, or particulate emissions, and NO<sub>x</sub> emissions were reduced below that produced under firing of natural gas. Methyl-fuel is especially attractive as a fuel substitute for motor vehicles, and can be utilized as an additive to current fuel stocks without special adaption. Its research-octane blend value of 130 makes it a possible octane booster substitute, and because it has no lead or sulfur it can be used compatibly with motor vehicles equipped with catalytic exhaust control devices. When methyl-alcohol is used as a complete motor fuel substitute (requiring engine adaption estimated at \$100 per vehicle), exhaust emissions are reduced by 80%.<sup>10,11</sup>



Methanol is produced by reacting synthesis gas ( $\text{CO}$ ,  $\text{CO}_2$ , and  $\text{H}_2$ ) at various temperatures and pressure in the presence of a catalyst. In the typical commercial production of methanol, the synthesis gas is produced by reacting steam and methane. However the synthesis gas can also be produced from natural gas and carbonaceous materials such as oil shale, coal, and refuse. In the manufacture of methanol the output can be increased by 50% if small amounts of other alcohols can be tolerated in the product. Such a mixture is called "methyl-fuel," and can be produced in larger quantities and lower prices than pure methanol, and has superior properties as a fuel.

In the near term, coal must be utilized to achieve large-scale methyl-fuel production. However the desirability of coal for methyl-fuel production depends heavily upon successful coal gasification design. Intensified development is now under way to provide these designs, and some have proven feasible already. These systems are similar to those already built on commercial scale for the U.S. Bureau of Mines and various chemical companies.

#### Economics of Methyl-Fuel Production

Due to the relatively limited production of synthesis gas from coal in this country, the economics and technology for this process are not well defined. Preliminary cost estimates developed in the fall of 1972 for a plant producing 20,000 tons/day of methyl fuel (equivalent in heating value to gasoline produced by a 160,000 barrels/day petroleum refinery) are given in Table 3-13. The cost of production for methanol is estimated at 8.51¢/gal, or 148¢/10<sup>6</sup> BTU. This production cost can be compared with other fuels as follows:

TABLE 3-12. PRODUCTION COST OF ENERGY IN FUELS, SEPTEMBER 1972

<u>Fuel</u>	<u>Source</u>	<u>Cost, \$/10<sup>6</sup> BTU</u>
Gasoline	crude oil	1.05
Fuel oil	crude oil	.96
Hydrogen gas	coal	1.32
Methyl-fuel	coal	1.48

Source: Reference (12).

TABLE 3-13. ECONOMICS OF SYNTHESIS OF 20,000 TONS/DAY  
OF METHANOL (MeOH) FROM COAL

Item	Unit	Units /Day	Cost		¢/gal MeOH
			\$/Unit	\$/Day	
Synthesis Gas Manufacture <sup>6</sup> (Capital for Plant: \$260 x 10 <sup>6</sup> )					
Coal <sup>a</sup>	Ton	26,000	7.00	182,000	3.02
Chemicals				1,000	0.02
Process water	10 <sup>3</sup> gal	6,250	0.20	1,250	0.02
Cooling water	10 <sup>3</sup> gal	346,000	0.02	6,920	0.11
Operating labor	Man-hr	960	4.00	3,840	0.06
Supervision				380	0.01
Maintenance				35,600	0.59
Overhead				4,220	0.07
Precapital manufacturing cost				235,110	3.90
Capital charges at 15%/year				106,800	1.77
Total cost				341,910	5.67 (99¢/10 <sup>6</sup> Btu)

Methanol Synthesis from Provided Syngas  
(Capital for Plant: \$135 x 10<sup>6</sup>)

Steam	10 <sup>3</sup> lb	38,200	0.65	24,800	0.41
Fuel	10 <sup>6</sup> Btu	21,600	0 <sup>b</sup>		
Electricity	KWhr	100,000	0.01	1,000	0.02
Cooling water	10 <sup>3</sup> gal	540,000	0.02	10,800	0.18
Catalyst and chemicals				15,000	0.25
O&M labor and supervision				50,000	0.83
Overhead				14,000	0.23
Precapital manufacturing cost				115,600	1.92
Capital charges at 15%/year				55,400	0.92
Subtotal				171,000	2.84
Total cost				512,910	8.51 (148¢/10 <sup>6</sup> Btu)

<sup>a</sup>Combined raw material and fuel.

<sup>b</sup>Purge gas from synthesis gas plant.

The costs above reflect the market two years ago. Dramatic changes have since occurred in the world economic situation, affecting the cost of many types of raw materials. The price of petroleum has increased by a factor of five, and costs are now rising to reflect the increased demand for coal. While the current uncertainties in the marketplace suggest restraint in economic projection, it does appear that the current trend is pricing alternative fuels into competition. The cost of fuel oil to the fuel-burning utility companies is presently \$15 per barrel, or \$2.46 per million BTU. Vulcan-Cincinnati Company, a process designer for the manufacture of the methyl-fuel, now estimates a cost to the consumer of \$2 to \$3 per million BTU.

One of the principal drawbacks to the immediate use of methyl-fuel as a substitute in fuel combustion equipment is its availability. Currently the projected market for this fuel is limited. In addition, it may be difficult to provide the coal resources needed for expansive manufacturing of methyl-fuel. The Nation is currently engaged in a program to increase utilization of coal for generation of electric power, and limited coal availability has already placed uncertainties on that effort. Environmental concern over land abuse by coal mining is a primary constraint to plentiful coal supply. However, an advantage contained in the methyl-fuel production is that it will use "low quality" lignite coal, a cheaper and lower demand coal.

In addition to material supply problems confronting any immediate plan for large scale production of a substitute fuel, there are obvious social and political disruptions inherent in a plan proposing radical manufacturing and consumer conversions. If air quality standards are to be met in the near term through fuel conversion policy, the disruptions are inevitable, and probably, intolerable. However, if environmental standards are promulgated to promote alternative fuels over the long term, the transition would appear to be feasible. The market demand may very well supplant this long term possibility. It has been estimated that by 1975 there will exist a market for 18 methyl-fuel plants by coal gasification. By 1980 the demand will be 28. According to the Vulcan-Cincinnati Company, who has a proprietary hold for the manufacture of methyl-fuel, it would be possible to construct these fuel plants by 1980. By 1990 the market demand is projected at 120 plants.<sup>11</sup>

In the long term, methyl-fuel conversion appears practical. In fact, the apparent far reaching attractiveness of methyl-fuel conversion as a long term approach to air resources management problems would seem to raise serious questions as to the sensibility of current air quality achievement goals predicated on rapid timetables. In the long term, deferment of present short term air quality objectives could have significant impact on the rate of development of far reaching alternatives such as methyl-fuel substitution. More investigation is needed to determine the relationship between these factors.

### 3.4 NON-TECHNICAL CONTROL MEASURES

The total regional emission rate from a certain type of air pollution source can usually be described as a product of three factors:

$$\left( \begin{array}{c} \text{Total} \\ \text{Regional} \\ \text{Emission} \\ \text{Rate} \end{array} \right) = \left( \begin{array}{c} \text{Number of} \\ \text{Source Units} \\ \text{In Region} \end{array} \right) \times \left( \begin{array}{c} \text{Average} \\ \text{Source} \\ \text{Usage} \\ \text{Level} \end{array} \right) \times \left( \begin{array}{c} \text{Average} \\ \text{Source} \\ \text{Emission} \\ \text{Factor} \end{array} \right)$$

The controls considered so far in this chapter have essentially dealt with methods for reducing the last of these three factors. The above controls have consisted of modifications of processes or additions of cleaning devices so as to reduce average source emission factors. As such, they might be called "Technological" controls.

This section will briefly examine "non-technical controls", that is, controls aimed at reducing source numbers or source usage. Source relocation and growth restrictions will be the two methods examined for decreasing source numbers. The discussion of source usage control will emphasize vehicle use reductions, i.e., vehicle miles travelled (VMT) restrictions.

It is not inappropriate that non-technological controls are considered last in this chapter. As will be evidenced by the discussions below, there are very great socio-economic costs and implementation problems associated with non-technological controls, especially when they are considered over the short-term, (say 5 to 10 years). It may be difficult to implement strict technological controls for motor vehicles, aircraft, power plants, or industries. However, the resistance to measures such as 50 percent VMT

reduction, industry relocations, or a no gravity policy can be much greater. On the short-run, non-technological controls are somewhat a last resort. They should be considered here, however, since very large reductions in total emission levels will be needed to approach the national air quality standards for particulates in the Los Angeles Region.

#### 3.4.1 Growth Restrictions

Control measures which limit community growth provide an important means of maintaining air quality. These measures may be geared toward discouragement of new growth (disincentive measures) or toward total prohibitions. Alternative measures providing disincentive to growth have been outlined in a recent TRW study on Air Quality Maintenance for the San Diego Area<sup>13</sup>. The measures include various restrictions on land use such as special residential zoning ordinances, environmental impact reporting, special taxation rates, open space planning, and capital improvements requirements. The severity of the restrictions is established to reflect the degree of growth control needed to maintain air quality levels within standards.

Due to the substantial magnitude of the air pollution problem in the Los Angeles Area, it may be necessary to consider implementation of control measures which would actually prohibit certain types of growth. These prohibitions might be directed at the more significant sources, and could include such restrictions as a limit on motor vehicle registrations, prohibitions on industrial expansion, prohibition of airport expansions, limits on utility service hook-up, etc.

#### 3.4.2 Relocation

Source relocation is potentially a very effective method for reducing total regionwide emission levels. However, unless one is moving significant portions of the human population out of the air basin, (which some may agree is the step that is actually necessary to attain all present air quality standards in Los Angeles), source relocation appears to be most appropriate for large, concentrated sources. It is usually a much more difficult problem to relocate area sources, such as traffic, residence, etc. Accordingly, in this study, relocations will be considered only for concentrated or point sources.

The major candidates for relocation in the Los Angeles area are the international airport, power plants, refineries, and certain large

industries. The re-shifting of any of these facilities would involve a tremendous cost and would be resisted by very strong political forces. It is not within the scope of this study to examine these costs and implementation problems in detail. Rather, this study will just note the amount of relocation that may be necessary to meet the air quality standards. If relocation is actually chosen by control agencies as a viable measure, further study will have to be given to the impact associated with its implementation.

### 3.4.3 Source Usage

Restriction of source usage rates is potentially a very effective method of reducing emissions. Examples would be limits on power plant operating level, refinery throughput, or motor vehicle travel. Usage limits for large stationary sources would be equivalent to growth control (for slight restrictions) or to partial relocation (for severe restrictions). The following discussion will concentrate on use controls for motor vehicles.

Recent transportation studies have examined the effect of alternative policies for reducing vehicle miles travelled (VMT)<sup>14, 15, 16</sup>. The list of potential measures which have been studied include the following:

- Improvements in bus services
- New rail transit service
- Auto free zones
- Increased parking costs
- Carpool promotion
- Exclusive bus and/or carpool lanes

A study for Los Angeles indicates that each of these measures (when carried out at a reasonable level) would produce only marginal reductions in VMT, (from .1 percent to 5 percent)<sup>14</sup>. A comprehensive program comprised of all these would only be expected to reduce VMT by 10 to 20 percent. In order to produce larger changes in VMT, say on the order of 50 percent, gasoline rationing appears to be the most appropriate step. The reader is referred to references 14, 15, and 16 for a detailed discussion of potential VMT reduction measures and their impacts.

#### REFERENCES FOR SECTION 3.0

1. "Basic Technology", Section IV Air Pollution Control, Desk Book Issue, Chemical Engineering, April 27, 1970.
2. National Air Pollution Control Administration, "Control Techniques for Particulate Air Pollutants", Publication of U.S. Department of Health Education and Welfare, January 1969.
3. Christensen, R., Chevron Research Company, "Low Sulfur Products from Middle East Crudes", National Petroleum Refiners Association, AM-73-38, April 1973.
4. Steele, D., G. Gould, R. Roselius, W. Haunschild, Chevron Research Company, "Clean Fuels Through New Isomax Technology", American Petroleum Institute, Document 40-73, May 1973.
5. Miller, Stan, "The Business of Air Pollution Control", Environmental Science and Technology, November 1973.
6. Slack, A., Division of Chemical Development, Tennessee Valley Authority, "Removing SO<sub>2</sub> from Stack Gases", Environmental Science and Technology, February 1973.
7. Barry, Charles, Barry & Richardson, "Reduce Claus Sulfur Emission", Hydrocarbon Processing, April 1972.
8. Olds, F., "SO<sub>2</sub> & NO<sub>x</sub>", Power Engineering, August 1973.
9. "The Largest U.S. Wet Scrubber System", Environmental Science and Technology, June 1974.
10. Reed, T., R. Lerner, "Methanol: A Versatile Fuel for Immediate Use", Science, December 1973.
11. "Outlook Bright for Methyl-Fuel", Environmental Science and Technology, November 1973.
12. Atomic Energy Commission Synthetic Fuels Panel, "Hydrogen and Other Synthetic Fuels", Prepared for the Federal Council on Science and Technology R&D Goals Study, September 1972.
13. TRW Transportation and Environmental Operations, "Development of a Sample Air Quality Maintenance Plan for San Diego," Prepared for Environmental Protection Agency, September 13, 1974.
14. TRW Transportation and Environmental Operations, "Transportation Control Strategy Development for the Metropolitan Los Angeles Region," Prepared for Environmental Protection Agency, January 1973.

15. Rand Corporation, "San Diego Clean Air Project," R-1366-SD/Appendix 4, December 1973.
16. Horwitz, J., Kuhrtz, S., Environmental Protection Agency, "Transportation controls To Reduce Automobile Use and Improve Air Quality in Cities," November 1974.



## 4.0 PETROLEUM INDUSTRY

Operations of the petroleum industry broadly include production, refining, and marketing. Production concerns locating and drilling oil wells, pumping and pretreating the crude oil, recovering gas condensate, and shipping raw products to the refinery. Refining involves the conversion of crude oil to a finished saleable product. Marketing includes the distribution and actual sale of the finished products.

The following sections provide a characterization of atmospheric emissions arising from the petroleum industry, the prevailing emission control technology being utilized, and alternative emission control technology available or in development which will reduce atmospheric pollution generated by the petroleum industry.

### 4.1 BASELINE CHARACTERIZATION

The main sources requiring emission control in petroleum production are the process equipment and storage vessels. Pollution control measures for refining operations have been directed principally at elimination of particulates, hydrocarbons, sulfur compounds, and carbon monoxide. Emission control for marketing operations are directed primarily at hydrocarbon vapors which escape during the storage and transfer of the saleable petroleum products, and controls for refining operations are designed to manage the particulate and  $\text{SO}_2$  emissions emanating from the process equipment. These emission problems are characterized in the following section.

#### 4.1.1 Emissions

The most significant emissions from the petroleum industry are  $\text{SO}_2$  gases deriving from operations during refining processes. The petroleum industry accounts for about 15% of all atmospheric  $\text{SO}_2$ , but less than 5% of other particulate precursors, and only 2% of the primary particulates (Figure 4-1). Virtually all of the emissions of the petroleum industry originate in Los Angeles County.

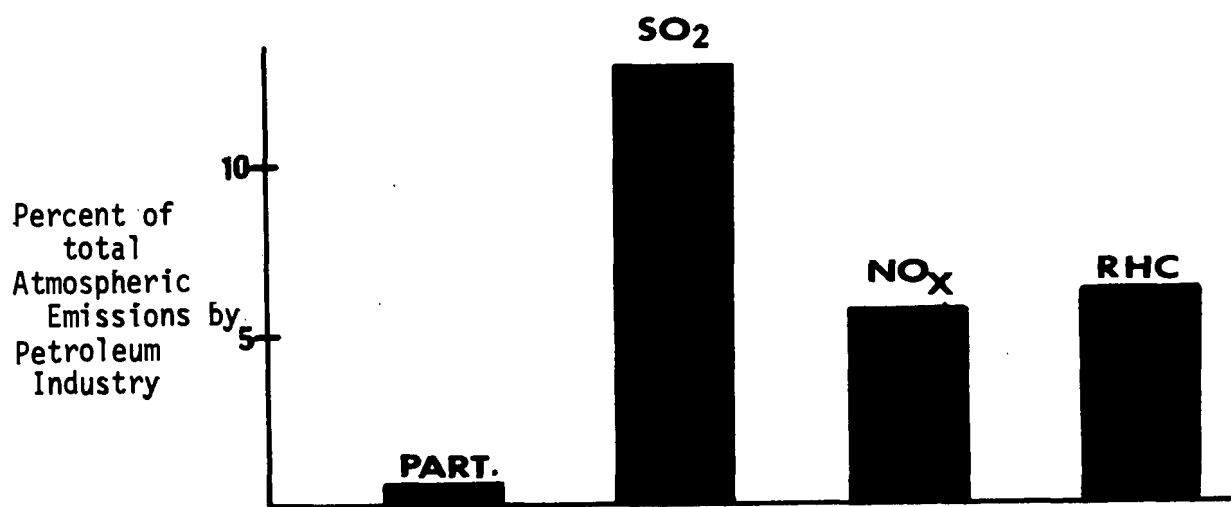


Figure 4-1. Role of Petroleum Industry in Atmospheric Pollution of Four-County Area, 1972.

Projected emissions for the four-county area from the petroleum industry are illustrated in Table 4-1. Due to regulations imposed in the California Air Program Implementation Plans<sup>1</sup> for petroleum marketing operations, the overall RHC emissions from the petroleum industry will be reduced by approximately 75% by 1977. These controls will not affect primary particulates, SO<sub>2</sub>, or NO<sub>x</sub> emissions.

TABLE 4-1. EMISSIONS FROM THE PETROLEUM INDUSTRY, PRESENT AND FUTURE, FOUR-COUNTY AREA.

Year	Particulates	SO <sub>2</sub>	NO <sub>x</sub>	RHC
1972	3	60	67.5	74.1
1977	3	60	67.5	17.8
1980	3	60	67.5	18.7

## Refining

The greatest quantity of air contaminants from the petroleum industry originate from refinery operations. The three primary refinery emission sources include catalyst regeneration, coking operations, and sulfur recovery plants. For purposes of emission inventory compilations, sulfur recovery plants are typically considered as a chemical process. Accordingly, consideration of emissions from sulfur recovery plants is discussed in Section 11.0 (Chemical Processing Industry).

Catalyst regeneration is a continuous process integral to the catalytic cracking of petroleum. During the refining process, the molecular structure of the different distillates of the crude oil are chemically converted by catalytic cracking to produce products such as gaseous hydrocarbons, gasoline, gas oil, and fuel oil. The catalyst utilized in this process becomes contaminated with coke build-up and must be continually regenerated by burning off the coke under controlled combustion conditions. The resulting flue gases contain particulates (coke and catalyst fines), and products of combustion such as hydrocarbons,  $\text{SO}_2$  and  $\text{NO}_x$ . The quantities of these emissions generated from refineries in the Four County area are given in Tables 4-2 and 4-3 and 4-4 below.

TABLE 4-2. PARTICULATE EMISSIONS FROM PETROLEUM INDUSTRY OPERATIONS, FOUR-COUNTY AREA<sup>a</sup>, 1972

Process	Emissions to Atmosphere Ton/Day	% of Particulate Emissions in This Industry
Petroleum Coke Operations	.7	22.4
Catalytic Cracking	2.2	73.2
Other	.1	4.4
TOTALS	3.0	

<sup>a</sup>The distribution of emissions from the operations is based on the tabulation of the APCD inventory file for Los Angeles County only. This distribution was applied to the Four-County Area total emission inventories to obtain the daily emission figures above.

Source: Reference (2)

TABLE 4-3. SO<sub>2</sub> EMISSIONS FROM OPERATIONS OF THE PETROLEUM INDUSTRY, FOUR-COUNTY AREA<sup>a</sup>

Process	Emissions to Atmosphere Ton/Day	% of SO <sub>2</sub> Emissions in This Industry
Catalytic Cracking	57.2	95.4
Other	2.8	4.6
Total	60	

Source: Reference (2)

TABLE 4-4. NO<sub>x</sub> EMISSIONS FROM OPERATIONS OF THE PETROLEUM INDUSTRY, FOUR-COUNTY AREA<sup>a</sup>

Process	Emission to Atmosphere Ton/Day	% of Particulate Emissions in This Industry
Catalytic Cracking	60.5	89.8
Other	7.0	10.3
Total	67.5	

<sup>a</sup> The distribution of emissions from the operations is based on the tabulation of the APCD inventory file for Los Angeles County only. This distribution was applied to the 4 county area total emission inventories to obtain the daily emission figures above.

Source: Reference (2)

Coking operations involve the processing of the heavy residual of the crude oil's initial separation. The residual is heated and injected into a drum where vaporization to dryness forms a solid material called "coke". The coke is removed from the drum by steam drilling, and subsequently crushed and transferred to storage. The APCD estimates that the crushing and transfer operations account for a significant portion of atmospheric particulate discharges from the refineries (see Table 4-2).

#### Marketing and Production Operations

A network of pipelines, terminals, truck fleets, marine tankers, and storage and loading equipment are used to deliver the finished petroleum product to the user. The significant emissions arising from marketing activities are hydrocarbon vapors from storage vessels and filling operations. Similarly, significant emissions arising from production activities are the hydrocarbon vapors which emit during storage and filling operations. The quantities of hydrocarbon emissions from the types of petroleum activities are summarized below. These sources (as well as all other hydrocarbon sources)

Reactive Hydrocarbon Emissions from Petroleum Industry

	1972 RHC, tons/day
Production	2.0
Refining	5.0
Marketing	67.1

have been a target of pollution control under the EPA oxidant reduction plan, and their control will therefore not be addressed in this report (as mentioned previously in Section 1.0).

#### 4.1.2 Emission Control

Table 4-5 lists the type of control equipment currently being utilized to reduce particulate emissions of petroleum refining emission sources. It has been estimated by the LAAPCD that over 90% of refinery particulate emissions are prevented from entering the atmosphere. These

TABLE 4-5. CHARACTERIZATION OF CONTROL METHODS CURRENTLY UTILIZED IN PETROLEUM INDUSTRY FOR CONTROL OF MAJOR PARTICULATE EMISSION SOURCES, FOUR-COUNTY AREA, 1972

Process Operation	Actual Emissions lb/day <sup>a</sup>	Control	Average Efficiency
Petroleum Coke - Conveying	1020	None(except for wet treatment)	--
	15	Baghouse	89.6
Size Reduction	14	Baghouse	94.7
Storage	381	None	--
Catalytic Cracking	4400	Electrical Precipitation	95.0

<sup>a</sup>These figures are based on the APCD inventory file information for Los Angeles County. They have been adjusted to reflect the overall four County emission totals as reported in the total emission inventory of Reference (12).

preventions are attained by employment of baghouses and electrical precipitators, and in the instance of coke conveying, particulate pollution control is accomplished mainly by wetting procedures, similar to those used in the mineral industry to prevent dust generation during aggregating operations. These wetting practices provide controls which enable the industry to comply with current APCD regulations (Rule #50 - Opacity, and Rule 51 - Nuisance). Particulates emitted from catalyst regeneration are prevented from discharge to the atmosphere by employing

a cyclone separator and electrical precipitator to the regenerator flue gases, as shown in Figure 4-2 below. The APCD estimates a particulate recovery rate of 95% due to these controls.

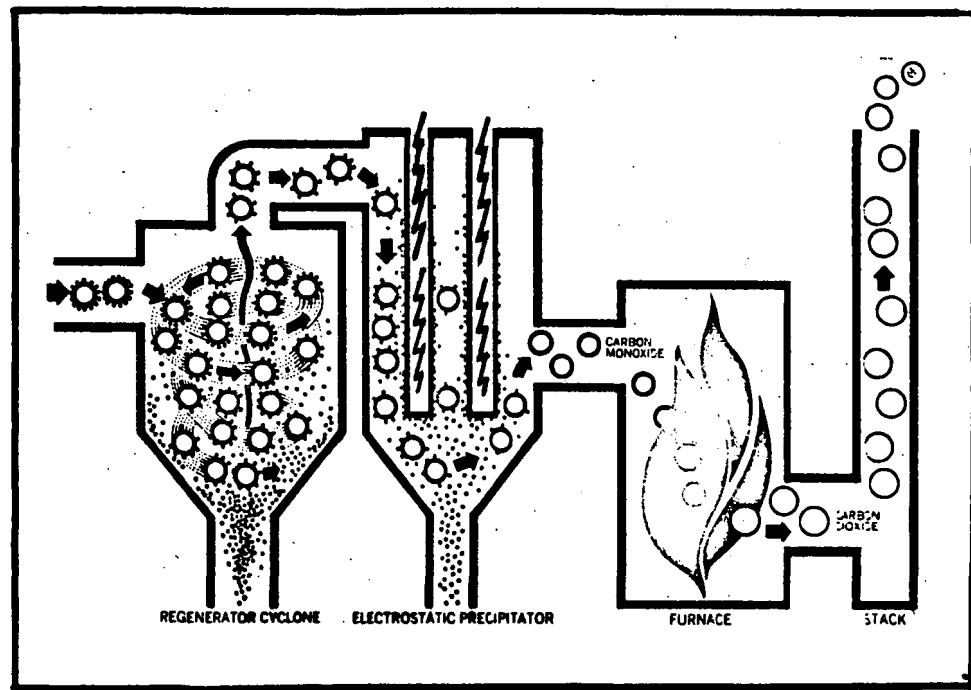


Figure 4-2. Control of Particulates and Carbon Monoxide in Catalytic Regeneration Systems

Source: Reference (3)

The major  $\text{SO}_2$  and  $\text{NO}_x$  emissions of the petroleum industry result from catalytic regeneration operations, and are uncontrolled at present. There are currently no scheduled preventions planned for these sources.

#### 4.2 ALTERNATIVE CONTROL MEASURES

Alternative controls which may be applied to refinery operations to reduce particulate and gaseous precursors emissions consist of both add-on equipment and process alterations.

##### 4.2.1 Particulates - Electrical Precipitators

The traditional air pollution control devices, electrical precipitators, fabric filters, mechanical collectors, and wet scrubbers are used throughout the petroleum industry to control particulate emissions from large sources and a variety of small pollution generating sources. This equipment is suitable

for reducing most emissions to negligible levels. However, despite levels of control which are in the neighborhood of 95% removal efficiency, the volumes of gases (up to 150,000 cfm) vented from a large regenerator still carry substantial emissions approaching the 30 lb/hr maximum (Rule #54, Solid Particulate Matter).

The cost of a precipitator removal system rises sharply with performance and cost penalty is substantial for the manufacturer who provides emission control beyond that required by law. Consequently precipitators are typically designed for a given application to provide the degree of emission control required by air pollution regulations. A versatile precipitator design incorporates provisions for future addition or modification to improve efficiency in the event it becomes necessary to adapt to process changes, or changes in air pollution control regulations. When no provision has been made for future additions, increasing the efficiency of the unit may be more costly than exchanging the unit altogether.

Installing additional high voltage electrostatic precipitator sections is the most common technique for improving particulate collection efficiency. Changing the voltage or power supply may also improve the performance. Changing the temperature of the gas stream or injecting other materials into the gas stream may improve efficiency.

Retrofits to precipitators for improved performance is generally possible with newer equipment, but because of the rapid evolution of technology in the air pollution control industry, older generations of precipitators cannot be practically retrofitted. An additional problem in the retrofitting of existing precipitators is the space limitation constraining the retrofit. Typically most manufacturers have utilized all available space in the initial control equipment installation, such that retrofits may be extremely costly and probably less desirable than replacement alternatives.

Due to a history of stringent air pollution controls in the Los Angeles Area, all local refineries have operated air pollution control equipment for several years. Most of this equipment has been updated in the last 3 to 5 years to reflect increasingly stringent emission regulations. Thus some of the equipment may be retrofittable to meet further demands for air pollution prevention, but is likely that a large portion of the existing equipment would be replaced, due either to the economical or physical unfeasibility of configuration changes, or to the unavailability of adaptable retrofits on previous generation equipment. <sup>4</sup>



The impact of equipping the refineries in the Los Angeles area with higher performance (99% removal) particulate emission control equipment on overall refinery emissions is outlined in Table 4-6. The costs of implementing these controls (from a 95% efficiency level to 99%) are shown in Table 4-7. To obtain the increased precipitator performance it will be necessary to replace existing equipment with larger, more efficient precipitator units. The capital expenditures required for these air pollution preventions appear substantial, reflecting considerable involvement on the part of the refineries and the air pollution control industry, and suggest that long lead times will be necessary before equipment supply demands can be met.

#### 4.2.2 Gaseous Precursors

The methods available to reduce emissions of gaseous precursors include 1) process change, and 2) add-on emission control equipment.

##### Add-On Emission Control Equipment

As previously mentioned, the available control technology for  $\text{SO}_2$  removal equipment is now in its infancy. There are many commercial methods for  $\text{SO}_2$  removal from effluent gas streams, but to date relatively few of these have been thoroughly tested (see Section 3.2.2). Hence the operating and performance data associated with these recovery systems is very limited. Since refinery operations are not the primary contributor to  $\text{SO}_2$  air pollution, none of the pilot installations are directed at the removal of  $\text{SO}_2$  from refinery regenerators. Most of the applications of commercial systems are now being used to recover sulfur from power plant stacks and sulfur recovery plant tail gases. However a number of the  $\text{SO}_2$  removal systems now being commercially promoted are applicable to a variety of flue gases containing  $\text{SO}_2$ . Particularly adaptable to a wide range of effluent gases are wet scrubbing techniques, such as the Wellman Lord process, The Double Alkali-system, and the lime-scrubber technique.

The Wellman-Lord  $\text{SO}_2$  removal system may be particularly well suited to application in refineries since its process produces a concentrated  $\text{SO}_2$  gas, which can be delivered to sulfur recovery plants already existing at the refineries. While the quantity of sulfur which can be recovered from regenerator flue gases is not of appreciable magnitude to generate important economic benefits, the employment of the sulfur recovery using the Wellman-Lord principle avoids some of the supply and waste discard problems inherent in most wet scrubbing techniques. The Wellman-Lord process is now being utilized in 10 systems of different magnitude throughout the United States, and presently, 12 other systems are in construction. The manufacturer, Davy Power Gas Company, can guarantee an effluent  $\text{SO}_2$  concentration of less than 100 ppm. Obtaining this level of emissions would correspond to a 90%  $\text{SO}_2$  emission reduction from the regenerator effluent stream.

Several other  $\text{SO}_2$  removal systems may also be applied to the regenerator flue gases. A number of these may be able to remove over 90% of the  $\text{SO}_2$ , although their performance under the conditions of this application is unproven. These systems, notably the wet absorption methods, have been discussed in Section 3.0.

The impact of add-on  $\text{SO}_2$  removal systems to cracker units at the refineries in Los Angeles is given in Table 4-6. A 90% removal of  $\text{SO}_2$  in the stack gases was assumed, providing a 51.4 ton per day reduction in  $\text{SO}_2$  emissions from refinery emissions in 1977. The annual cost of these controls is estimated to be \$3.8 million per year, or \$193 per ton of  $\text{SO}_2$  removed (Table 4-7).

#### Process Alterations

Another approach to the control of  $\text{SO}_2$  emissions from refinery effluent streams is the desulfurization of those petroleum distillates targeted for catalytic cracking. In the typical desulfurization process the various fractions of the crude are catalytically processed in a fixed bed catalyst system. This system is closed and emits no air pollution. Regeneration of the catalyst is necessary only once or twice a year. The various off-stream fuel gases arising from this system, containing sulfur as  $\text{H}_2\text{S}$ , are routed to a claus split stream process where

the  $\text{H}_2\text{S}$  is separated out. The fuel gases are then fed to furnace for heating fuel, and the  $\text{H}_2\text{S}$  stream is further treated in the claus sulfur recovery unit to remove the sulfur.  $\text{H}_2\text{S}$  remaining after treatment is incinerated to  $\text{SO}_2$  in the claus vent gas. This incinerated claus vent gas containing high concentrations of  $\text{SO}_2$  (6000 to 30000 ppm), is treated with add on  $\text{SO}_2$  removal technology recently required under new amendements to Rule 53 of the APCD (see Section 11.0, Chemical Industry).

The desulfurization of all those petroleum fractions fed to the catalytic cracker unit cannot be achieved with existing desulfurization equipment. However the technology to desulfurize all portions of the crude does exist. Currently this technology requires separate facilities for the various different distillates. Such facilities are becoming more prevalent in the refining industry due to new regulations stemming from the Clean Air Act. For example, construction of new facilities for the desulfurization of the residual part of the crude are now planned at the Atlantic Richfield and Standard Oil refineries. These facilities will provide low sulfur fuel oil ( $< .5\% \text{ S}$ ) for power plants per APCD fuel composition regulations. The addition of these facilities will not affect emissions from the catalytic regeneration unit since the residual portion of the crude is not normally processed through the cracker unit. However the trend to increased desulfurization regulations for all petroleum products suggests the probable construction of other desulfurization facilities which will process those distillates which are feed for the catalytic cracker unit. Hence there are two incentives for desulfurization of cracker feed: 1) as an emission control for  $\text{SO}_2$  in the effluent of the regenerator unit, and 2) to anticipate new regulations for low sulfur content of petroleum products (particularly gasoline).

The Chevron VGO Isomax Desulfurization Process (see Section 3.2.1) is suitable for the desulfurization of catalytic cracker feed stock. Sufficient sulfur removal may be achieved to produce low sulfur products from the cracker and to reduce the sulfur oxides content in the regenerator stack gas to appreciably lower levels. Figure 4-3 illustrates the effect of sulfur content in the cracker feed stock on the catalytic regenerator stack  $\text{SO}_2$  emissions.

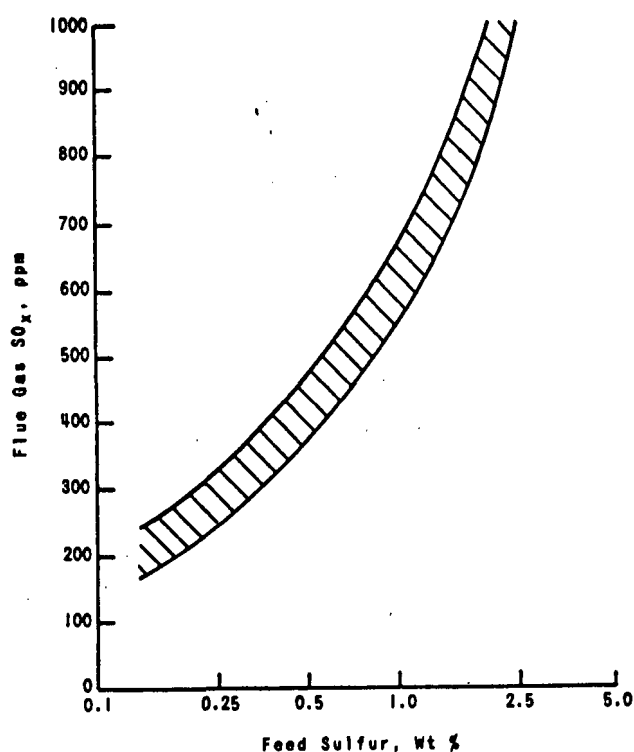


Figure 4-3. Effect of Sulfur Content on Cracker Feed Stock on Regeneration Unit Stack SO<sub>2</sub> Emissions

Source: Reference (5).

It is evident that pretreatment of catalytic cracker feed through the Isomax unit can substantially reduce SO<sub>2</sub> refinery emissions.

Operation of the desulfurization process produces some tradeoff emissions of H<sub>2</sub>S which must be routed to claus sulfur recovery units at the refinery. The claus unit is a standard facility utilized at all major refineries. Recent improvements in the emission control of SO<sub>2</sub> from claus units in Los Angeles County has resulted in very effective treatment of the H<sub>2</sub>S off stream refinery gases. It is expected therefore, that H<sub>2</sub>S effluent from the proposed desulfurization facilities would be managed without significant increases in SO<sub>2</sub> emissions from the current sulfur recovery processes, and that the tradeoff emissions of SO<sub>2</sub> resulting from the proposed facilities would be inconsequential.

Construction of new desulfurization facilities with the capability of throughputting current cracker feed volumes and processing the feed to .05% sulfur will be required if refinery SO<sub>2</sub> emissions are to be reduced substantially

by this route. The expected emission reductions from these facilities would amount to a prevention of 51.4 tons per day of SO<sub>2</sub> emitted to the atmosphere (Table 4-6). The cost of construction, operation, and maintenance of the desulfurization facilities would amount to an annual cost of \$19 million (Table 4-7). When reviewed as a separate facility entirely for the purpose of refinery emission control, its cost is high (\$964 for each ton of SO<sub>2</sub> prevention). However, the value of the desulfurization unit additions to the refineries will be realized in investment returns generated by its economical production of high demand low sulfur products.

TABLE 4-6. IMPACT OF ALTERNATIVE CONTROLS ON EMISSIONS FROM PETROLEUM REFINERIES, 1977.

Control Measure	Emissions Reductions, Tons/Day	
	Particulates	SO <sub>2</sub>
Improve efficiency of regenerator unit particulate control to 99%	1.8	0
Require SO <sub>2</sub> removal equipment for stack control (90% removal assumed)	.7 <sup>a</sup>	51.4
Require desulfurization (to .05%) of all petroleum feed to catalytic cracker	0	51.4

<sup>a</sup>It is assumed that the scrubbing mechanism of SO<sub>2</sub> removal systems would provide 30% removal of particulates from the effluent of regenerator dust control systems.

<sup>b</sup>It is assumed that desulfurization of cracker feed was carried out to .05% sulfur content from an initial level of 1.0% by weight of sulfur. The percentage emission reduction due to this removal was then estimated to be 90% (Figure 4-3).

TABLE 4-7. COST EFFECTIVENESS OF ALTERNATIVE CONTROLS FOR  
REFINERY MAJOR EMISSION SOURCES IN FOUR-COUNTY AREA, 1977

Control Measure	Cost In Millions of Dollars			Cost per ton of Particulate or SO <sub>2</sub> Emissions Reduced
	Initial Capital	Operation Cost Increase	Total Annualized Cost	
Improve regenerator particulate emission control system to 99% efficiency	1.8 <sup>a</sup>	.6 <sup>b</sup>	.25 <sup>c</sup>	\$512
Require SO <sub>2</sub> removal equipment for stack control (90% removal)	28 <sup>d</sup>	.70 <sup>e</sup>	3.8 <sup>c</sup>	\$193
Require desulfurization of all petroleum feed to catalytic cracker to .05% sulfur content.	70 <sup>f</sup>	12 <sup>g</sup>	19 <sup>c</sup>	\$964

<sup>a</sup>Initial equipment cost is based on rates of Western Precipitator products, obtained by personal communication with Joy Manufacturing, Los Angeles (\$1.50/cfm processed). Installation cost estimate data is from Reference (6). It was estimated, by communication with oil refineries and control system manufacturers, that dust emission control systems of the 7 catalytic cracking units of the 4-County Area may be 50% retrofitted at one-half the cost of full replacement, while the remaining 50% will require total replacement with new units.

<sup>b</sup>Operation cost based on data from Reference (6).

<sup>c</sup>Based on estimated equipment life of 30 years @ 10%.

<sup>d</sup>Based on approximate cost figures for Envirotech Double Alkali SO<sub>2</sub> Scrubber System, proportioned from total overall rates including all equipment and installation, communicated to TRW by Envirotech.<sup>7</sup> This corresponds to \$4.0 million per 100,000 cfm (an average catalytic cracker effluent rate) of effluent processed.

<sup>e</sup>Based on annual operating figures (including all materials, equipment and labor) as communicated to TRW by Envirotech<sup>7</sup> (.1 million per 100,000 cfm effluent processed).

<sup>f</sup>Based on an estimated 290,000 barrels of cracker feed stock per day <sup>8,9</sup> processed at the 7 Los Angeles refineries with cracker units, it will be necessary to construct 7 VGO high severity Isomax units with an average capacity of 400,000 barrels per day each. Capital costs are based on Reference (5) and Reference (10).

<sup>g</sup>Operating costs are based on cost of similar desulfurization facilities discussed in Reference (11).

#### REFERENCES FOR SECTION 4.0

1. Environmental Protection Agency, "Air Programs; Approval and Promulgation of Implementation Plans", California Transportation Control Plan, Federal Register, Part II, November 12, 1973.
2. Los Angeles County Air Pollution Control District, Air Emissions Computer Inventory File, obtained by purchase from the District.
3. Standard Oil, "Pollution Prevention in Pictures," Standard Oiler, June-July 1972.
4. Personal communication with Standard Oil, Union Oil, and Joy Manufacturing (distributor of Western Precipitators).
5. R. Christensen, Chevron Research Company, "Low Sulfur Products from Middle East Crudes" , National Petroleum Refineries Association, Document AM-73-38, April, 1973.
6. U.S. Department of Health, Education, and Welfare, National Air Pollution Control Administration, "Control Techniques for Particulate Air Pollutants", January, 1969.
7. Personal communication with Envirotech Emission Control Division, San Mateo, California.
8. P. Roberts, P. Roth, C. Nelson, Systems Applications, Inc., "Contaminant Emissions in the Los Angeles Basin - Their Source Rates, and Distribution."
9. Personal communication with Union Oil Research, Los Angeles.
10. D. Steele, G. Gould, R. Roselius, W. Haunschild, Chevron Research Company, "Clean Fuels Through New Isomax Technology." American Petroleum Institute, Document 40-73, May 1973.
11. Statement of the Shell Oil Co., Hearings Before the Committee on Public Works, United States Senate, Nov. 5 and 6, 1973.
12. TRW Transportation and Environmental Operations, "The Development of A Particulate Implementation Plan for the Los Angeles Region," Report No. 2, Emission Inventories and Projections, Prepared for Environmental Protection Agency, June 1974.

## 5.0 STATIONARY FUEL COMBUSTION

Stationary combustion sources in the Four-County Area include power generating plants, industrial and commercial boilers, and domestic combustion units. Combustion of fuel oils and natural gas in these units produces emissions of particulates, sulfur dioxide, nitrogen oxides, and hydrocarbons.

The following sections provide an overview of the type and quantity of emissions arising from combustion sources, the existing control methods in use to control these emissions, and alternative control technology which may be utilized to improve the present emission management.

### 5.1 BASELINE EMISSIONS

The most significant emissions arising from stationary fuel combustion are sulfur dioxide gases. Combustion sources presently account for about 46 percent of all atmospheric  $\text{SO}_2$ , 21 percent of the particulate emissions, and 20 percent of the  $\text{NO}_x$ . These emissions are distributed throughout the Four County Area.

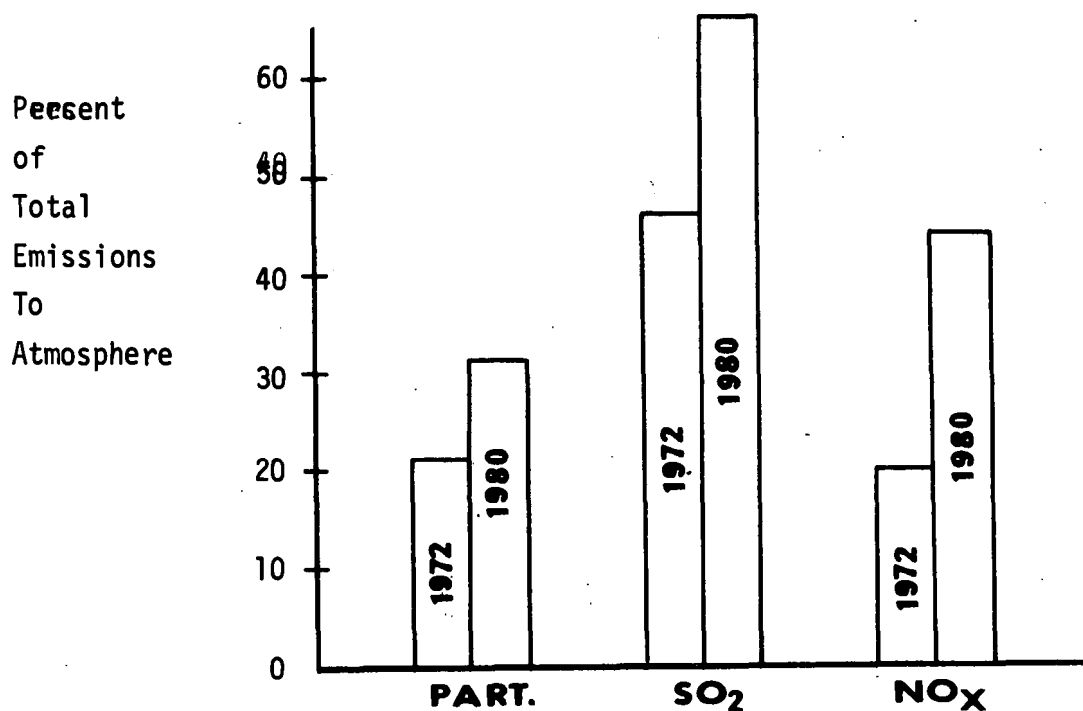


Figure 5-1. Role of Fuel Combustion in Atmospheric Pollution of Four-County Area, 1972 and 1980.



Projected and baseyear emissions for the Four-County Area from fuel combustion sources are illustrated in Table 5-1. By the year 1980 it is projected that emissions from fuel combustion equipment will account for a greater role in the overall emission totals. By that time SO<sub>2</sub> emissions from fuel combustion will generate 71 percent of all atmospheric SO<sub>2</sub>, 44 percent of all the NO<sub>x</sub> pollution, and 32 percent of the primary particulate emissions throughout the Four-County Area. The trend to increasing emissions from fuel combustion operations derives principally from anticipated fuel schedule changes which will include utilization of higher proportions of fuel oil in industrial boilers and power generating plants, and 2) increased consumption of power and industrial growth. No new regulations have been projected for control of these emissions. The present and projected emissions (Table 5-1) reflect compliance with the current regulations.

TABLE 5-1. EMISSIONS OF FUEL COMBUSTION, FOUR-COUNTY AREA

Year	Particulates	SO <sub>2</sub>	NO <sub>x</sub>
1972	44.9	208	282
1977	83.5	374	672
1980	86.1	380	629

Source: TRW Inventory Volume III

Emission rates vary widely among the various types of stationary combustion equipment. The emissions are dependent on type and size of equipment, the method of firing, and the degree of maintenance. Table 5-2 provides a summary of various types of fuel burning equipment found in the South Coast Air Basin. The smaller units (domestic and commercial) burn entirely on a schedule of natural gas and the larger industrial units burn either natural gas or fuel oil. Many industrial units are equipped for fuel conversion, and still others are able to burn both natural gas and fuel oil simultaneously.

TABLE 5-2. SUMMARY OF FUEL BURNING EQUIPMENT

<u>Equipment Category</u>	<u>Description</u>
Power Plants	Power plant boilers
Industrial	Large and medium sized boilers, refinery heaters, stationary internal combustion engines
Domestic & Commercial	Residential, combustion (space heaters, water heaters, ranges), and small commercial boilers.

The essential mechanism of the combustion unit is the burner. Burners are designed to operate with oxidation reactions as close as possible to completion, minimizing unburned and partially oxidized matter in the exhaust. The burner is basically a metering device for the two reactants, oxygen and fuel, and serves as a means of mixing the reactants before and with ignition. The simplest burners are employed with gaseous fuels while more complex designs are required for use with fuel oils. The burner design and operation greatly affects the rate of exhaust emissions from combustion units. In boilers, heaters, steam generators, furnaces, and other similar combustion equipment, the emissions are a direct result of the combustion of gas or fuel oil at the burners.

The effect of fuel type on emissions from combustion units of power generating stations is illustrated in Table 5-3 below. Emission rates of both nitrogen oxides and particulate matter are substantially higher when

TABLE 5-3. COMPARISON OF POLLUTANTS EMITTED FROM POWER PLANTS WHEN BURNING NATURAL GAS AND FUEL OIL

	<u>Emissions - Lbs. per 1000 Equivalent Barrels of Fuel</u>		
	<u>SO<sub>2</sub></u>	<u>NO<sub>x</sub></u>	<u>Particulates</u>
Low Sulfur Fuel (.5% S)	3300	1550	300
Natural Gas	Negligible	1000	15

Source: Reference (7).

burning fuel oil than when burning natural gas. There are essentially no emissions of sulfur dioxide when natural gas is burned.

Projected fuel schedules for power plants and industrial combustion units in the South Coast Basin are shown in Table 5-4 below.

TABLE 5-4. PROPORTION OF FUEL USAGE (PERCENT) AS NATURAL GAS FOR BASIC COMBUSTION CATEGORIES IN SOUTH COAST BASIN

<u>Year</u>	<u>Power Plants</u>	<u>Industrial</u>	<u>Domestic</u>
1972	58	96	100
1977	7	65	100
1980	8	72	100

Source: 1973 California Gas Report, July 11, 1961

Due to the decline in natural gas supply, the proportion of oil burning emissions are projected to increase. The distribution of emissions by fuel type consumption for the three basic combustion categories is shown in Table 5-5.

TABLE 5-5. POLLUTANT EMISSIONS BY FUEL TYPE CONSUMED FOR BASIC COMBUSTION CATEGORIES IN FOUR-COUNTY AREA

<u>Year</u>	<u>Pollutant</u>	<u>Power Plant</u>			<u>Industrial</u>			<u>Domestic</u>
		<u>Nat.Gas</u>	<u>Oil</u>	<u>Total</u>	<u>Nat.Gas</u>	<u>Oil</u>	<u>Total</u>	<u>Nat.Gas</u>
1972	Particulates	1.5	20.8	22.3	6.6	5.5	12.0	10.6
	SO <sub>2</sub>	1.1	179	180	.3	27.3	27.6	.3
	NO <sub>x</sub>	44.0	49.5	93.3	26.4	88.4	114.8	74.1
1977	Particulates	.1	35.9	36.0	3.7	32.2	35.9	11.6
	SO <sub>2</sub>	.2	292	292	.2	81.0	81.2	.4
	NO <sub>x</sub>	6.2	129	135	31.0	445	476	61.1
1980	Particulates	.1	36.7	36.8	4.5	28.0	32.5	12.3
	SO <sub>2</sub>	.2	304	304	.2	85.0	75.2	.4
	NO <sub>x</sub>	7.6	135	143	37.0	388	425	61.1

1. Emissions for power plants were segregated by fuel type by weighting the emission rates (Table 5-3) with fuel type usage (Table 5-4) and normalizing to the total emissions given in Reference (1).
2. The emissions by fuel type for industrial combustion units was derived from local APCD data and Southern California Gas Company data. This distribution was then used to adjust the total emissions of Reference (1) to the segregated emissions by fuel type.

## 5.2 CURRENT EMISSION CONTROLS

Applied emission control technology for combustion units includes: 1) fuel modification, 2) burner design and operation techniques, and 3) removal of pollutants from stack gases. The effectiveness of fuel modification for pollution control has been illustrated in Table 5-3. This pollution control approach is used whenever the supply of natural gas permits. However, as was seen in Table 5-4, the effectiveness of this approach will be limited in future years due to the smaller quantities of fuel gas available.

Stack treatment for removal of pollutants from combustion systems has not been employed in the Four-County Area. In the past, emission regulations have been met through the use of clean fuels and burner adjustments. Projected regulations are not expected to provoke any changes in this status.

The pollutant most susceptible to control by burner modifications or operational changes is  $\text{NO}_x$ . To date, the emission control progress accomplished by these modifications has been applied to larger sources, such as power plant boilers. This emphasis has increased in recent years since larger generating stations, and hence larger boilers, have increased in number. Because the ratio of furnace cooling surface to furnace volume in the active combustion zone is smaller in larger boiler units, the average flame temperature increases. As a result larger boilers typically emit greater rates of nitrogen oxides.

Reduction of  $\text{NO}_x$  in existing boilers large enough to be under jurisdiction of Rule 68 (Fuel Burning Equipment) has been accomplished by operation changes or combustion modifications. These control methods are applicable to smaller burner units but are not required under present regulations. Rule 68 limits  $\text{NO}_x$  emissions to low levels (325 ppm stack gas concentration) and is targeted for larger boilers at the power plants. Table 5-6 shows the control methods utilized by Edison Company and the effect of these controls in complying with Rule 68. The controls methods include 1) off stoichiometric diffusion flame operation, 2) two-stage combustion, and 3) flue gas recirculation. (These methods are discussed in the next section). The overall reduction of  $\text{NO}_x$  emissions due to these controls from all units tested at Edison plants was over 50 percent.

TABLE 5-6. SUMMARY OF NO<sub>x</sub> EMISSION RATE REDUCTIONS ACHIEVED AT EDISON COMPANY UTILITY BOILERS WHEN BURNING GAS FUEL

Plant	Unit mfgr <sup>a</sup>	Size MW	NO <sub>x</sub> , ppm, for Normal Operation <sup>b</sup>		Modified Operation			
			Single- Stage	Two- Stage	Method <sup>c</sup>	Excess O <sub>2</sub> , %	NO <sub>x</sub> , ppm <sup>b</sup>	
Huntington								
1	B&W	215	500	-	OS <sup>b</sup>	3.1	200	
2	B&W	215	520	-	OS	1.8	200	
3	B&W	225	555	500	Two-stage + OS	3.1	230	
4	B&W	225	335	285	Two-stage + OS	2.2	210	
Alamitos								
1 & 2	B&W	175	450	330	Two-stage + OS	2.1	245	
3 & 4	CE	320	330	-	Recirculation	2.0	110	
5 & 6	B&W	480	700	390	Two-stage + OS	2.5	150	
Etiwanda								
3 & 4	CE	320	330	-	Recirculation	-	-	
El Segunco								
1 & 2	B&W	175	450	330	Two-stage + OS	-	- <sup>d</sup>	
3 & 4	CE	330	330	-	Recirculation	-	150	
Redondo								
5 & 6	B&W	175	450	330	Two-stage + OS	2.3	300	
7 & 8	B&W	480	750	400	Two-stage + OS	3.1	220	
Mandalay								
L & 2	B&W	215	520	-	OS	2.4	210	

<sup>a</sup>B&W - The Babcock & Wilcox Co., New York; CE = Combustion Engineering, Inc.

<sup>b</sup>Based on ASTM D1608-60, reported dry at 3 percent excess oxygen.

<sup>c</sup>OS - off-stoichiometric.

<sup>d</sup>Not yet tested - expected to give results comparable to Redondo 5 & 6.

Source: Reference (2).

### 5.3 ALTERNATIVE CONTROL MEASURES

The technology available to reduce emissions discharged by fuel combustion consists of equipment modification and operational changes, flue gas treatment, and fuel substitution. Except for fuel substitution, no single control method is effective in preventing emissions of all pollutant species (particulates,  $\text{SO}_2$ ,  $\text{NO}_x$ ). Therefore control of each pollutant is discussed separately in the following sections.

#### 5.3.1 Control of Particulates

With conventional use of burner equipment, particles in the flue gases can generally be maintained well below the emission standard of .3 grain per scf of exhaust (Rule 53b). Given proper operation of the combustion burners, the rate of particulate emissions depends primarily on fuel type. The efficient burning of a common heavy residual oil of .1% ash results in a stack gas concentration of only .03 grain per scf. There is no measurable inorganic ash in exhaust gases from the combustion of natural gas. Low sulfur oil contains small amounts of ash. Hence the exhaust gases of typical fuel burning is not likely to exceed local standards.

Table 5-3 demonstrates the effectiveness of fuel substitution as a preventive measure for particulate emissions. The burning of natural gas produces emissions of particulates twenty times less than when burning low sulfur fuel oil. It is clear that use of natural gas produces very desirable air quality effects, and its utilization is currently maximized as fuel supply permits. However the diminishing supply of natural gas for the larger combustion equipment (Table 5-4), and the corresponding rising level of particulate emissions from fuel combustion stacks (see Table 5-1), is now provoking substantial concern that new controls be examined for application to the large fuel burning equipment which must burn fuel oil in the years ahead. This is exemplified by the Rules and Regulations governing the control of air pollution in Maryland, where low sulfur oil (.5% S) fired boilers are required to be equipped with dust collectors which provide 50 to 80% efficiency, and emissions of .03 to .01 grains per scf, for boilers of various specified sizes.

While the relative emission rate of particulates from fuel combustion is low, the immense volumes of exhaust gases produced by large oil burning units result in appreciable discharges of particulate matter to the atmosphere. Because of the large volumes of exhaust and the small size of particulates in the gas stream (see Table 5-7), only the electrical precipitation and the fabric filter are suitable candidate controls for this application.

TABLE 5-7. PARTICLE SIZE DISTRIBUTION OF TYPICAL MATERIAL COLLECTED FROM A STEAM GENERATOR STACK DURING THE BURNING OF RESIDUAL FUEL OIL

	% In Each Micron Range				Largest Particle Size, $\mu$
	0 to 1	1 to 2	2 to 5	5	
Absolute filter	86.6	7.3	4.2	1.9	50
Millipore filter	88.5	7.3	2.3	1.9	50

A removal efficiency of 99.9% is typically obtained with a fabric filter for particles in the submicron range. By comparison, electrical precipitators which collect submicron size particles at over 95% efficiency require additional equipment at greatly increased costs.<sup>3</sup> However fabric filters have not been used to handle applications in which the gas volumes to be treated are as large as that emitting from a utility boiler. Manufacturers of fabric filters state this is because the fabric filter is not competitive when installed for such immense effluent volumes.<sup>4</sup>

#### Impact on Emissions

The impact of equipping oil-burning equipment in the Four County Area with high efficiency (95% removal) electrical precipitators, or fabric filter baghouses (99.9% removal) on fuel burning emissions is shown in Table 5-8. These controls would each reduce the amount of fuel-burning particulate emissions in the Four County Area to levels less than 40% of the 1972 baseyear rate.

#### Cost of Particulate Controls

Table 5-9 summarizes the cost of the two particulate control options for oil-burning combustion equipment. The electrical precipitator is slightly more cost effective as a control for larger fuel burning equipment, and equally cost effective to the fabric filter when processing the smaller

TABLE 5-8. THE EFFECT OF PARTICULATE CONTROLS ON OIL-BURNING COMBUSTION EQUIPMENT, 1977

Emission-Generating Equipment	Projected Particulate Emissions, tons/day		Control Option	Particulate Emission Reduction, 1977	
	1977	1980		%	tons/day
Power plant boilers (large and small), large non-power plant boilers, and refinery heaters	68	65	1) High efficiency electrostatic precipitator	95 <sup>a</sup>	64.6
" "	"	"	2) High efficiency baghouse with high temperature synthetic fabric & continuous cleaning	99	67.9
Power plant boilers and large non-power plant boilers	60	57	3) Desulfurization of fuel oils to .05% S with new desulfurization technology	20% by <sup>c</sup> 1977 40% by 1980	12 by 1977 23 by 1980

Notes:

1. As an approximation related to the above emissions, medium sized boilers were assumed to operate on natural gas for the next few years, although fuel usage projections (Table 5-4) indicate some of these units may be using fuel oil. As a counter assumption, all large non-power plant boilers have been assumed to run 100% on fuel oil. Thus the oil-burn industrial emissions of Table 5-5 originate entirely from large non-power plant boilers as other industrial sources use natural gas<sup>b</sup> or refinery-make gas and oil.

2. Control alternative #3 is targeted for SO<sub>2</sub> removal but is included here to show its beneficial secondary effect on particulate emission preventions.

<sup>a</sup>Personal communication with Joy Manufacturing, and Envirotech regarding the maximum feasible collection efficiency for particles of sub-micron size in combustion flue gases.

<sup>b</sup>Reference (5).

<sup>c</sup>This efficiency estimate is based on 1) typical relationship for fuel ash content as a function of sulfur content, determined from data from Ref.(6). 2) Source data from measurements of particulate matter per barrel of low sulfur fuel of .5% sulfur content. The actual particulate matter produced per volume of oil burned was considered to be composed of both inorganic ash attributable to the fuel ash content, and organic carbonaceous hydrocarbons resulting from incomplete combustion. The latter component was then assumed to persist when very low sulfur fuels, having negligible traces of ash, are burned.



TABLE 5-9. COST OF PARTICULATE EMISSION CONTROL FOR  
OIL-BURNING COMBUSTION EQUIPMENT, 1977

Equipment	Number of Units	Control	Cost in Millions of Dollars			Cost per Ton of Particulate Reduced
			Initial Purchase & Installation Cost x 10 <sup>6</sup>	Operation Cost Increase	Annualized Cost Increase	
Large power plant boilers (Average size = 260 MW)	35 <sup>b</sup>	high efficiency electro- static precipitator	48.1	7.0	12.6	\$1452
	"	high efficiency baghouse	38.5	10.5	15.0	1671
Small power plant boilers (Average size = 65 MW)	49 <sup>b</sup>	high efficiency electro- static precipitator	13.5	2.0	3.6	932
	"	high efficiency baghouse	12.2	2.2	3.6	904
Large non-power plant boilers (Average size = 78 MW)	152 <sup>c</sup>	high efficiency electro- static precipitator	68.4	9.1	17.1	1530
	"	high efficiency baghouse	60.8	11.4	18.5	1590
Refinery heaters (Average size = 6.5 MW)	220 <sup>c</sup>	high efficiency electro- static precipitator	28.6	3.3	6.7	2410 <sup>e</sup>
	"	high efficiency baghouse	28.6	2.1	5.4	1863

Notes:

1. Costs based on supplying control equipment to clean stack gas flow of 310,000 cfm per 100 MW boiler rating.<sup>a</sup>
4. Combined purchase and installation cost of electrical precipitator based on rates of Western Precipitator Products<sup>d</sup> (2.5 times greater than cost as given in Figure 3-9. Operation cost estimate based on data from Figure 3-13.
5. Annualized cost computations based on 20 year lifetime at 10%.
6. Particulate emission reductions due to the controls, for each of the equipment categories, was estimated based on 1) the relative approximate stack flue gas volume processed for the entire category, 2) the relative particulate emission factors given in Reference (10) for power plant boilers and industrial boilers when operating on fuel oil (small power plant boilers were assumed to generate particulate emissions at a rate between these two types). Hence large power plant boilers produce 25 tons/day; small power plant boilers, 11 tons/day; and larger non-power plant boilers, 32.2 tons/day.
7. Installation and purchase cost of baghouse based on Figure 3-12, operation costs based on Figure 3-13.

<sup>a</sup>Reference (8).

<sup>b</sup>Reference (9).

<sup>c</sup>Reference (5).

<sup>d</sup>Reference (3).

effluent volumes associated with boilers of less thermal rating. Since the baghouse has not been used extensively to control emissions from large boiler units, it appears that its selection for this application would be unwarranted. The baghouse is significantly more cost effective as a collector for refinery heater emissions, and should probably be recommended for this application. Further testing and pilot studies should be performed to demonstrate the practicability of baghouse installations for high volume effluent treatment.

### 5.3.2 NO<sub>x</sub> Control

The control of NO<sub>x</sub> emissions from combustion units is primarily a function of the control of temperature and residence time in the primary flame zone. Both of these functions can be managed by modification of operating conditions and by modification of design features in existing combustion units. Numerous methods of modifying the operating conditions have proven successful and may be adopted for use in existing combustion units. These include 1) low excess air firing, 2) two stage combustion, 3) flue gas recirculation, 4) steam or water injection, and 5) direct temperature control. Design modifications which may be utilized for NO<sub>x</sub> control generally involve an alteration in the burner and furnace configuration, or the location and spacing of burners.

Low excess air firing involves the manipulation of the excess air rate to the burner. The effect of burner air rates on NO formation rates (Figure 5-2) has been established in various tests for both oil fired and gas fired combustion units. It has been determined that reductions from the normal excess air rate of 10 percent to 5 percent will reduce NO<sub>x</sub> emissions by approximately 40% in boiler and heater units. Further reduction of excess air rates are not feasible due to the hazardous conditions which develop when explosive mixtures of unburned fuel are formed.

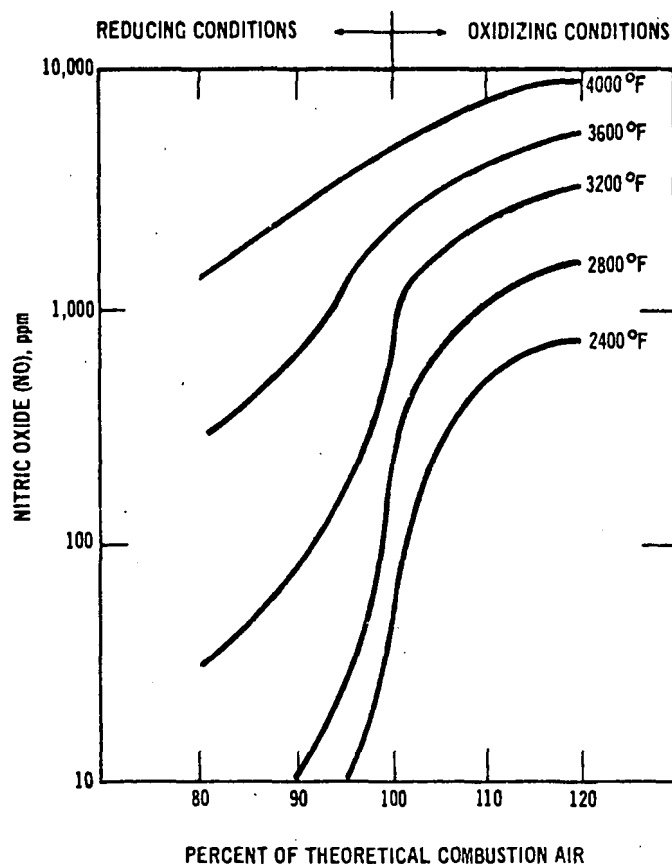


Figure 5-2. Effect of Combustion Air Quantity on NO Formation

Source: Reference (6).

In two-stage combustion, the primary air to the burners is decreased below the stoichiometric quantity, and fuel is then combusted completely by injecting secondary air at lower temperatures. This procedure has been applied in power plant boilers to achieve substantial reductions (see Table 5-6). It was designed specifically for utility boilers, and is not considered feasible for control of other sized combustion units.

Flue gas recirculation lowers the peak flame temperature by diluting the primary flame zone with flue gases. Flue gas acts as an inert dilutant, and reductions of 30 to 60% in  $\text{NO}_x$  emissions are obtained.<sup>11</sup> This control approach is applicable to all combustion units.

In steam or water injection, the primary portion of the flame is diluted by steam or water as in flue gas recirculation. This approach is not as effective as flue gas circulation, producing about a 10% reduction in  $\text{NO}_x$  emissions.

Direct temperature control is another technique for reducing the temperature in the primary combustion zone. This is achieved by reducing the preheat temperature of combustion air. The effect of this operation on NO formation is shown in Figure 5-3. Direct temperature control can be used to accomplish reductions in NO<sub>x</sub> emissions comparable to flue gas recirculation. The disadvantage of this control is the accompanying decrease in boiler thermal efficiency, and consequently the high annual cost of the operation.

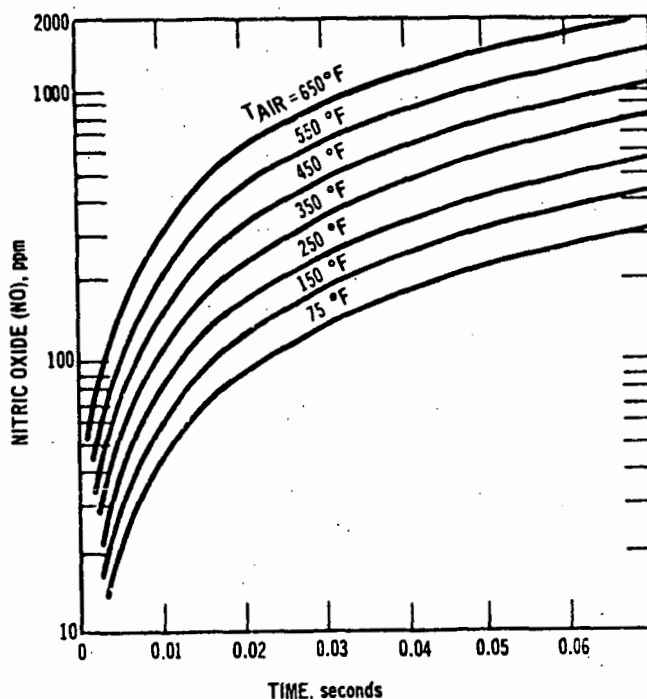


Figure 5-3. Effect of Combustion Air Preheat Temperature on NO Formation

Source: Reference (6).

A variety of burner and furnace design modifications may be applied to reduce NO<sub>x</sub> formation. The type of burner configuration is essential as a design consideration for NO<sub>x</sub> formation. The front-fired burner yields complete mixing and combustion in immediate proximity to the burner, with subsequent high temperatures and high NO formation. Corner fired burners provide for slower mixing of air and fuel, such that a major portion of the combustion occurs in the center of the furnace at lower than peak

temperature.  $\text{NO}_x$  formation in the corner fired burners (500 to 1500 ppm) is therefore substantially lower than in the front fired type (350 ppm)<sup>2</sup>. Boilers and heaters cannot be economically retrofitted to alter the basic method of firing. Other less dramatic design retrofits may be applied to reduce  $\text{NO}_x$  emissions (such as spacing of burners to increase radiant heat transfer), but these methods are generally not as effective as the operational modifications discussed above, and because of higher costs for implementation, they are not as cost effective.

#### Impact of $\text{NO}_x$ Control Options on Emissions

The effect of implementing the various  $\text{NO}_x$  control alternatives for combustion units in the Four-County Area is summarized in Table 5-10. The most feasible combinations of  $\text{NO}_x$  control options have been examined. As a single control, low excess air firing was considered the most appropriate option, due to its cost advantages over other equally effective options (such as direct temperature control, or flue gas recirculation). Studies by ESSO<sup>11</sup> have determined that low excess air firing results, on the average, in 40% reductions of  $\text{NO}_x$  emissions from commercial and industrial boilers. These boilers generally are fired to 15-30% excess air, and may be reduced to 2-6% according to tests<sup>11</sup>. In power plant boilers less than 1775 MBTU/HR, excess air firing is typically 5-15%, and  $\text{NO}_x$  reductions from lower excess air firing averages about 30%. Tests conducted with refinery heater units<sup>5</sup> have confirmed 40% reductions are attainable.

To develop additional  $\text{NO}_x$  removal, flue gas recirculation may be used with low excess air firing to achieve  $\text{NO}_x$  reductions of 70%<sup>11</sup> from boilers. The feasibility of utilizing flue gas recirculation in refinery heaters as a retrofit is not clear at this time. There is currently evidence which indicates this approach requires development of an entire new heater design. Hence this control option was not considered for implementation on refinery heaters.

TABLE 5-10. THE EFFECT OF NO<sub>x</sub> EMISSION CONTROLS ON FUEL COMBUSTION EQUIPMENT, FOUR-COUNTY AREA

Combustion Unit Description	Average Size MBTU/Hr	Projected NO <sub>x</sub> Emissions Tons/Day		Control Measure	NO <sub>x</sub> Reduction In 1977		Cost/Ton of NO <sub>x</sub> Reduction
		1977	1980		Percent	Tons/Day	
1. Large power plant boilers (1825-3550 MBTU/hr)	2630	105	111	None--already equipped with advanced combustion control (emissions are controlled to about 20% of uncontrolled emissions level)	-	0	0
2. Small power plant boilers (100-1775 MBTU/hr)	660	30	32	Low excess air firing & flue gas recirculation	30 50	9 15	\$200 450
3. Large non-power boilers (30-400 MBTU/hr)	80	118	105	Low excess air firing & flue gas recirculation	40 70	47 83	22 127
4. Medium sized boilers (2-30 MBTU/hr)	9	205	183	Low excess air firing & flue gas recirculation	40 70	82 144	694 870
5. Large refinery heaters (90-290 MBTU/hr)	120	38	34	Low excess air firing	40	15	27
6. Small refinery heaters (5-90 MBTU/hr)	45	27	24	Low excess air firing	40	11	226
7. Large stationary internal combustion engines (>300 H.P.)	700 H.P.	69	61	Water injection or exhaust gas recirculation	75	52	13
8. Small compressor engines (<300 H.P.)	200 H.P.	19	17	Water injection or exhaust gas recirculation	75	14	37
9. Domestic (residential) fuel combustion (space & water heaters, ranges)	-	46	46	None	-	0	-
10. Small commercial and industrial boilers (< 2 MBTU/hr)	-	15	15	None	-	0	-

1. Emissions for power plants were segregated into small boiler and large boiler contributions by applying the emission ratio between these 2 source sizes as reported in Reference (3) to the power plant emissions totals projected in the Reference (1).
2. Emissions for industrial, or commercial and domestic, were segregated by equipment categories by applying the emission distribution of Reference (5), (after Reference (5) had been updated to reflect current anticipated fuel schedules) to the aggregated equipment category (industrial, commercial & domestic) emission totals reported in Reference (1).

Many controls have already been applied in power plants to comply with the  $\text{NO}_x$  emission reductions required by Rule No. 68. These control options are applicable to large utility boilers and have not been considered as candidate alternatives in Table 5-10. The compact size and limited number of burners in other boilers and in heaters render these options technically unretrofitable for applications other than large utility boilers. These alternatives include two stage combustion, relocation of burners, modification of burner spacing, and others.

There are currently no retrofit controls developed to manage the  $\text{NO}_x$  emitting from residential fuel combustion, and small industrial and commercial boilers. New units may be designed to control  $\text{NO}_x$  emissions<sup>12</sup>, but because retrofit controls would require relatively extreme costs for these small units, they would probably not be politically acceptable. Hence no controls have been considered in Table 5-10 for these smaller source categories.

Stationary internal combustion engines (used primarily in gas and oil industry for gas compression) can be retrofitted with water injection or exhaust gas recirculation equipment to obtain  $\text{NO}_x$  emission reductions of about 75%. The two approaches are equally cost effective. Stoichiometric fuel adjustments have been shown effective in reducing  $\text{NO}_x$  emissions to 70%, but the associated loss in power and fuel economy make this control method less desirable than water injection or exhaust gas recirculation.<sup>11,5,13</sup>

In calculating the impact of various control options on emissions from combustion equipment, a substantial amount of relevant information was extracted from Reference (5). This study contains an analysis of the effects of implementing various  $\text{NO}_x$  emission controls among a definitive number of combustion equipment categories. The analysis is based on a survey of fuel burning equipment and associated emission characteristics, a review of  $\text{NO}_x$  control technology and its effectiveness and cost as applied to the various equipment types, and a projection of future equipment growth and fuel

schedules. Information of Reference (5) was updated to reflect current fuel schedule projections. The level of emissions reported for each of the combustion categories for 1975 in Reference (5) were adjusted to reflect the overall emission projections of the aggregated combustion equipment categories reported in Reference (1) for 1977 and 1980.

Application of feasible, state-of-the-art control technology to the various types of combustion equipment in the Four-County Area, may achieve  $\text{NO}_x$  reductions as large as 334 tons/day (Table 5-10) in 1977. This control strategy would reduce  $\text{NO}_x$  emissions from combustion equipment by 50% in 1977, to a level of 338 tons/day. Unfortunately, the strategy would not be sufficient to return combustion category  $\text{NO}_x$  emissions to the 1972 level of 282 tons/day.

#### Cost of $\text{NO}_x$ Controls

The cost effectiveness of the various  $\text{NO}_x$  control options for combustion units in the Four-County Area is summarized in Table 5-10. The least costly control alternative consists of either water injection or exhaust gas recirculation, applied to stationary internal combustion engines. This measure may be incorporated on large engines at a cost of only \$13 per ton of  $\text{NO}_x$  emissions prevented. The most costly  $\text{NO}_x$  control option is also the most significant in terms of overall  $\text{NO}_x$  emissions low excess air firing and flue gas recirculation in medium sized boilers. The cost for this retrofit is \$870 per ton/day of  $\text{NO}_x$  removed.

#### 5.3.3 Control of $\text{SO}_2$

The methods available to reduce emissions of  $\text{SO}_2$  from fuel burning equipment include 1) fuel modification, and 2) add-on emission control equipment.

##### Fuel Modification

An obvious means of reducing emissions of  $\text{SO}_2$  from fuel combustion is to remove the sulfur from the fuel. Present regulations permit .5% sulfur content in fuel oil (Rule 62). This standard was initially adopted with the intention of motivating utility companies to substitute natural gas for fuel oil. At the time the regulation became law, natural gas was more abundant



and less expensive than the low sulfur (.5%S) fuel oil. Hence the desired switch to gas use occurred quickly and emissions from power plants decreased appreciably. These gains in air pollution control have diminished in recent years and are expected to be realized even less because of the continuing shortage of natural gas, and the increased burning of low sulfur fuel oils.

Currently, low sulfur fuel oils of .5% sulfur content are typically produced by 1) desulfurization of heavy distillate to produce very low sulfur blend stocks, and 2) blending these low sulfur stocks with the high sulfur residuum portion of the barrel. Low sulfur processing of the residuum has not been practiced extensively, but it is becoming evident that this will be required if petroleum products are to be manufactured according to the increasingly stringent standards. Several processing schemes are being proposed as possible routes to very low sulfur fuel oils. Two of the most feasible methods are discussed in Section 3.2.1. These methods have been tested in pilot development and are termed 1) VGO Isomax Plus Solvent Deasphalting, and 2) VGO Isomax Plus VRDS Isomax. Both of these processes lend to stepwise construction at the refinery and are integrateable with existing refinery equipment. The level of sulfur content obtained by these processes is .05%.

### SO<sub>2</sub> Removal Systems

Several SO<sub>2</sub> cleanup processes are commercially available to manage emissions from fuel-burning combustion unit stacks. These methods are discussed in Section 3.2.2. Several installations are now operating at various power plants throughout the nation (Table 3-X) to control SO<sub>2</sub> emissions within new and more stringent state pollution standards. Many of the SO<sub>2</sub> removal processes are being tested under pilot projects (mainly utility boiler stacks) sponsored by the EPA. In general, each of the processes involves a reduction or oxidation conversion of sulfur as it is found in the stack effluent to a sulfur product which may be removed physically from the system. The sulfur product is generally elemental sulfur, or a sulfate or sulfuric acid.

The majority of the development effort to date has been applied to processes with throwaway products (sulfates) such as those using lime or

limestone as an absorbent for  $\text{SO}_2$  in the flue gas. Most of these systems yield waste products which must be disposed of. Other systems circumvent the disposal problem by generating useful sulfur compounds, or elemental sulfur.

Comparative evaluations of the various  $\text{SO}_2$  cleanup processes is not possible since many problems still remain to be identified during development and commercial operation. It seems certain however that a number of processes will be available to provide guaranteed reductions of 90% for a variety of applications.<sup>14</sup>

#### Impact of Alternative Controls

The effect of implementing the potential  $\text{SO}_2$  control methods on fuel combustion emissions throughout the Four-County Area is shown in Table 5-11. Both the option of add-on  $\text{SO}_2$  removal system and desulfurization of fuel oil offer the same emission control effectiveness in the long term. However desulfurization of fuel oils is not expected to affect emissions from refinery heaters, since these units operate primarily on refinery made gas and fuel oil. These fuels are generally heavy residual oils and high sulfur content gas streams. They are not practically marketed or further processed, and are therefore burned in the heating equipment as an economical expedient. Unless these refinery by-product gases and oils can be disposed of alternately, it does not appear feasible that low sulfur supply stock could be used in its place. Hence only flue gas cleanup systems were considered a candidate control for refinery heater emissions.

Implementation of either control (desulfurization or stack  $\text{SO}_2$  removal) would result in substantial preventions of  $\text{SO}_2$  entering the atmosphere. When stack  $\text{SO}_2$  control is employed, a 64% reduction in  $\text{SO}_2$  emissions from all sources in the Four-County Area is realized in 1977. The option of fuel oil desulfurization cannot be implemented totally by 1977 due to lead time required to construct the processing facilities. However, by 1980, this option can be fully implemented.

TABLE 5-11. IMPACT OF CANDIDATE CONTROLS ON SO<sub>2</sub> EMISSIONS FROM FUEL COMBUSTION UNITS IN FOUR-COUNTY AREA, 1977

Equipment Description	Baseyear and Projected SO <sub>2</sub> Emissions Tons/Day			Control Measure	SO <sub>2</sub> Reductions in 1977	
	1972	1977	1980		%	Tons/day
All equipment scheduled to use fuel oil through 1980 except refinery heaters.	189	336	342	Desulfurization of residuum for fuel oil sulfur content of .05%.	50% <sup>a</sup> by 1977 90% by 1980	168 308
All combustion equipment to use fuel oil through 1980 (power plant boilers, large non-power plant boilers, and refinery heaters)	206	373	379	SO <sub>2</sub> removal from stack effluent	90%	336
Refinery heaters	17	37	37	SO <sub>2</sub> removal from stack effluent	90%	33.3

<sup>a</sup>Due to lead time requirements for design and construction, it was assumed that only 1/2 of all desulfurization plants could be operational by 1977, with the remaining desulfurization facilities to be provided by 1980.

Desulfurization of fuels to low sulfur levels creates beneficial side effects as the ash content is reduced concurrently with sulfur removal. Consequently, particulate emissions are reduced when low sulfur fuels are burned. While there is little data to demonstrate the degree of particulate emission control associated with burning very low sulfur fuels (.05% S) some data has been developed for the emission characteristics of higher sulfur fuel combustion. For example, tests have shown that burning of high sulfur oil (approximately 1.5% S) produces about three times the particulate matter produced by low sulfur fuel burning (.5% S). Particulate emissions originate from unburned hydrocarbons as well as the inorganic ash contained in the fuel, but when combustion conditions are adjusted properly, the ash content is the main factor causing particulate emissions. Most of the materials found in stack emissions consist of metal oxides, sulfates, and chlorides, all of which are directly attributable to the sulfur and ash content of the fuel. Therefore it may be expected that the provision of very low sulfur fuel oil from new desulfurization facilities will result in appreciable particulate emission reductions. These reductions have been estimated in Table 5-8, based on source measurement data of the Los Angeles APCD,<sup>7</sup> and fuel analysis data of residual fuels used in Los Angeles.<sup>6</sup> It was estimated that a 40% reduction in particulate emissions may be obtained when burning the higher quality very low sulfur fuels manufactured by the new refinery equipment. These fuels will contain a negligible quantity of ash.<sup>15</sup> Additional study should be conducted to provide a definitive assessment of the implications of this sulfur control strategy on particulate emissions.

Emissions of pollutants anticipated from the additional refinery installation needed for fuel desulfurization have not been definitively quantified. However the principal potential pollutant will be  $H_2S$  gas, and its treatment for removal is well known in the refinery industry (see Section 11 ). The increased quantities of  $H_2S$  which must be handled may range from 50 to 100%

TABLE 5-12. COST OF CONTROLS FOR SO<sub>2</sub> EMISSIONS FROM FUEL COMBUSTION UNITS IN FOUR-COUNTY AREA

Emission Generating Equipment	Number of Units	Control	Initial Purchase & Installation Cost in Millions of Dollars	Operation Increase	Annualized Cost Incr. <sup>9</sup> in Millions of Dollars	Cost/Ton of SO <sub>2</sub> Reduced Dollars
Power plant boilers and large non-power plant boilers <sup>b</sup>	236	1. Stack SO <sub>2</sub> removal system	678 <sup>a</sup>	108 <sup>c</sup>	176	\$1590
Desulfurization plants VGO/VRDS Isomax plus (comp-delayed coking (40000 barrels/day plant size)). <sup>9d</sup>	(complete by 1980)	2. Desulfurization of fuel oil to .05% S for use in oil-burning equipment, except for refinery heaters	480 <sup>e</sup>	70 <sup>e</sup>	118	1040
Refinery heaters	220 <sup>f</sup>	3. Stack SO <sub>2</sub> removal system	95.1 <sup>a</sup>	6.4 <sup>b</sup>	15.9	1310
All fuel burning equipment scheduled to use fuel oil through 1980 (power plant boilers, large industrial boilers, & refinery heaters)	456	4. No. 1 and 3 above	773	114	192	1540
Desulfurization plants. Refinery heaters.	9 220	5. No. 2 & 3 above	575	76.4	134	1075

<sup>a</sup>Based on average of approximate initial cost & installation figures for Envirotech Double Alkali Scrubber System (\$83/KW)<sup>16</sup> and Wellman-Lord SO<sub>2</sub> Recovery Process (\$50/KW).<sup>17</sup>

<sup>b</sup>These boilers average a rated 102 MW each, and stack gas flow average is 293,000 cfm (see Table 5-9).

<sup>c</sup>Based on average of operating cost figures of \$.003 million/MW (Envirotech) and \$.0086 million/MW (Wellman-Lord).

<sup>d</sup>Based on VGO/VRDS Isomax plant size for 40,000 barrels/day yield. Fuel oil requirements are as follows: For 1980, industrial usage projected at 8.5 x 10<sup>6</sup> barrels,<sup>18</sup> and power plant usage projected to 111 x 10<sup>6</sup> barrels (derived from reference(19), Table 5-4, and assumed growth rate of 8%/yr.) costs are computed based on 1980 oil demands since all the necessary facilities cannot be constructed until that year.

<sup>e</sup>Based on cost figures from Reference(20). \$53.3 million for 40,000 barrels/day facility installed at existing refinery, and operating-manufacturing cost increase of 50¢ per barrel (plus 10% profit). This is applied to 129 x 10<sup>6</sup> barrels of fuel oil required per year in Four-County Area.<sup>19</sup>

<sup>f</sup>Reference (5). The refinery heaters average 6.5 MW rating.

<sup>9</sup>Annualized cost was based on 50 year life and 10% interest.

the level previously recovered. This control problem could be alleviated by offsite construction in permissible remote locations, however the cost penalty for this strategy could be severe.

#### Cost of Alternative SO<sub>2</sub> Controls

The cost effectiveness of implementing the candidate SO<sub>2</sub> controls is shown in Table 5-12. Desulfurization of fuel oils is the most cost effective alternative at \$1040 per ton of SO<sub>2</sub> emissions prevented. This is about 35% less than the cost of adding stack SO<sub>2</sub> removal processes to all oil burning combustion units in the Four-County Area. However desulfurization of fuel oils itself does not obtain the same total prevention as overall stack control since it is not applicable to refinery heaters in which refinery make gases are disposed of. Hence stack SO<sub>2</sub> add-on control must be used with fuel desulfurization (Control No. 5 in Table 5-12.) to obtain 90% prevention of SO<sub>2</sub> emissions.

Because of the magnitude of the design, manufacture, and installation effort involved with implementing the SO<sub>2</sub> control options, it is probable that this cannot be completely accomplished before 1980. This is particularly the case for desulfurization by stack SO<sub>2</sub> removal equipment. Manufacturing volume for the SO<sub>2</sub> stack control market has been limited to date, and the industry could not easily provide the equipment demand imposed by legislation of the control options.

#### 5.3.4 Fuel Substitution - A Control for Particulates, SO<sub>2</sub>, and NO<sub>x</sub>

The impact of converting to methyl-fuel in fuel burning units in the Four-County Area is shown in Table 5-13. The effect is dramatic as the alternate fuel burns virtually pollution free, except for small amounts of NO<sub>x</sub>.

The cost analysis of Table 5-14 can only be considered preliminary. It does not include consideration of adaptations which will be required for fuel burning equipment when converting from fuel oil to methyl-fuel (equipment such as fuel pumps and nozzles will require modification). Since most of these adaptations are not expected to incur substantial expense, estimates of their cost have been neglected in previous studies.

TABLE 5-13. IMPACT OF CONVERSION TO METHYL-FUEL IN COMBUSTION UNITS IN FOUR-COUNTY AREA

	<u>Particulates</u>	<u>SO<sub>2</sub></u>	<u>NO<sub>x</sub></u>
Emissions Expected in 1980 from Fuel Oil Burning Combustion Units, tons/day	65	379	431
Emission Reductions when methyl-fuel is used, 1980, tons/day	65	379	328

<sup>a</sup>Based on NO<sub>x</sub> emissions known to be less than when units are fired with natural gas, on emission rate of 1000 lbs/NO<sub>x</sub> per 1000 equivalent barrels of natural gas, and projected fuel requirement of  $111 \times 10^6$  barrels fuel oil in 1980. (18)

The economic impact of the methyl-fuel conversion by 1980 is illustrated by Table 5-14 below.

TABLE 5-14. COST OF CONVERSION TO BURNING TO METHYL-FUEL IN COMBUSTION EQUIPMENT

<u>Equipment Description</u>	<u>No. of Units</u>	<u>Control</u>	<u>Initial Cost &amp; Installation</u>	<u>Annual Operating Cost Increase to Fuel-Burning Industry</u>	<u>Annualized Cost Increase</u>	<u>Cost of Ton of Emissions Prevented</u>
			<u>Cost in Millions of Dollars</u>			
Methyl-Fuel Producing Plant 20,000 tons/day <sup>a</sup>	3	Fuel Substitution	1422 <sup>b</sup>	0 <sup>c</sup>	142	\$6000 (Particulates) \$1030 (SO <sub>2</sub> ) \$1190 (NO <sub>x</sub> )

<sup>a</sup>Equivalent in heating value to 137,000 barrels/day of fuel oil.

<sup>b</sup>Cost data from Table 3-13, with offsite costs (transportation and storage facilities) of 20% included. (21)

<sup>c</sup>Based on current cost to fuel burning industry of fuel oil:  $\$2.46/10^6$  BTU<sup>9</sup> applied to 1980 requirement of  $111 \times 10^6$  barrels, (18) a current methyl-fuel cost estimate of  $\$2.46/10^6$  BTU. (8)

<sup>d</sup>Based on 30 year lifetime at 10% interest.

The preliminary data demonstrate clearly that methyl-fuel should be given serious consideration as 1) a clean burning fuel which would solve many air pollution problems, and 2) an economical fuel substitute which can be manufactured from domestic raw materials, without dependence on foreign petroleum stocks. The lead time to build a methyl-fuel producing plant, is 3 to 4 years, would pose serious difficulties in imposing fuel substitution plans in the near term. In addition, the political and social disruptions resulting from an enforced imposition of fuel substitution would make a near term conversion unfeasible.



## REFERENCES FOR SECTION 5.0

1. TRW Transportation and Environmental Operations, "The Development of a Particulate Implementation Plan for the Los Angeles Region", Report #2, Emission Inventories and Projections, June, 1974.
2. A. Bell, "Combustion Control for Elimination of Nitric Oxide Emissions from Fossil Fuel Power Plants," presented at 13th International Symposium on Combustion, University of Utah, Salt Lake City, Utah, March 1970.
3. Personal Communication with Joy Manufacturing, Precipitator Division, Los Angeles, California.
4. "Future Bright for Fabric Filters", Environmental Science and Technology, June 1974.
5. John Trijonis, "An Economic Air Pollution Control Model Application: Photochemical Smog in Los Angeles County in 1975, Thesis at the California Institute of Technology, May 1972.
6. Air Pollution Control District of Los Angeles, "Air Pollution Engineering Manual," U.S. Environmental Protection Agency Publication AP-40, May 1973.
7. Air Pollution Control District of Los Angeles, Report to the Los Angeles County Energy Commission on "The Feasibility of Burning Combinations of Natural Gas and High Sulfur Fuel Oil," May 1974.
8. Brian Potter, Wellman Power Gas, Inc., "The Wellman Lord SO<sub>2</sub> Recovery Process", National Engineering, 1973.
9. Personal Communication with Southern California Edison Company.
10. U.S. Environmental Protection Agency "Compilation of Air Pollutant Emission Factors", Document AP-42, April 1973.
11. ESSO Research and Engineering Company, "Systems Study Control Methods for Stationary Sources", Volume II, Prepared for National Air Pollution Control Association, November 1969.
12. HEW (Department of Health, Education and Welfare), "Control Techniques for Nitrogen Oxide Emissions from Stationary Sources," Report #AP-67, March 1970.
13. P. Downing and L. Stoddard, "Benefit/Cost Analysis of Air Pollution Control Devices for Used Cars," Project Clean Air Research Reports, Volume 3, (Riverside, California: University of California, 1970).
14. Personal Communication with Arthur D. Little, Inc., New York
15. Personal Communication with Chevron Research, San Francisco, California.

## 6.0 MINERALS INDUSTRY

Most of the emissions coming from the mineral industry in the Four-County Area are from twelve basic universal process categories. These are aggregate operations, abrasive blasting, clay and clay related operations, cement operations, asphalt saturation, glass and frit operations, concrete batching, sand handling, asphalt batching, foundry sand operations, catalyst production, and lime and limestone operations. Emissions are generally in the form of dust from screening, crushing, storage, and handling operations where the material being handled is dry. Those emissions which are most difficult to control are those emitted from processes such as quarrying, yard storage and transportation. Manufacturing process emissions, however, are generally well controlled with the current emission control technology. Baghouses are widely used along with other dry fabric filters, dry inertial separators, scrubbers, electrical precipitators, mist collectors, and dust suppression systems. The following section describes the results of an investigation of the nature of the emissions and of the existing emission control technology for the twelve basic mineral processes in the Four-County Area.

### 6.1 BASELINE EMISSIONS AND CONTROLS

12.3 tons/day of particulate emissions come from mineral operations in the Four-County Area. This amount is 6% of the total particulate emission coming from all emission source types in this area.  $\text{NO}_x$  and  $\text{SO}_2$  emissions from mineral operations are negligible in Los Angeles County. In the Four-County Area these emissions occur to a very small degree as certain mineral operations give off small quantities of these emissions in working with raw materials. Due to the widely dispersed and relatively infrequent nature of  $\text{NO}_x$  and  $\text{SO}_2$  emissions in mineral operations, a detailed inquiry of existing and potential controls for these pollutants was not attempted. Certain mineral operations involving a furnace where there is a great deal of fuel burned and  $\text{NO}_x$  and  $\text{SO}_2$  is given off, have been categorized under the fuel combustion category.

Table 6-1 provides a categorization of the various mineral operations. The list of operations is presented in the order of the most significant emitter to the least significant emitter. Approximately 90% of mineral particulate emissions come from twelve basic types of mineral separation. Other separations, comprising about 10% of the emissions include, asbestos conveying, pertite operations, soda and caustic operations, mineral wool operations, gypsum operations, and some asphalt processing operations. Due to the relative insignificance of the amount of emissions coming from these source types, more attention is given to the twelve basic categories.

Aggregate operations and processing is the most significant mineral processing operation in the Four-County Area. It is responsible for 24.3% of the total mineral particulate emissions in the area. Most aggregates come from alluvial formations in valleys, where various size aggregates are processed by screening and crushing operations for paving and other construction purposes. About 75% of the particulate emissions from aggregate operations are reported to be uncontrolled.

TABLE 6-1. PARTICULATE EMISSIONS FROM MAJOR MINERAL PROCESS AND PRODUCT INDUSTRIES IN THE FOUR-COUNTY AREA

<u>Category</u>	<u>Particulate Emissions</u>	
	<u>lbs/day</u>	<u>Percent of Total</u>
1. Aggregate Operations	5963	24.3
2. Abrasive Blasting	5223	21.3
3. Clay and Clay Related Operations	1758	7.3
4. Cement Operations	1677	6.8
5. Asphalt Saturation	1397	5.7
6. Glass and Frit Operations	1276	5.2
7. Concrete Batching	1064	4.4
8. Sand Handling	923	3.8
9. Asphalt Batching	778	3.2
10. Foundry Sand Operations	669	2.7
11. Catalyst Production	666	2.7
12. Lime and Limestone Operations	569	2.3
13. Other Operations	<u>2538</u>	<u>10.3</u>
	24501	100.0

Source: Data tabulated from APCD emission inventory file, and adjusted to reflect official APCD inventory totals.

TABLE 6-2. SUMMARY OF EMISSION CONTROLS CURRENTLY UTILIZED  
IN MINERALS INDUSTRY OF LOS ANGELES COUNTY

<u>Process</u>	<u>Control</u>	<u>Particulates Efficiency of Control</u>		<u>Lbs/Day Emitted</u>	<u>Lbs/Day Preven- tion</u>
		<u>Range</u>	<u>Average</u>		
1. Aggregate Operations	Dry Filter, Baghouse	0	0	4472	8771
	Dry Filter, Other	50-99	98	179	29
	Dry Inertial Separator	90-95	94	60	940
	Dust Suppression System	90-93	93	566	7520
	Scrubber	20-95	52	686	743
2. Abrasive Blasting	None	0	0	104	0
	Dry Filter, Baghouse	98	98	5.2	255
	Dry Filter, Other	99	99	4701	465400
	Separator				2793
	Scrubber	97			841
3. Clay and Clay Related Operations	Mist Collector	98	98	33	1617
	None	0	0	971	0
	Dry Filter, Baghouse	90-99	97	601	19432
	Dry Inertial Separator	98	98	21	1029
	Scrubber	0-80	80	165	660
4. Cement Operations	None	0	0	238	0
	Dry Filter, Baghouse	90-99	99	1430	141570
	Dry Filter, Other	0-99	69	9	20
5. Asphalt Saturation	None	0	0	244	0
	Dry Filter, Other	97	97	249	8051
	Electrical Precipitator	93	93	493	
	Mist Collector	89	89	204	6550
	Scrubber	75	75	207	1651
6. Glass and Frit Operations				621	
	None	0	0	804	0
	Dry Filter, Baghouse	87-99	96	159	3816
	Spray Booth Ceramic	0	0	30	0
	Dry Inertial Separator	93	93	62	824
7. Concrete Batching	Scrubber	0-87	85	221	1252
	None	0	0	522	0
	Dry Filter, Baghouse	96	96	195	4680
	Dry Filter, Other	0	0	2	0
	Scrubber	50	50	69	69
	Dust Suppression System	98	98	276	13524

TABLE 6-2. (CONTINUED) SUMMARY OF EMISSION CONTROLS CURRENTLY UTILIZED  
IN MINERALS INDUSTRY OF LOS ANGELES COUNTY

<u>Process</u>	<u>Control</u>	<u>Particulates Efficiency of Control</u>		<u>Lbs/Day Emitted</u>	<u>Lbs/Day Preven- tion</u>
		<u>Range</u>	<u>Average</u>		
8. Sand Handling	None	0	0	269	0
	Dry Filter, Baghouse	99	99	529	52371
	Dry Inertial Separator	83	83	9	44
	Scrubber	78	78	116	411
9. Asphalt Batching	Dry Filter, Baghouse	99+	99+	143	14160
	Scrubber	99+	99+	635	62865
10. Foundry Sand Operations	None	0	0	509	0
	Dry Filter, Baghouse	93-98	97	58	1875
	Scrubber	79-89	88	102	748
11. Catalyst Production	None	0	0	13	0
	CO Boiler Cyclone	0	0	20	0
	Dry Filter, Baghouse	99-99+	99	7	693
	Scrubber	81	81	579	2468
	Incineration, Direct Flame	98	98	47	2303
12. Lime Limestone Operations	None	0	0	94	0
	Dry Filter, Baghouse	80-99	98	351	17199
	Scrubber	98	98	124	6076
Totals				21667	853871

Notes:

1. Where control is designated as "none" it is probable that wetting techniques are being utilized to reduce dust emissions (see text).

Source: Los Angeles County Air Pollution Control District  
Computer Emission Inventory File.

Surface cleaning and preparation by a forcibly propelled stream of abrasive material is the second leading emitter of particulate mineral emissions in the Four-County Area. 21.3% of the particulate emissions come from each operation. Of the emissions coming from this particular category only 2% come from uncontrolled sources. However, due to the substantial number of operations involved, emissions are substantial.

The production of clay and clay related products such as bricks, clay pipes and pottery account for 7.3% of the Los Angeles County mineral particulate emissions. Grinding, screening, blending, forming, cutting, drying, and firing of the final product are the operations involved which produce particulate emissions. Of these emissions, over half (55.2%) come from uncontrolled sources.

Equipment used in cement handling operations include hoppers, bins, screw conveyors, elevators, and pneumatic conveyors. Cement operations are responsible for 6.8% of the county's mineral emissions. This is a well controlled process category, and only minor emissions originate from uncontrolled sources.

Roofing material such as shingles, and asphalt saturated felt rolls are produced by spraying and dipping paper felt with hot asphalt. Asphalt saturation is another category which is widely controlled. This category emits 5.7% of the county's mineral emissions and only 17.5% of these emissions come from uncontrolled sources.

Glass is produced from soda-lime, silica sand, dry powders, granular oxides, carbonates, cullet (broken glass), and other raw materials. Frit is prepared by fusing certain raw materials in a smelter, quenching it, then solidifying and shattering it, and grinding it so that it can be used in solution with wet clay to produce ceramic coatings. Glass and frit operations contribute 5.2% of the mineral emissions in L.A. County. In this category, 63.1% of the emissions come from uncontrolled sources.

Concrete batching plants proportion sand, gravel, and cement using weigh hoppers and conveyors. Such operations emit 4.4% of the county's mineral emissions. 49.1% of these emissions come from uncontrolled sources.

Sand and gravel processing for market use involve a combination of washers, screens, crushers and storage and loading facilities. 3.8% of the county's mineral emissions come from this category. 29.2% of the emissions from this category come from uncontrolled sources.

Asphalt batching is the combining of hot asphalt and aggregate in the proper proportions to create certain desired asphalt paving mixes. This operation emits 3.2% of the county's mineral particulate emissions. There are essentially no uncontrolled sources in this category.

Foundry sand operations consist of separating a sand casting from the mold, and then reconditioning the sand. 2.7% of the county's mineral particulate emissions come from this process, and 76.1 percent of these emissions are uncontrolled.

Catalysts are used in the oil industry for aiding the cracking process of crude oil. Catalyst dust occurs during catalyst production and in rejuvenation. 2.7% of Los Angeles County's mineral particulate emissions come from these catalyst operations, and only 2% of these emissions come from uncontrolled sources.

Lime and limestone operations involve the production of lime from the calcination of limestone. This category contributes only 2.3% of the county's mineral particulate emissions and only 16.6% of these emissions are due to uncontrolled sources.

Table 6-2 shows a summary of emission controls for each of the twelve major mineral operation categories. In the table, each emission control method as it is applied to each category is listed. The range of efficiency and average efficiency is shown for each control method along with the amount of particulates emissions associated with the category and specific control method. It can be seen that the most frequently applied control devices in the mineral industry are the fabric filter and mechanical collector. The use of high efficiency particulate control devices have been used whenever economically feasible to control emissions at the larger point sources. Because the industry typically handles immense process volumes, the preventions accomplished by the emission control equipment has been substantial - over 100 tons per day.

According to the APCD computer data<sup>1</sup> many mineral operations are uncontrolled. The data of Table 6-2 indicates that a total of approximately four tons per day of particulate matter is emitted from uncontrolled mineral operations. It has been found through further investigations that many of these so called uncontrolled sources are, in fact, controlled. Many operations involving aggregates, clay products, cement, concrete, and sand are conducted while the material is wet or damp. Wetting the material, suppressing dust emissions, is an effective and economical control which is not identified as such in the available data.

## 6.2 ALTERNATIVE CONTROL MEASURES

To employ additional controls, such as baghouses, other dry filters, inertial separation, cyclones, and scrubbers to control mineral industry emission sources, it would be necessary to reduce the size of each operation considerably, and, due to the nature of such operations, further operations would be run very uneconomically.

The data clearly show that the vast majority of significant particulate emission sources of the mineral industry are controlled by standard collector devices. Improving emission control in this industry would necessarily involve the employment of additional devices (such as baghouses, scrubbers, and cyclones) at the numerous "uncontrolled" process transfer points. Currently, dust emissions from various transfer operations are minimized by insuring all materials are wetted as they are processed from one operation to another. Of the four tons per day of particulates arising from the numerous uncontrolled point sources, it is probable that nearly all of it could be collected with additional control equipment installations. However, it is clear that such an installation program would involve severe economic penalties.

It is significant that wetting practices have proven effective in reducing dust emissions to levels complying with APCD regulations. The emissions are not visible (meeting with Ringleman Rule No. 50), do not pose a nuisance (Rule 51), do not exceed the maximum permissible concentration (Rule 52), and do not violate the process weight rule



(Rule 54). If any source has, in the past, violated any of these regulations, it has since been equipped with additional particulate emission controls or been given a variance. Hence the controls which are being applied at present have for the most part been applied according to the present concept of particulate emission control and the associated technology.

While economically it appears clear that more stringent controls cannot be feasibly imposed on the mineral industry in the Four County Area, there are in addition, inherent limitations in the emission inventory which make untenable the proposal for increased control expenditures. The quantification of particulate emissions generated at various points in a mineral processing system is extremely difficult, if not impossible. The "average" emission rates used in the inventory tabulation are presumed to reflect varied process conditions and configurations which in many cases have never been investigated empirically or theoretically,<sup>2</sup> and which in many cases, have been modified significantly since the initial analysis.

It appears that if improvements can be made to the level of existing controls, they should be directed toward good practice, proper operation, and maintenance of control efficiency. For example, control equipment should be carefully inspected prior to initial installation and after maintenance to insure that no production faults have occurred such as bad or only partially completed fabric filter seams.

#### REFERENCES FOR SECTION 6.0

1. Printout of Computer Emission Inventory File, developed by Los Angeles County Air Pollution Control District.
2. Personal communication with Los Angeles Air Pollution Control District.

## 7.0 AIRCRAFT OPERATIONS

Aircraft operations are carried out at air carrier, general aviation, and military airfields throughout the Four County Area.<sup>1</sup> Baseline information characterizing aircraft emissions and the prevailing emission control technology being utilized, plus alternative emission control technology available or in development which will reduce atmospheric pollution from aircraft operations, are discussed in the following sections.

### 7.1 BASELINE CHARACTERIZATION

Baseline data characterizing aircraft activity at the major airports, the mix of aircraft class and engine types, and emission rates and effect of existing and projected controls, have been used to construct the overview of the following sections.

#### 7.1.1 Aircraft Emissions

The most significant type of emissions deriving from aircraft operations are particulates. Figure 7-1 shows that particulate emissions from aircraft accounted for 7% of the total particulate emissions discharged to the atmosphere of the Four County Area in 1972, and are expected to account for 15% of the particulate discharges by 1980. Aircraft operations accounted

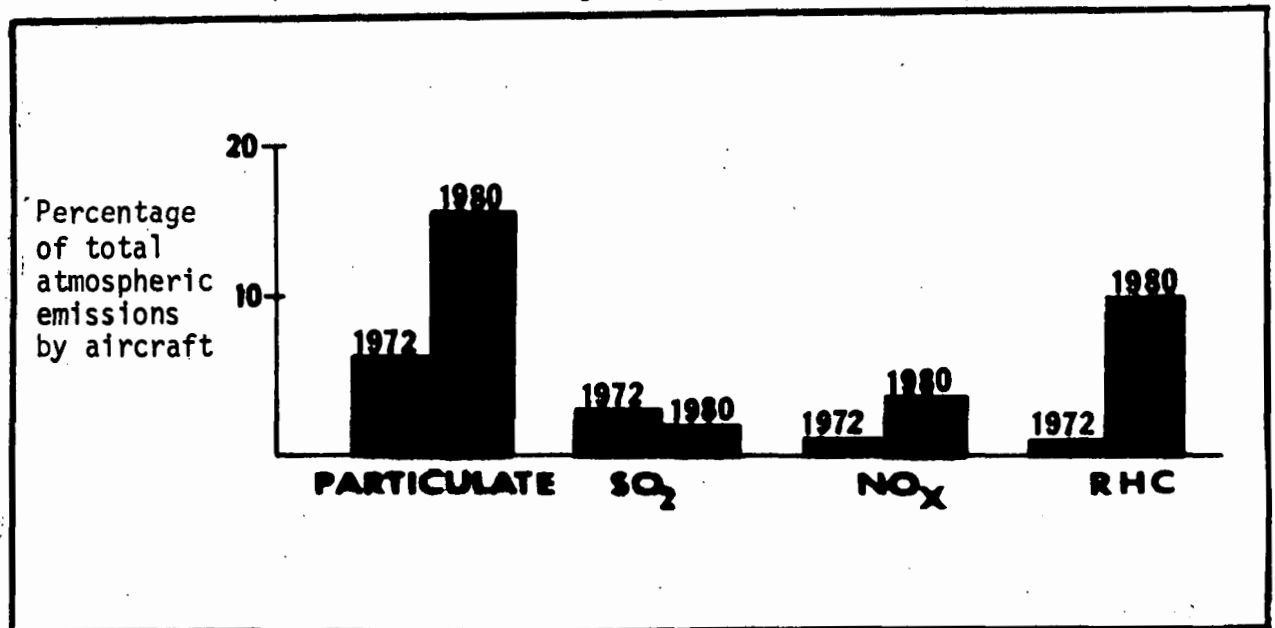


Figure 7-1. Role of Aircraft Emissions in Atmospheric Pollution of Four County Area

for a small portion of the gaseous particulate precursors emitted in 1972, but are expected to exercise a more significant role in this type of pollution by 1980. Actual emission quantities of various pollutants from aircraft in the year 1972, and in projected years, are shown in Table 7-1. As can be seen, the projections indicate that pollution from aircraft will increase substantially in the next decade.

TABLE 7-1. EMISSIONS FROM AIRCRAFT, PRESENT AND PROJECTED, FOUR-COUNTY AREA

<u>Year</u>	<u>Total Particulate</u>	<u>SO<sub>2</sub></u>	<u>NO<sub>x</sub></u>	<u>RHC</u>
1972	15.0	3.6	18.6	15.7
1977	26.8	6.5	32.2	26.7
1980	38.3	9.6	45.4	37.1

Source: Reference (1).

The quantities of pollutants emitted by jet aircraft are far greater than that from aircraft powered by piston engines. Table 7-2 and 7-3 show the emission characteristics of a jumbo jet and a single engine piston plane during a representative landing and takeoff cycle. The jumbo jet emits significant amounts of all pollutants with nearly all the CO and HC emissions occurring during the taxi-idle mode. Oxides of nitrogen and particulate emissions occur at higher power settings used in approach and takeoff for both the turbine and piston engines.

The magnitude of atmospheric pollution arising from piston aircraft and jet aircraft in the Four County Area is shown below. Emissions from both piston and jet powered aircraft are expected to increase in future years, owing to the imminent growth rates of these motive types and the limited pollution control currently scheduled for implementation. Due to the increasing predominance of jet powered aircraft operations at the various airports, piston aircraft are expected to contribute a lesser percentage of the anticipated aircraft pollution.

TABLE 7-2. JUMBO JET EMISSION CHARACTERISTICS

	Operating Mode			Total LT0 Cycle
	Approach	Taxi-idle	Take-off and Climb-out	
Time in mode (min)	4.0	26.0	2.9	32.9
Hydrocarbons, lb	0.7	44.4	.5	45.6
% of Total	2	97	1	
Carbon monoxide, lb	18.8	165.89	2.0	175.9
% of Total	5	94	1	
Oxides of nitrogen, lb	13.7	9.8	95	118.5
% of Total	12	8	80	
Particulates, lb	11.6	30.8	13.6	56.0
% of Total	21	55	24	
SO <sub>2</sub> , lb	4.0	7.6	7.2	18.8
% of Total	22	39	39	

Source: 1) Reference (2).

2) Emission factor data used by the APCD in preparing the report, "Jet Aircraft, A Threat to Air Quality," APCD.

TABLE 7-3. GENERAL AVIATION PISTON EMISSION CHARACTERISTICS

	Operating Mode			Total LT0 Cycle
	Approach	Taxi-idle	Take-off and Climb-out	
Time in mode (min)	6.3	16.0	.8	27.3
Hydrocarbons, lb	0.038	0.057	.064	0.159
% of Total	24	36	40	
Carbon monoxide, lb	2.33	2.00	4.82	9.20
% of Total	26	22	52	
Oxides of Nitrogen, lb	0.005	0.002	.003	0.01
% of Total	50	20	30	
SO <sub>2</sub> , lb	.007	.002	.005	.014
% of Total				
Particulates	-	-	-	.02
% of Total				

Quantification of particulate by mode are not available in the data.

Source: 1) Reference (2).

2) Emission factors for Teledyne/Continental O-200 (Cessna), obtained from Environmental Protection Agency, Ann Arbor, Michigan. This data was used in preparation of Reference (3).

TABLE 7-4. AIRCRAFT EMISSIONS, PRESENT AND PROJECTED  
PISTON AND JET

<u>Year</u>	<u>Engine Type</u>	<u>Particulates</u>	<u>SO<sub>2</sub></u>	<u>NO<sub>x</sub></u>	<u>RHC</u>
1972	jet	11.5	3.4	12.4	9.9
1972	piston	3.5	.2	6.2	5.8
1977	jet	22.2	6.5	23.9	19.0
1977	piston	4.6	-	8.3	7.7
1980	jet	32.8	9.6-	35.4	28.1
1980	piston	5.5	-	10.0	9.0

#### 7.1.2.2 Emission Controls

General awareness of aircraft as a source of air pollution developed in the late 1950's with the introduction of turbine engine aircraft. Visible exhaust plumes and increased exhaust odors at airport stimulated investigations into the nature and extent of aircraft emissions. Congressional studies (1969) evolving from the Air Quality Act of 1967 identified visible emissions as the most significant problem associated with aircraft, and as a result, three airlines voluntarily agreed to retrofit the widely-used Pratt and Whitney JT8D engines with smoke combustors by the end of 1972. The smoke combustor retrofit program was further extended to include all JT3D engines by 1976. Since air operation activity at the major airports is predominantly composed of aircraft powered by either JT3D or JT8D engines, it is estimated that the reduced smoke combustion retrofit substantially affected the quantities of pollutants emitting from aircraft activity. Table 7-5 shows that hydrocarbon emissions were the most

TABLE 7-5. EFFECT OF SMOKE COMBUSTOR RETROFIT ON  
EMISSIONS IN LOS ANGELES COUNTY

<u>Year</u> <sup>1</sup>	<u>Particulates</u>	<u>SO<sub>2</sub></u>	<u>NO<sub>x</sub></u>	<u>THC</u>
1970	13	4	13	80
1972	9	3	13	11.4

Source: 1) Reference (4).  
2) Reference (1).

drastically affected by this retrofit program, while particulate emissions were also significantly reduced.

Standards requiring major changes in engine emission characteristics were promulgated for turbine engines on July 17, 1973 (Table 7-6). The standards consist basically of the following control categories:

1. Retrofit control of smoke emissions and fuel venting for in-use turbine engines.
2. Standards in 1979 to reduce emissions for new turbine and piston engines built in 1979 and after.
3. Standards in 1981 to reflect emission reductions achievable with new large aircraft engine designs.

TABLE 7-6. AIRCRAFT EMISSION STANDARDS

	Fuel Venting Prohibited	1979 New Manufactured				1981 New Certified			
		H <sub>Ca</sub>	CO <sub>a</sub>	NO <sub>a</sub>	SMOKE <sup>b</sup>	H <sub>Ca</sub>	CO <sub>a</sub>	NO <sub>x</sub> <sup>a</sup>	SMOKE <sup>b</sup>
Turbine (T1)	Jan.1, 1975	1.6	9.4	3.7	x				
Turbine (P2)	Jan.1, 1975	4.9	26.8	12.9	x				
Turbine (T2)	Jan.1, 1974	0.8	4.3	3.0	x	0.4	3.0	3.0	x
Turbine (T3) <sup>c</sup>	Jan.1, 1974	0.8	4.3	3.0	x				
Turbine (T4) <sup>c</sup>	Jan.1, 1974	0.8	4.3	3.0	x				
Piston (P1) <sup>d</sup>		1.9	42.0	1.5					
APU		0.4	5.0	3.0					

T1-Turbofan or turbojet engines of rated power less than 8000 lb thrust. (Aircraft examples: business & private jets such as Lear, Grumman, Cessna.)

T2-Turbofan or turbojet engines, except classes T3 and T4, of 8000 lb thrust or greater. (Aircraft examples: Boeing 747, Lockheed L1011, and DC-10))

T3-All JT8D model engines. (Aircraft examples: Boeing 707, DC-8).

T4-All JT8D model engines. (Aircraft examples: Boeing 727, 737, DC-9)

P1-All piston engines, except radials. (Aircraft examples: All piston engine planes ranging from Cessna 150 or Piper Cherokee 140 to Beechcraft Queen Air).

P2-All turboprop engines. (Aircraft examples: Lockheed Electra, Fairchild F27).

APU-Auxiliary Power Unit - Any Engine on the plane exclusive of prop. engines.

APU's used to operate onboard power systems when propulsion engines not operating.

<sup>a</sup>lb/1000 x rated power/cycle - piston engines: lb/1000 hp hr of power output - auxiliary power unit; lb/1000 lb-thrust hr/cycle-aircraft turbine engine.

<sup>b</sup>Smoke standard set with respect to engine thrust to insure no visible emission.

<sup>c</sup>Smoke retrofit required. (T3) by Jan.1,1978, to smoke number 25 and (T4) by Jan. 1, 1974, to smoke number 30.

<sup>d</sup>Effective for engines built after December 31, 1979.

Source: Reference (2).

These emission standards will result in substantial pollutant preventions only after attrition of pre-1979 engines. Additional controls will be required to bring about significant near term reductions. The possibilities for alternative near term controls are discussed in the following section.

## 7.2 ALTERNATIVE CONTROL MEASURES

The current emission standards will result in substantial emission reductions only after attrition of pre-1979 engines. Additional controls will be required to bring about significant near term reductions. Feasible control technology which may be applied includes:

- Modification of ground operations
- Engine modification (retrofits) for turbine and piston fleets

### 7.2.1 Retrofit Alternatives: Turbine Engines

The EPA has studied the technology which may be applied to reduce emissions from turbine aircraft. Engine modification methods feasible for turbine engines as retrofits are described briefly below (Table 7-7). These modifications can be combined (with the exception of T4 and T6) to achieve increased emission control effectiveness as they are not mutually exclusive.

TABLE 7-7. ENGINE MODIFICATIONS FOR EMISSION CONTROL FOR EXISTING AND FUTURE TURBINE ENGINES

Control Method	
Existing engines	
t1 - Minor combustion chamber redesign	Minor modification of combustion chamber (smoke combustor retrofit) and fuel nozzle to achieve best state-of-art emission performance
t2 - Major combustion chamber redesign	Major modification of combustion chamber and fuel nozzle incorporating advance fuel injection concepts (carburetion or prevaporization).
t3 - Fuel drainage control	Modify fuel supply system or fuel drainage system to eliminate release of drained fuel to environment.
t4 - Divided fuel supply system	Provide independent fuel supplied to subsets of fuel nozzles to allow shutdown of one or more subsets during low-power operation.
t5 - Water injection	Install water injection system for short duration use during maximum power (takeoff and climb-out) operation.



TABLE 7-7. (CONTINUED) ENGINE MODIFICATIONS FOR EMISSION CONTROL FOR EXISTING AND FUTURE TURBINE ENGINES

<u>Control Method</u>	<u>Modification</u>
t6 - Modify compressor air bleed rate	Increase air bleed rate from compressor at low-power operation to increase combustor fuel-air ratio.
Future engines	
t7 - Variable-geometry combustion chamber	Use of variable airflow distribution to provide independent control of combustion zone fuel-air ratio.
t8 - Staged injection combustor	Use of advanced combustor design concept involving a series of combustion zones with independently controlled fuel injection in each zone.

Source: Reference (3).

The estimated effectiveness from these measures are presented in Table 7-8 in terms of the reductions attainable from the lowest current emission rates realistically obtainable for the given turbine engine class. This is equivalent to the emissions resulting when an engine is well maintained and operates with control method t1 (smoke combustor). The basis for the effectiveness estimates are documented in Table 7-9.

#### 7.2.1.1 Impact of Turbine Engine Controls on Air Emissions

The overall reduction to atmospheric emissions by implementation of the turbine engine modifications depends on the mix of turbine aircraft classes operating at the various airports throughout the South Coast Basin. In addition, the overall reductions also depend on the mix of engine makes within each engine class, and the degree to which each of these contribute total emissions during the various segments of the idle-take-off-approach cycle.

The various turbine engine classes are defined in Table 7-10. The typical engines representative of these classes contribute to overall atmospheric emissions as shown in Table 7-11. While Table 7-11 portrays the case at Los Angeles International Airport, it reflects the general case in which a small number of the turbine engines in use contribute the vast

TABLE 7-8. EFFECTIVENESS OF ENGINE MODIFICATION IN CONTROL OF EMISSIONS FROM TURBINE ENGINES, BY OPERATING MODE<sup>a</sup>

Control Method	Engine Class	Pollutant	Mode		
			Idle/taxi	Approach	Takeoff
t2 <sup>b</sup>	T1	DP	0.5	0.5	0.5
t2	T1	NO <sub>x</sub>	NC <sup>c</sup>	NC	0.5
t2	T2	DP	0.5	0.5	0.5
t2	T3	NO <sub>x</sub>	NC	NC	0.5
t3	T1	THC	NC	NC	0 <sup>d</sup>
t3	T2	THC	NC	NC	0 <sup>d</sup>
t3	T3	THC	NC	NC	0 <sup>d</sup>
t4	T1	CO	0.25	NC	NC
t4	T1	THC	0.25	NC	NC
t4	T2	CO	0.25	NC	NC
t4	T2	THC	0.25	NC	NC
t4	T3	CO	0.25	NC	NC
t4	T3	THC	0.25	NC	NC
t5	T1	NO <sub>x</sub>	NC	NC	0.1
t5	T2	NO <sub>x</sub>	NC	NC	0.1
t5	T3	NO <sub>x</sub>	NC	NC	0.1
t6	T1	CO	0.5	NC	NC
t6	T1	THC	0.5	NC	NC
t6	T2	CO	0.5	NC	NC
t6	T2	THC	0.5	NC	NC
t6	T3	THC	0.5	NC	NC
t6	T3	CO	0.5	NC	NC
t7 or t8 <sup>e</sup>	T1	CO	0.1	NC	NC
t7 or t8	T1	THC	0.1	NC	NC
t7 or t8	T1	NO <sub>x</sub>	NC	NC	0.75
t7 or t8	T1	DB	0.5	0.5	0.5
t7 or t8	T2	CO	0.1	NC	NC
t7 or t8	T2	THC	0.1	NC	NC
t7 or t8	T2	NO <sub>x</sub>	NC	NC	0.75

TABLE 7-8. (CONTINUED) EFFECTIVENESS OF ENGINE MODIFICATION IN CONTROL OF EMISSIONS FROM TURBINE ENGINES, BY OPERATING MODE<sup>a</sup>

Control Method	Engine Class	Pollutant	Mode		
			Idle/taxi	Approach	Takeoff
t7 or t8	T2	DP	0.5	0.5	0.5
t7 or t8	T3	CO	0.1	NC	NC
t7 or t8	T3	THC	0.1	NC	NC
t7 or t8	T3	NO <sub>x</sub>	NC	NC	0.75
t7 or t8	T3	DP	0.5	0.5	0.5

<sup>a</sup>Emission rate is fraction of best current rate assumed to be attainable through minor combustion chamber redesign and with control method cited.

<sup>b</sup>t2 = Major combustion chamber redesign.  
t3 = Fuel drainage control  
t4 = Divided fuel supply system  
t5 = Water injection  
t6 = Modify compressor air bleed rate  
t7 = Variable geometry combustion chamber  
t8 = Staged injection combustor

<sup>c</sup>NC indicates no change

<sup>d</sup>Refers to raw fuel drainage only.

<sup>e</sup>Refers to new design standards for engines manufactured in 1979 and after - not a retrofit.

Source: Reference (3).

TABLE 7-9. BASIS FOR CONTROL METHOD EFFECTIVENESS ESTIMATES  
FOR TURBINE ENGINES

Control Method	Rationale
t1 - Minor combustion chamber redesign	The assumption is made that emission rates for all engines within a given class can be reduced to common, optimum levels (on a lb/1000 lb fuel basis) by minor combustor modifications. These optimum emission rates are based on the best performance reported for each engine class, excluding extreme data points.
t2 - Major combustion chamber redesign	Estimates are based on reports of carbureting fuel injector performance and reduction of smoke emission. Concept is incorporated in some Class T3 engines. Estimates are based on assumption that best emission rate for Class T1 and T2 engines is at an exhaust visibility threshold at maximum power. Carburetion appears to reduce smoke level, and presumably particulate emissions, to approximately half that level. Additionally, premixing of air and fuel can be used to give substantial NO <sub>x</sub> reduction by decreasing residence time in the combustor.
t3 - Fuel drainage control	Estimate is based on the assumption that fuel drainage can be completely eliminated by collecting drained fuel and returning to fuel tank.
t4 - Divided fuel supply system	Control method results in combustion zone fuel-air ratio similar to that at approach condition. Reduction in CO and THC from idle to approach is approximately 90 percent in Class T1 and T2 engines and 90 percent in Class T3 engines. Effectiveness is reduced by one order because combustor is not operating at "well-designed" condition.
t5 - Water injection	Water injection is assumed only at takeoff at a rate up to twice the fuel rate. Water injection into compressor or diffuser is assumed to be by system similar to those in current use. Effectiveness based upon published results with steam injection. Water injection assumed to be of equal effectiveness when injected upstream of combustor.
t6 - Modify compressor air	Assumptions are (1) fraction of air that can be bled is small so that engine operating point is nearly unchanged, (2) combustor f/a varies inversely with air bleed rate, and (3) CO and THC emissions at idle vary as the (air mass flow rate) <sup>3</sup> and inversely as (f/a) <sup>3</sup> . This relationship is based upon data from Reference 14. If maximum air bleed rate is 20 percent, CO and THC emission rates are reduced by 50 percent.

TABLE 7-9. (CONTINUED) BASIS FOR CONTROL METHOD EFFECTIVENESS ESTIMATES FOR TURBINE ENGINES

Control Method	Rationale
t7 - Variable-geometry	Combustor primary zone is assumed to operate at a constant f/a equal to normal f/a at approach power condition (primary equivalence ratio = 0.6). CO and THC emissions at idle are reduced to levels corresponding to approach power, or by 90 percent for Classes T1, T2, and T3. This incorporates design characteristics that provide a good mixture in the combustion zone. This feature and constant f/a operation combine to reduce NO <sub>x</sub> emissions at full power by 75 percent <sup>26</sup> and particulate emissions by 50 percent at all power levels as in t2.

Source: Reference (3).

TABLE 7-10. TURBINE ENGINE CLASSIFICATION

Turbine Engine Class	Engine Class Description	Typical Engine Makes
T1	Small engine class	Allison T56A7 Allison 501-D13
	Business and small commercial jet aircraft	GE CJ 610 JT-12A PT-6A
T2	Turbojet and turbofan engine	JT-3D JT-4A
	Medium to large commercial aircraft	JT 8D J-79 J-69
T3	Large turbofan engines for jumbo transport and SST engines	JT9D

TABLE 7-11: AVERAGE ANNUAL TONS OF AIR CONTAMINANTS EMITTED IN LOS ANGELES COUNTY  
BY GAS TURBINE AIRCRAFT ENGINES OPERATED AT LAX IN 1970

ENGINE MODEL NUMBER	TOTAL NUMBER OF ENGINE LTO PER YEAR AT LAX	PARTICULATE MATTER		CARBON MONOXIDE		OXIDES OF NITROGEN		COMBUSTIBLE ORGANIC GASES		SULFUR DIOXIDE		TOTAL AIR CONTAMINANT IN TONS PER YEAR
		POUNDS PER LTO	TONS PER YEAR	POUNDS PER LTO	TONS PER YEAR	POUNDS PER LTO	TONS PER YEAR	POUNDS PER LTO	TONS PER YEAR	POUNDS PER LTO	TONS PER YEAR	
(a)	(b)	(c)		(c)		(c)		(c)		(c)		(rounded)
JT4A	40,772	13.806	280	42.640	870	9.138	185	12,194	250	4.308	90	1,675
JT9D	24,672	13.340	165	30.684	380	18.600	230	9.580	120	4.574	55	950
JT3D	315,616	9.366	1,480	38.656	6,100	6.416	1,010	19.142	3,020	2.804	440	12,050
JT8D	244,185	13.236	1,615	20.328	2,480	7.210	880	115.724	14,130	2.842	345	19,450
JT3C-6	16,060	15.374	125	30.624	245	5.570	45	6.246	50	4.238	35	500
CJ805	13,140	12.564	85	25.500	170	6.050	40	68.546	450	3.494	25	770
501-D	21,900	6.456	70	1.294	15	6.824	75	3.790	40	1.734	20	220
TOTAL	676,345		3,820		10,260		2,465		18,060		1,010	35,615

(a) A test was run on an engine of this model number. See Table II.

(b) From Table II.

(c) The values in the column are from Source Test Data of the Los Angeles County Air Pollution Control District.

Source: Reference (5).

majority of pollution arising from aircraft operations. Currently the JT3D, JT8D and JT4A turbine engines generate approximately 90% of all polluting emissions from turbine engines. The importance of the JT9D engine (jumbo aircraft) is expected to increase in the future emission profile.

Emissions for the different engines vary for the different modes of operation. Table 7-12 demonstrates that particulate and SO<sub>2</sub> emissions from jet aircraft engines are most conspicuous during the taxi and idle modes. This is due primarily to the fact that emissions in this mode are sustained over approximately 80% of the total LTO cycle. Oxides of nitrogen emissions are most prevalent during the higher loading conditions of takeoff and climbout. The distributions are based on actual field measurements performed by the LAAPCD of aircraft operating at Los Angeles International Airport. It was presumed that these figures could be used to devise representative modal emission distributions. It should be noted however, that the "best emission rates" reported by the EPA in their study on control technology do provide a different perspective (emissions of particulates are typically far less in the idle taxi mode, while hydrocarbon emissions are substantially greater in idle taxi operations). However, emission rates published by the EPA<sup>6</sup> do yield a modal emission distribution similar to that calculated herein from APCD data.

Modal emission distribution for the smoke-combustion retrofitted JT8D engines was calculated from EPA data since available APCD emission rates did not reflect the retrofitted version. The modal distribution of the JT3D was assumed to be the same as the JT8D.

From the control effectiveness data (Table 7-8) and the engine LTO modal emissions data (Table 7-12) it can be seen that among the retrofit control possibilities, T2 will be most effective for overall emission reduction of particulates, t5 for NO<sub>x</sub> and t4 for hydrocarbons and CO. None of the control methods is expected to have a significant effect on SO<sub>2</sub> emissions.

TABLE 7-12. MODAL EMISSIONS DISTRIBUTION FOR PRINCIPAL JET ENGINES IN USE

Pollutant	Turbine Engine	Engine Class	Percentage of Emissions per LTO		
			Idle-Taxi	Approach	Takeoff and Climbout
Particulates	JT3D	T2	47	12	41
	JT8D	T2	36	37	27
	JT4A	T2	70	11	18
	JT9D	T3	55	21	24
SO <sub>2</sub>	FT3D	T2	42	18	40
	JT8D	T2	39	28	33
	JT4A	T2	46	18	37
	JT9D	T3	39	22	39
NO <sub>x</sub>	JT3D	T2	12	14	74
	JT8D	T2	15	30	55
	JT4A	T2	15	17	68
	JT9D	T3	9	15	76
THC	JT3D	T2	95	3.1	1.2
	JT8D	T2	95	3.1	1.2
	JT4A	T2	90	4	5
	JT9D	T3	60	18	22

Calculations for modal distribution above are based on 1), Reference (7), 2), Reference (6).

Based on the JT8D and JT3D, the most widely used engines in the turbine fleet, the estimated relative effectiveness of the retrofit controls is as shown in Table 7-13.

Obviously the exactness of the estimates of Table 7-13 is limited by several analytical uncertainties. The effectiveness of the various controls estimated in Table 7-8 is based on the degree to which current best emission rates can



TABLE 7-13. IMPACT OF ALTERNATIVE CONTROL ON OVERALL JET AIRCRAFT EMISSIONS

Control Method	Percent Reduction in Overall Engine Emissions			
	Particulates	THC	NO <sub>x</sub>	SO <sub>2</sub>
t2	50	NC	34	NC
t3	NC	1 <sup>a</sup>	NC	NC
t4	NC	71	NC	NC
t5	NC	NC	58	NC
t6	NC	48	NC	NC
t7 or t8 <sup>b</sup>	50	86	16	NC

NC = no change.

<sup>a</sup>Refers to reduction due to elimination of raw fuel drainage only, which constitutes a small portion of emissions in takeoff mode.

<sup>b</sup>New design standard for engines manufactured in 1979 and after (not a retrofit measure).

be further reduced. The modal emission distributions of Table 7-12 are based on measurements performed by the APCD on actual jet aircraft operating in the field (reflecting a substantially higher emission rate than the "best emission rates"). Consequently, the reduction figures calculated in Table 7-13 may well be conservative, and hence greater reductions than those calculated are likely. A number of other problems complicate the estimations: 1) discrepant emission factors published between the EPA and the LA APCD; 2) the variations in modal temporal patterns at the various airports; 3) limited data.

#### 7.2.1.2 Cost of Retrofit Controls

Presently the EPA is proposing that all aircraft engines be retrofitted to 1979 standards by 1979. The technical feasibility of this proposal is not a certainty as the alternative retrofits are not in a good state of refinement at this time.<sup>8</sup> Few of the control methods have been developed or applied to aircraft engines. Table 7-14 lists the development time requirements for each of the control methods. A major consideration in development time

TABLE 7-14. TIME AND COSTS FOR MODIFICATION OF CURRENT  
CIVIL AVIATION<sup>a</sup> ENGINES

<u>Control Method</u>	<u>Development Time, Years</u>	<u>Development Cost, 10<sup>6</sup> Dollars</u>	<u>Implementation Cost, 10<sup>6</sup> Dollars</u>
Major combustion chamber redesign	2.5 to 7.5	74	665
Fuel drainage control	1 to 2.5	1.5	5.4
Divided fuel supply	5 to 7.5	84	102
Water injection	2.5 to 4	25	175
Compressor air bleed	4 to 6.5	90	58

Source: Reference (3).

consists of the maintenance facilities and procedures accompanying the retrofitting equipment. The minimum time for implementation of most of the emission control methods for turbine engines is estimated to be two and one-half years.

Of the potential methods for aircraft emission control, the retrofitting of in-use engines is the most costly. The cost of modifying existing designs for emission control in new engines is approximately one-half of that incurred by retrofitting. The incorporation of new control technology during new engine design incurs the least cost, estimated at a 3 to 4% increase over the base engine cost.<sup>8</sup> Table 7-14 provides cost estimates for implementing the various retrofit control methods. Implementation includes initial installation of the control method on all engines of a given class and the additional effort required for the control method throughout the remaining life of the engines (assuming 10 year life).

The cost of the turbine retrofit alternatives for each engine class is presented in Table 7-15. For a typical class T2 turbine engine, the cost of developing, installing, and maintaining control systems range from \$300 to \$69,900. Based on a total engine cost of \$250,000, the retrofit control costs represent .1 to .25 percent of the total engine cost.

TABLE 7-15. COST RESULTS FOR TURBINE ENGINE POPULATION BY SEPARATE USE CATEGORIES

Engine Class	Control Method	Development cost per Engine Family, 10 <sup>6</sup> Dollars	Implementation cost per Engine, 10 <sup>3</sup> Dollars	Total Cost, 10 <sup>6</sup> Dollars		
				Air Carrier	General Aviation	Civil Aviation <sup>a</sup>
T1	t1	0.90	12.4	19.2	90.5	109.7
T1	t2	1.80	21.3	34.5	159.3	193.8
T1	t3	0.05	0.1	0.4	1.0	1.4
T1	t4	1.80	3.7	14.9	51.5	66.4
T1	t5	0.62	5.5	9.8	43.6	53.4
T1	t6	2.20	2.1	15.5	48.1	63.6
T2	t1	0.90	35.5	243.0	17.8	259.8
T2	t3	0.05	0.3	2.0	--	2.0
T2	t4	1.80	10.5	87.0	8.3	98.3
T2	t5	0.62	15.6	108.7	8.2	116.9
T2	t6	2.20	6.0	61.5	7.1	68.6
T3	t1	0.90	58.3	50.0	--	50.0
T3	t2	1.80	100.0	95.0	--	95.0
T3	t3	0.05	0.6	2.0	--	2.0
T3	t4	1.80	17.2	13.7	--	13.7
T3	t5	0.62	25.6	29.5	--	29.5
T3	t6	2.20	9.9	16.0	--	16.0

<sup>a</sup>"Civil Aviation" includes air carrier and general aviation engines.

Source: Reference (3).

The cost effectiveness of the various retrofit controls, in terms of air pollution at the Four-County Area, is portrayed in Table 7-16. The only measure affecting particulate emissions is the major combustion chamber redesign, which requires a cost of \$4100 per ton of particulate recovered. NO<sub>x</sub> emissions are reduced most drastically by water injection control, at a cost of \$820 per ton of NO<sub>x</sub> controlled. The cost effectiveness estimates of Table 7-16 reflect the expenditure required to retrofit those aircraft operating through the Four County Area to reduce emissions in the area.

TABLE 7-16. COST EFFECTIVENESS FOR TURBINE RETROFIT MEASURES, 1977, FOUR-COUNTY AREA

Control Method	Cost of Emission Control Per Ton of Pollutant Prevention			
	Particulates	SO <sub>2</sub>	NO <sub>x</sub>	THC
Major combustion chamber redesign	\$4100	-	\$5770	-
Fuel drainage control	-	-	-	917000
Divided fuel supply	-	-	-	550
Water injection	-	-	\$820	-
Compressor air bleed	-	-	-	550

Calculations above based on:

1. 1968 survey determining there were 1674 jet engines in use at LAX. 94% were Pratt & Whitney, mainly of JT3D and JT8D type, and principally on Class T2 aircraft. These engines were involved in 487 LTO's per day.<sup>9</sup>
2. Survey of jet aircraft activity in 1970 at LAX showing 560 LTO's per day.<sup>5</sup> This figure was used to update jet engine numbers information of (1) above to baseyear 1972 by direct proportioning.
3. Figures for LAX were adjusted to reflect the Four County Area by apportioning the ratio of emissions from LA County versus the Four County Area (data from Reference (1)).
4. Cost of air pollution control benefits are figured for Four County Area only, and do not reflect the tons of emission reductions due to operation of the aircraft fleet in other areas.

The emission reductions benefitted by other areas traveled by these aircraft are not included in the perspective. Hence if expressed in terms of the total emission reductions for LTO's performed in the nation, the cost effectiveness of the retrofits would be 4 or 5 times greater (based on normal operating usage for class T2 aircraft,<sup>3</sup> and an assumed flight to hours ratio of 1 per every 2 hours).

### 7.2.2 Modification of Ground Operations

Aircraft ground operations contribute a substantial portion of the emissions of particulates,  $\text{SO}_2$ , and THC arising from overall aircraft operations (see Table 7-12). This is due to relatively high emission rates of the pollutants at low engine power levels, as well as the extended period of operation characteristic of idle-taxi modes for jet powered aircraft. A number of ground operation modifications have been proposed to reduce taxi-idle mode emissions.<sup>3</sup> Regulations which may arise from these proposals have been deferred until operational and safety considerations can be studied jointly by the EPA and FAA. The procedures devised to control emissions by reducing the time of taxi-idle or by operating turbine engines at higher and more efficient thrust settings are:

1. Increase engine speed during idle and taxi operations.
2. Increase engine speed and reduce number of engines during idle and taxi.
3. Reduce idle operating time by controlling departure times from gates.
4. Reduce taxi operating time by transporting passengers to aircraft.
5. Reduce taxi operating time by towing aircraft between runway and gate.
6. Reduce operating time of aircraft auxiliary power supply by providing ground-based power supply.

Modification of ground operations has been proposed primarily for reduction of HC and CO emissions. To this end, the most attractive option for ground control is the use of fewer engines at higher more efficient power settings during taxi and idle modes. This conclusion is based on modal emission characteristics of turbine engines, typically portrayed as in Figure 7-2. Figure 7-2 demonstrates the effects of improved combustion at high thrust settings. At the elevated thrust required when only one engine is used during taxi and idle, the emission reduction is approximately 80% for HC during this mode. Since the idle mode accounts for a substantial portion of all turbine engine emissions (see Table 7-12), the introduction of this ground operation modification could reduce turbine aircraft hydrocarbon emissions by approximately 50% (see Table 7-17).

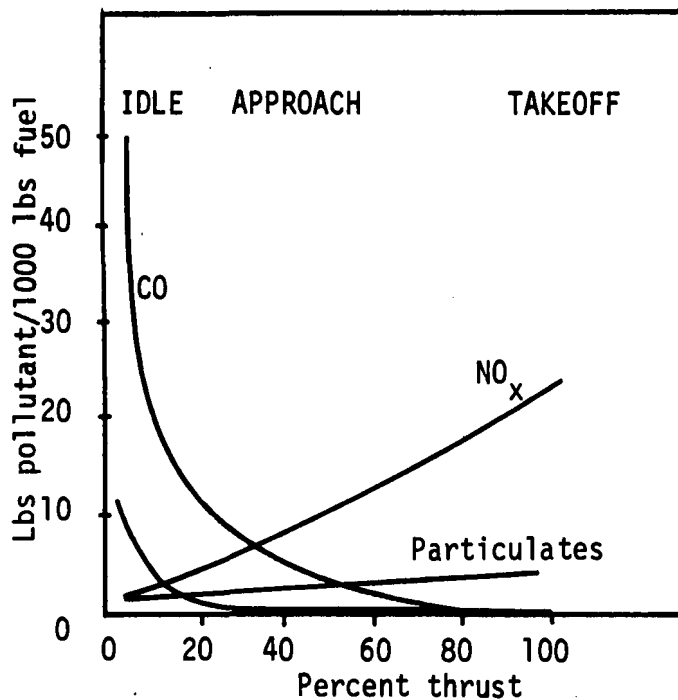


Figure 7-2. Gaseous Emission Characteristics of a JT8D Turbine Engine

Source: 1. Reference (2)  
2. Reference (8).

However, introduction of the same ground operation modification will result in increases in particulate, SO<sub>2</sub> and NO<sub>x</sub> emissions. Other options for ground operation controls, such as reducing the amount of time in the taxi and idle mode, would enable overall reductions in hydrocarbon emissions as well as particulate and NO<sub>x</sub> emissions. The most effective overall option in this respect is the towing of aircraft to avoid taxi emissions. Table 7-17 gives the anticipated reductions resulting from ground control methods applied to the Los Angeles Airport.

TABLE 7-17. COMPARATIVE REDUCTIONS RESULTING FROM CONTROL METHODS APPLIED AT LOS ANGELES INTERNATIONAL AIRPORT

Control Method	Resultant Emissions, % of Baseline Emissions			
	Particulates	NO <sub>x</sub>	SO <sub>2</sub>	THC
1. Increase engine idle speed	150	164	150	93
2. Increase idle speed and use minimum engines for taxi				
two engines	134	142	134	66
single engine	168	186	168	51
3. Eliminate delays at gate and runway	96	99	96	91
4. Transport passengers between terminal and aircraft	98	100	98	97
5. Tow aircraft to avoid taxi emissions	78	91	78	42
6. Avoid use of aircraft auxiliary power units (APU)	99	100	99	98.5

Calculations of emission reductions are based on 1) gaseous emission characteristics of JT8D turbine engine,<sup>a</sup> 2) modal emission distributions (Table 7-12), and 3) hydrocarbon reductions resulting from control methods at Los Angeles International Airport.<sup>3</sup>

<sup>a</sup>Emission data obtained from Environmental Protection Agency, Ann Arbor, Michigan. This data was used in preparing Reference (3).

#### 7.2.2.1 Impact of Ground Operations Controls on Atmospheric Emissions

Only one of the proposed ground operations control options appears to be effective in reducing all types of pollutant emissions from turbine engines. Table 7-17 shows that towing of aircraft to avoid taxi emissions will reduce particulate and SO<sub>2</sub> emissions from turbine aircraft to 78% of the levels expected without controls. The projected emissions from turbine aircraft expanded to the Four-County Area, are as shown below.

TABLE 7-18. IMPACT OF GROUND OPERATION MODIFICATIONS ON TURBINE AIRCRAFT EMISSIONS OF FOUR-COUNTY AREA

Year	Turbine Emissions - Tons/Day			
	Particulates	NO <sub>x</sub>	SO <sub>2</sub>	RHC
1972 - no ground control	11.5	12.4	3.4	9.9
1977 - no controls	22.2	23.9	6.5	19.0
1977 - aircraft towing	17.3	21.8	5.1	8.0

#### 7.2.2.2 Cost of Ground Operation Controls

Initial cost, implementation time, annual operating cost, each of the ground control measures when applied to major airports are presented in below. While Measure No. 2 is most cost effective for hydrocarbon emission control, only Measure No. 5 is really suitable as a measure for control of particulate emissions. The annualized cost of Measure No. 5 is estimated to be (based on 15 year lifetime of initial equipment) \$.56 million per year at the Los Angeles International Airport. This cost amounts to an emission control effectiveness as follows:

Cost of Controlling Turbine Emissions by Towing of Aircraft to Reduce Taxi Engine Usage. (Dollars per ton of pollutant removed.)

Particulates	SO <sub>2</sub>	NO <sub>x</sub>	THC
\$300	\$740	\$1100	\$140

The overall cost effectiveness of the towing measure for the combined emission preventions, is \$79 per ton of pollutant.

#### 7.2.3 Fuel Alternatives

In a study funded by the EPA,<sup>3</sup> the effect of fuel modifications on aircraft engine emissions was found to be insignificant. Only SO<sub>2</sub> emissions were easily altered by modifying fuels. These reductions were accomplished by proportionate reductions of sulfur in the fuel. Increases in engine emissions were achieved when aeromatic content of the fuels exceeded 25%,



but this finding was determined of minor significance because of current fuel usage standards forbidding use of fuels with aeromatic content greater than 25%. The EPA was also motivated to terminate their investigations of cleaner burning fuels because of economic infeasibility associated with fuel control as an emission control measure.

#### 7.2.4 Retrofits for Piston Aircraft

The EPA has studied the technology which may be applied to reduce hydrocarbons and CO emissions from piston aircraft. Control methods considered feasible for aircraft piston engines include approaches that have been conceived or developed for automotive engines. Table 7-19 provides a summary of nine of the piston engine control methods identified by EPA as potentially feasible approaches. Recent research<sup>8</sup> indicates that control method P1, fuel-air ratio control, is the most technically feasible approach to substantial piston emission reductions. In this approach, leaner air-fuel ratios are obtained to produce reductions in hydrocarbons and CO. Figure 7-3 illustrates the effect of air-fuel ratio on piston emission characteristics. Operation at a 13 to 1 air-fuel ratio gives more than 50% reduction in CO and HC from levels at a 10 to 1 air-fuel ratio.

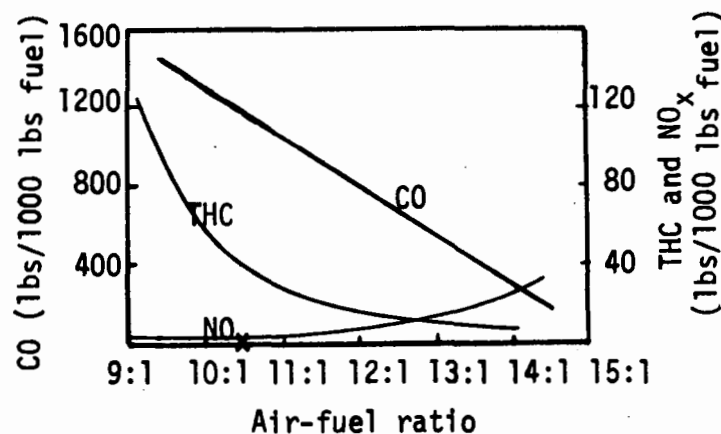


Figure 7-3. Emission Characteristics for Piston Engine

Source: Reference (2)

Because particulate and  $\text{NO}_x$  emission rates from piston aircraft are considered to be relatively low, the EPA has not been directly concerned with developing controls for these pollutant types. This is reflected in the aircraft emission standards (Table 7-6), which are directed at control for hydrocarbon, CO and  $\text{NO}_x$  emissions only. Consequently the available research data characterizing particulate emissions during various piston engine operating modes is quite limited.

Although particulate emissions associated with the candidate piston engine controls have not been specifically determined it is expected that those controls which reduce exhaust hydrocarbon emissions will also produce particulate emission reductions.<sup>8</sup> Experience with reciprocating automotive engines has shown that leaning air fuel ratios, currently the leading candidate measure for implementation as piston engine emission control, effects reductions in particulate emissions which are proportional to the resulting hydrocarbon emissions. The EPA has forecasted a 50% hydrocarbon reduction with incorporation of air-fuel ratio control methods.<sup>3</sup> It is not possible from the available data to estimate the degree of particulate emission reductions which would occur with leaner air fuel mixtures, but it was assumed that coordination of emission control objectives would enable reductions of particulate emissions of at least 20% when leaner air fuel mixture modifications are incorporated.

Currently there are numerous uncertainties associated with the technical and economical feasibility of the various control methods as a retrofit measure. For control P1 it is suspected that engine detonation and overheating will occur with leaner air fuel mixtures in existing engines. Hence a redesign of the cylinder head for operation at the elevated temperatures would be required, and retrofits for measure P1 would be economically unfeasible. FAA is currently funding research by piston engine manufacturers (Continental/Lycoming) to study the feasibility of retrofitting piston engines for lower emissions with timing and fuel mixture ratio modifications.

EPA has estimated the implementation time, development cost, and overall implementation cost for incorporating the candidate piston engine control methods. For a typical piston engine, implementation costs range from \$100 to \$4000, based on total cost for a 10 year life. These costs

represent 2 to 65% of the initial cost of the piston engines. Control of fuel-air ratio is the most cost effective method of reducing both hydrocarbon and CO emissions from piston engines.

TABLE 7-19. ENGINE MODIFICATIONS FOR EMISSION CONTROL FOR EXISTING AND FUTURE PISTON ENGINES

<u>Control Method</u>	<u>Modification</u>
<b>Existing engines</b>	
p1 - Fuel-air ratio control	Limiting rich fuel-air ratios to only those necessary for operational reliability
p2 - Simple air injection	Air injected at controlled rate into each engine exhaust port.
p3 - Thermal reactors	Air injection thermal reactor installed in place of, or downstream of, exhaust manifold.
p4 - Catalytic reactors for HC and CO control	Air injection catalytic reactor installed in exhaust system. Operation with lead-free or low-lead fuel required.
p5 - Direct-flame afterburner	Therman reactor with injection of air and additional fuel installed in exhaust system.
p6 - Water injection	Water injected into intake manifold with simultaneous reduction in fuel rate to provide for cooler engine operation at leaner fuel-air ratios.
p7 - Positive crankcase ventilation	Current PCV system used with automotive engines applied to aircraft engines. Effective only in combination with one of preceding control methods.
p8 - Evaporative emission controls	A group of control methods used singly or in combination to reduce evaporative losses from the fuel system. Control methods commonly include charcoal absorbers and vapor traps in combination with relatively complex valving and fuel flow systems.
<b>Future engines</b>	
p9 - Engine redesign	Coordinated redesign of combustion chamber geometry, compression ratio, fuel distribution system, spark and valve timing, fuel-air ratio, and cylinder wall temperature to minimize emissions while maintaining operational reliability.

Source: Reference (3).

## REFERENCES FOR SECTION 7.0

1. TRW Transportation and Environmental Operations. "The Development of a Particulate Implementation Plan for the Los Angeles Region," Report #2, Emission Inventories and Projections, June 1974. Prepared for the Environmental Protection Agency.
2. Jones, Kay, Robert Sampson, John Holmes, Environmental Protection Agency, "The Federal Aircraft Emissions Control Program: Standards and Their Basis," Journal of the Air Pollution Control Association, January 1974.
3. Environmental Protection Agency, "Aircraft Emissions: Impact on Air Quality and Feasibility of Control."
4. Air Pollution Control District, County of Los Angeles, "Profile of Air Pollution Control," 1971.
5. George, Ralph, John Nevitt, Julien Verssen, County of Los Angeles Air Pollution Control District, "Jet Aircraft Operations: A Threat to the Environment."
6. Environmental Protection Agency, "Compilation of Air Pollutant Emission Factors, AP42, Second Edition, April 1973.
7. Los Angeles Air Pollution Control District, "Study of Jet Aircraft Emissions and Air Quality in the Vicinity of the Los Angeles International Airport, April 1971.
8. Personal communication with Dick Munt, Environmental Protection Agency, Ann Arbor, Michigan.
9. George, Ralph, Julien Verssen, Robert Chass, County of Los Angeles Air Pollution Control District, "Jet Aircraft, A Growing Pollution Source," June 26, 1969.

## 8.0 MOTOR VEHICLES

Motor vehicles comprise a major source of air pollution in the Four-County Area. The pollution derives principally from three vehicle categories: light-duty vehicles (passenger cars and light trucks), heavy-duty trucks, and motorcycles. The role of these vehicle categories in atmospheric pollution, the current emission control technology being applied to them, and the alternative pollution control measures which may be applied to achieve further emission reductions, are discussed in the following sections.

### 8.1 BASELINE EMISSIONS AND EMISSION CONTROLS

TABLE 8-1. ROLE OF MOTOR VEHICLE EMISSIONS IN  
ATMOSPHERIC POLLUTION OF FOUR-COUNTY AREA

Percentage of Total Emissions in Four-County Area				
<u>Year</u>	<u>Particulates</u>	<u>SO<sub>2</sub></u>	<u>NO<sub>x</sub></u>	<u>Reactive Hydrocarbons</u>
1972	49	13	74	89
1977	35	11	51	85
1980	34	10	46	78

The important role of the motor vehicle in atmospheric pollution in the South Coast Four-County region is illustrated clearly above. With the federal promulgation of air program implementation plans for the State of California, hydrocarbon and NO<sub>x</sub> emissions from motor vehicles are expected to decline rapidly in the next few years. While the implementation programs do not address emissions of particulates and SO<sub>2</sub> directly, both these pollutant species will be affected by the control measure targeted for hydrocarbon and NO<sub>x</sub> emission reductions. SO<sub>2</sub> emissions from light-duty vehicles will be reduced by about 7%, and light-duty vehicle and particulate emissions by 37%, by the year 1980. The measures principally responsible for these emission reductions will be non-leaded fuel utilization, in combination with the use of catalytic converter exhaust control devices. These measures are to be required under a retrofit program for all gasoline-powered, light duty motor vehicles of model years 1966 through 1974 capable of operating on unleaded gasoline having a

research octane number of 91 or lower.<sup>1</sup> These measures are also to be utilized in attaining 1975-76 motor vehicle emission standards for new light-duty vehicles. By 1980 it is estimated that 90% of all light duty vehicle VMT will be accumulated by vehicles equipped with the catalytic exhaust control device.

In addition to oxidizing catalyst retrofits, other significant mobile source control measures scheduled for implementation in the South Coast Air Basin include inspection-maintenance programs for light duty vehicles, a nitrogen oxides control retrofit, and emission standards for new motorcycles beginning in 1975. Each of these control measures contribute in part to the emission reductions expected for  $\text{NO}_x$  and hydrocarbons. However, their effect on particulate and  $\text{SO}_2$  emissions is not considered to be significant.

Hydrocarbon and  $\text{NO}_x$  exhaust emission standards have also been established for heavy-duty gasoline powered vehicles, heavy-duty diesel powered vehicles, and motorcycles.<sup>1,2</sup> The effect of the standards on vehicular emission in future years for the various vehicle types is reflected in the projected emissions summary of Figure 8-1. The rapid decrease in vehicular hydrocarbon and  $\text{NO}_x$  emissions is consistent with the objective of the promulgated air programs to reduce photochemical smog for the attainment of the ambient air standards for oxidant. This objective is not incompatible with the goal to reach the ambient standard for particulate matter. The role which vehicular emissions of  $\text{NO}_x$  and hydrocarbons assume as precursors in the formation of particulates will be effectively mitigated by the EPA strategies to reduce oxidant air pollution. However the control of emissions of primary particulates has not been the target of these air programs, and the apparent benefit from the reduction of particulate emissions indirectly resulting from this strategy actually involves a serious trade-off pollution problem. This problem concerns the increased generation of sulfates and is discussed in the following section.

Except for the minor effects of certain transportation oriented constraints which would cause slight reductions in vehicle travel, the EPA implementation plans have no provisions which address the potential management of airborne particulate matter from vehicle tire wear. Unfortunately tire wear accounts for a substantial portion of the particulate emissions caused by vehicle travel. In 1972 tire wear in the Four-County Area

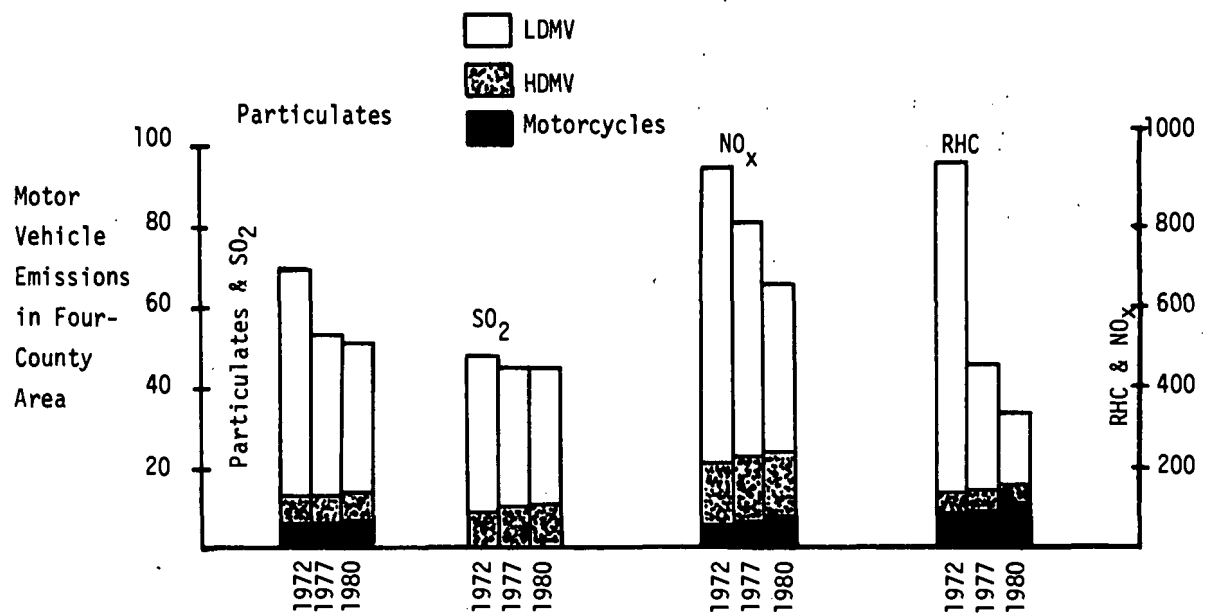


Figure 8-1. The Effect of Exhaust Emission Standards on Pollutant Emissions from Various Vehicle Categories (Note: Particulate emissions from tire wear are not included in above Figure)

produced 15.2 tons/day of airborne particulates, or about 22% of the motor vehicle particulate pollution. By 1980, tire wear will be responsible for 18.6 tons/day of particulate emissions, which amounts to 37% of the motor vehicle particulate pollution.

#### Catalytic Oxidizers

The most extensive studies addressing the effects of catalytic converters on automotive exhaust emissions have been conducted by the EPA and by ESSO Research Corporation.<sup>16</sup> These investigations employed measurement techniques for the determination of exhaust emissions which condense as sulfuric acid mist when emitted to the atmosphere. While only a trace of sulfuric acid is exhausted by conventional exhaust systems operating on leaded fuel, it was found that significant quantities of sulfuric acid aerosol are emitted from vehicles equipped with oxidation catalysts. The sulfuric acid emission rates depend on the fuel sulfur content, vehicle test procedure, and type of oxidation catalyst. Table 8-2, and 8-3, provide emission data for both a pelletized and monolithic oxidation catalyst equipped vehicle driven according to the 1975 federal test procedure, for various fuel.

It is evident that the total particulate emission rate of vehicles equipped with monolithic or pelletized oxidation catalyst increases markedly with increasing fuel sulfur content as a result of sulfuric acid production. It is also evident that, despite the alarming character change in particulate emissions, total particulates from the oxidizer devices are reduced from their former rate of .43 grams/mile.

TABLE 8-2. SULFURIC ACID EMISSIONS FROM PELLETIZED OXIDATION CATALYST EQUIPPED VEHICLE, 1975 FEDERAL TEST PROCEDURE

Catalyst	No. of Tests	Fuel Sulfur, %	Gaseous Emissions		Total Particulate, g/mi.	Sulfate g/mi.	Con- version S $\rightarrow$ SO <sub>4</sub> =
			CO, g/mi.	HC, g/mi.			
C	3	0.140	1.49	0.31	0.244 $\pm$ 0.072	0.111 $\pm$ 0.026	10.6
C	2	0.065	2.18	0.44	0.118 $\pm$ 0.037	0.036 $\pm$ 0.007	5.8
C	3	0.056	1.26	0.34	0.086 $\pm$ 0.043	0.015 $\pm$ 0.004	3.2
C	2	0.034	2.60	0.48	0.064 $\pm$ 0.031	0.011 $\pm$ 0.002	4.2
C	3	0.004	1.50	0.37	0.033 $\pm$ 0.014	0.003 $\pm$ 0.001	7.7

Source: Reference (16)

TABLE 8-3. SULFURIC ACID EMISSIONS FROM MONOLITHIC OXIDATION CATALYST EQUIPPED VEHICLES, 1972 FEDERAL TEST PROCEDURE

Catalyst	No. of Tests	Fuel Sulfur, %	Gaseous Emission		Total Particulate, g/mi.	Total SO <sub>4</sub> = g/mi.	% Con- version S $\rightarrow$ SO <sub>4</sub> =
			CO, g/mi.	HC, g/mi.			
A	5	0.067	1.37	0.39	0.290 $\pm$ 0.034	0.119 $\pm$ 0.007	21
A	4	0.032	1.83	0.36	0.184 $\pm$ 0.056	0.064 $\pm$ 0.025	24
B	3	0.004	--	--	0.033 $\pm$ 0.014	0.010 $\pm$ 0.001	29
B	2	0.067	1.32	0.12	0.208 $\pm$ 0.003	0.145 $\pm$ 0.002	25
B	2	0.032	2.47	0.32	0.183 $\pm$ 0.04	0.061 $\pm$ 0.007	23
B	2	0.004	2.44	0.16	0.040 $\pm$ 0.02	0.014 $\pm$ 0.007	40

Source: Reference (16)



The catalyst has proven an effective oxidizer of molecular organics, some of which were formerly precipitated and emitted as particulate matter in standard exhaust systems.<sup>17</sup> It has been found that about 90% of all particulate matter exhausting from oxidizer catalysts is in the form of sulfuric acid bound to water (sulfuric acid is very hygroscopic in nature). The mist particles are of the order of .2 micron or smaller depending on the humidity of the exhaust.<sup>15</sup>

The test results show that vehicles equipped with the pelletized oxidation catalyst exhibited lower sulfur to sulfuric acid conversion (Table 8-2) than did the monolithic catalyst vehicle (Table 8-3). At present no basis for the differences exhibited between monolithic and pelletized oxidation catalysts regarding sulfuric acid production is apparent. General Motors currently has planned to utilize pelletized catalyst while the remaining automobile manufacturers intend to employ the monolithic catalyst system.

Studies of condensate from catalytic converter equipped vehicles have shown large variations in the sulfate content of the condensate. Under lower temperature operation, sulfur is accumulated or stored in the catalyst, and is then released and passed through at high catalyst bed temperatures. The sulfur storage alters the chemical reactivity of the catalyst as shown in Figure 8-2 and 8-3.<sup>19</sup> The effect of the cycling of sulfur content in the catalyst on permanent deterioration of reactivity is not clear, but it is suspected it may play an important role in accelerated degradation of the catalyst.<sup>19</sup> Informal conversation with automobile manufacturers by EPA has indicated low level of confidence in catalyst durability.<sup>20</sup> Also, the question of degradation of catalysts retrofitted to in-use vehicles is indeterminate. The residual lead in conventional exhaust systems will present difficult retrofitting problems which currently have not been clearly resolved. Deterioration certification tests now in process in Detroit should provide some of the answers to these issues. It should be apparent however, that rapid deterioration will have serious impact on the control standards program. A 50% deterioration rate in new vehicles would render them equivalent to 1969-1970 emitters.<sup>21</sup>

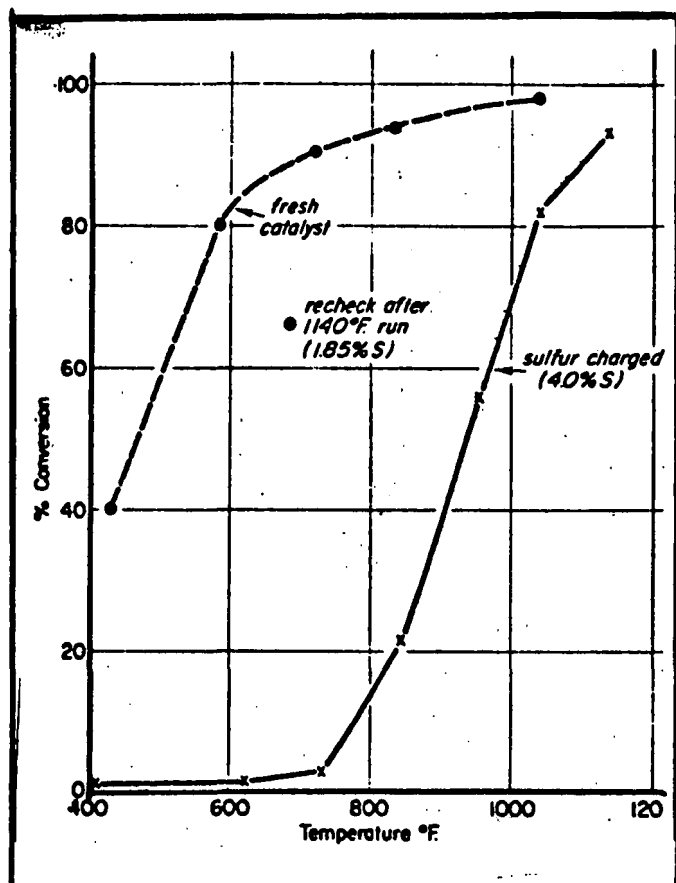


Figure 8-2. Effect of Lab Sulfur Charging on CO Reactivity of a Cu-Cr Catalyst.

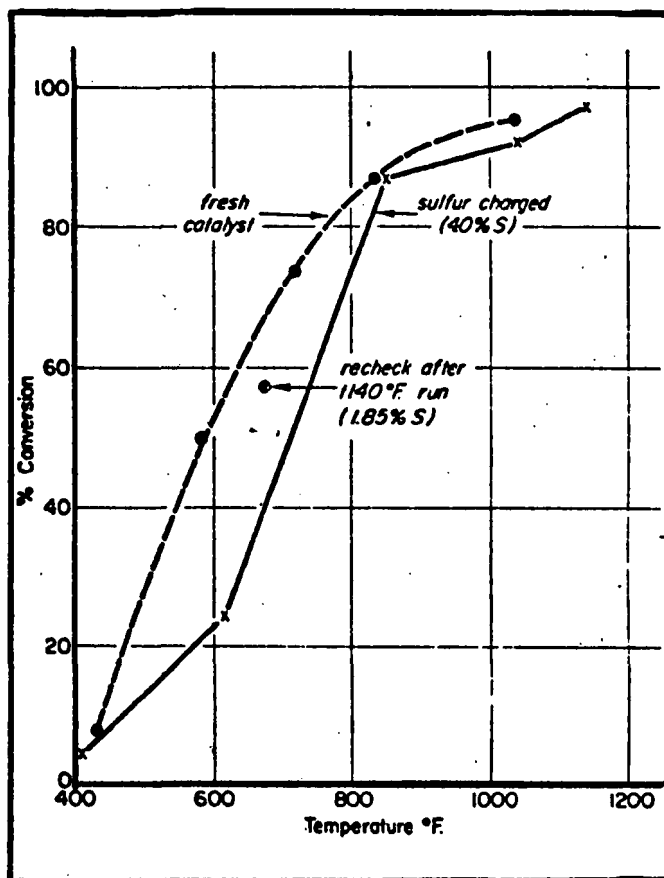


Figure 8-3. Effect of Lab-Sulfur Charging on HC Reactivity of a Cu-Cr Catalyst.

Source: Reference (19)

The degradation of the reactive effectiveness of the catalyst, and the generation of sulfuric acid pollution from vehicle exhaust systems pose serious trade-off questions as to the suitability of the catalytic converter as an exhaust emission control. The EPA is currently committed to investigating the public health consequences of vehicles operated with catalytic converters, but as yet has not withdrawn 1975 interim federal emission regulations which would necessitate catalytic devices to be installed on most new 1975 vehicles. Automobile manufacturers are currently scheduling installation of the catalytic converters in 1975 model year vehicles to meet these standards. EPA, in recent public hearings, has stated that sulfuric acid emissions will not become a serious problem until new cars with these

devices comprise a larger segment of the vehicle population. Reasonable concern over sulfuric acid emissions will be advisable, EPA recommends, in approximately two and one-half years, by which time it is presumed new technological developments will exist to resolve this problem. Of course it is apparent that this technology will be quickly overdue in the critical California Air Basins, where air quality implementation plans will insure that 65% of the light duty vehicle population be equipped with the oxidizing catalysts by 1977.

## 8.2 ALTERNATIVE CONTROL MEASURES

The problem of developing suitable emission controls for motor vehicles is compounded and confused by a great number of variables. Regulations apply for retrofits, for various types of vehicles, at different levels for certain years and for specific pollutants. Regulations and control alternatives are necessarily an outgrowth of extensive testing and research to evolve potential technology capable of attaining the proposed standards. The important options for control of motor vehicle particulate emissions are:

1. Modification of fuels
2. Particulate trap devices
3. SO<sub>2</sub> scrubbers
4. Fuel substitution
5. Tire options

### 8.2.1 Modification of Fuels

Numerous studies have demonstrated the effect of fuel composition on particulate emissions from motor vehicles. Typically it has been found that emission of particulate matter can be reduced with decreases in aeromatic, sulfur, or lead content in the fuel. The actual extent of these reductions depends on a number of variables, such as the driving test pattern, and the engine design, age, and condition.

#### 8.2.1.1 Lead Content in Fuels

Extensive testing has shown that approximately one-third of motor vehicle exhaust particulate matter is composed of lead. This lead discharge results directly from the lead content in the fuel. A characterization of particulate emissions, for leaded and unleaded fuel consumption, is shown in Table 8-4. The data show that stabilized unleaded-fuel cars emitted

about 40% less total particulates than the leaded fuel cars. Carbon represents about 70% of the total particulate matter when lead is absent in the fuel.

TABLE 8-4. SUSPENDED PARTICULATE EMISSIONS FROM MOTOR VEHICLES USING LEADED AND UNLEADED FUEL

Fuel	Federal Test Cycle	Particulates, g/mi.				
		Total	Lead	Carbon	% Lead	% Carbon
Commercial (leaded)	4 cold	.512	.085	.184	16.4	35.9
	4 hot	.240	.044	.076	18.3	31.7
	weighted	.339	.059	.115	17.4	33.9
Unleaded Commercial Premium	4 cold	.316	-	.242	-	76.5
	4 hot	.134	-	.074	-	55.2
	weighted	.197	-	.133	-	67.5

1. Weighted 35% cold and 65% hot.
2. Accumulated mileage range for vehicles on leaded fuel was 30,000 to 100,000; and for vehicles on unleaded fuel, 30,000 to 50,000 miles.

Source: Reference (4).

Current federal regulations require that gasoline manufacturers shall provide non-leaded gasoline (maximum of .05 gm/gal) for use in automobiles by the year 1975.<sup>3</sup> Federal regulations for fuel additives currently are restrictive also to automobile manufacturers and fuel retailers. These regulations insure that only unleaded gasoline shall be introduced into vehicles equipped with emission control devices which will be impaired by the use of leaded gasoline. The regulations also stipulate the automobile manufacturer shall be responsible for the visible labeling ("unleaded gas only") of catalyst equipped vehicle gas tank inlets. This rule, as well as that requiring manufacture of lead free fuels, was constructed to insure the use of fuels which would be compatible with catalyst exhaust controls which are projected for utilization in meeting the 1975 motor vehicle requirements. Hence in the next few years there will be a gradual change in the lead content of fuels on the market. Unleaded fuel will be available

in increasing amounts to be consumed primarily by those vehicles equipped with catalytic oxidizers, and leaded fuels will be available in smaller volumes for use in the remaining vehicles. This trend will be particularly marked in the South Coast Air Basin, where the law calls for a catalytic oxidizer retrofit for all light duty vehicles of model year 1966 to 1974.

An important question in the large scale production of unleaded fuels is the effect this modification will have on the overall fuel composition, and consequently, on particulate emissions. (The techniques for producing the small proportion of unleaded fuels now on the market could be very different from a large volume production. Hence the unleaded fuels of tomorrow could be very different in composition from those used for exhaust emission tests today.) Lead addition to fuel is currently the most economic path to achieving higher octane numbers. If lead were to be removed from motor fuels, equivalent octane numbers would have to be provided by higher concentrations of more expensive blending components. Depending on the process utilized to achieve the octane rating, particulate emissions from vehicles may or may not be increased.

After lead addition, the next most economic way to raise the octane number of motor fuel is by increasing aromatics content. To upgrade an existing "clean" regular motor fuel to its typical octane rating by addition of aromatics rather than lead, the aromatic content will typically be raised from 35% to 50%.<sup>7,9</sup> The effect of aromatics content in unleaded gasoline on particulate exhaust emissions has been studied in several independent investigations. According to typical findings<sup>4</sup> there would be an increase in automobile particulate emissions of approximately 30% associated with the projected 35 to 50% aromatics increase.

The impact of removing lead from motor fuels to overall fuel composition is lessened somewhat by the timely policy of automobile manufacturers to design 1971 and later model year cars to operate with 90-91 octane fuel. Previously the automobile companies manufactured engines with higher octane requirements, as reflected by leaded regular gasolines of 94-95 octane number which are produced to accommodate these engines. As the 1971 and

later model year automobiles began to comprise the majority of the car population, there will be a corresponding shift to lower octane motor fuel production by the refineries. This trend (toward lower octane motor fuels) will minimize the production shifts required to manufacture non-leaded motor fuels, and suggests that fuel composition may not change radically.

Figure 8-4 demonstrates the dependence of fuel octane number on lead content for typical gasolines. If all the components used in both premium and regular were mixed together in equal amounts, the "pool" octane number, with zero lead, would be about 89.<sup>8</sup> Thus the present average lead free pool gasoline will come close to satisfying the octane requirement for all production vehicles manufactured in the year 1971 and after, as well as those vehicles prior to 1971 able to operate on an ONR of 91. This observation, plus numerous other studies of the economics of lead removal,<sup>9,10,11</sup> has permitted the conclusion that a universally lead-free motor gasoline supply can be attained by 1977 without major dislocations in the petroleum refining industry, and without major changes in fuel composition.

#### Impact of Removing Lead on Motor Vehicle Emissions

The removal of lead to .05 grams/gal in all motor vehicle fuels by 1977 will affect particulate emission rates from all motor vehicle categories. Since a substantial portion of the motor vehicle population is soon scheduled to be equipped with the catalytic exhaust control devices (65% of the light duty vehicles by 1977 and 90% by 1980)<sup>6</sup>, it is evident that lead particulate emissions from this vehicle segment will be virtually eliminated in the near future. In addition, further particulate reductions will be affected by the behavior of the catalyst device itself. These particulate reductions have been accounted for in the tabulation of baseline mobile source emissions under the EPA implementation plan (Figure 8-1). Aside from the vehicles targeted for catalytic oxidizer installations, there will remain a significant portion of vehicles in 1977, and even 1980, which could potentially operate on leaded fuels. The impact of operating this vehicle segment on non-leaded fuels in terms of particulate emission reductions is shown in Table 8-5. The data show that total lead removal in fuels by 1977 will accomplish reductions of 28% of the motor vehicle exhaust particulate emissions in 1977, and 21% in 1980. This is based on

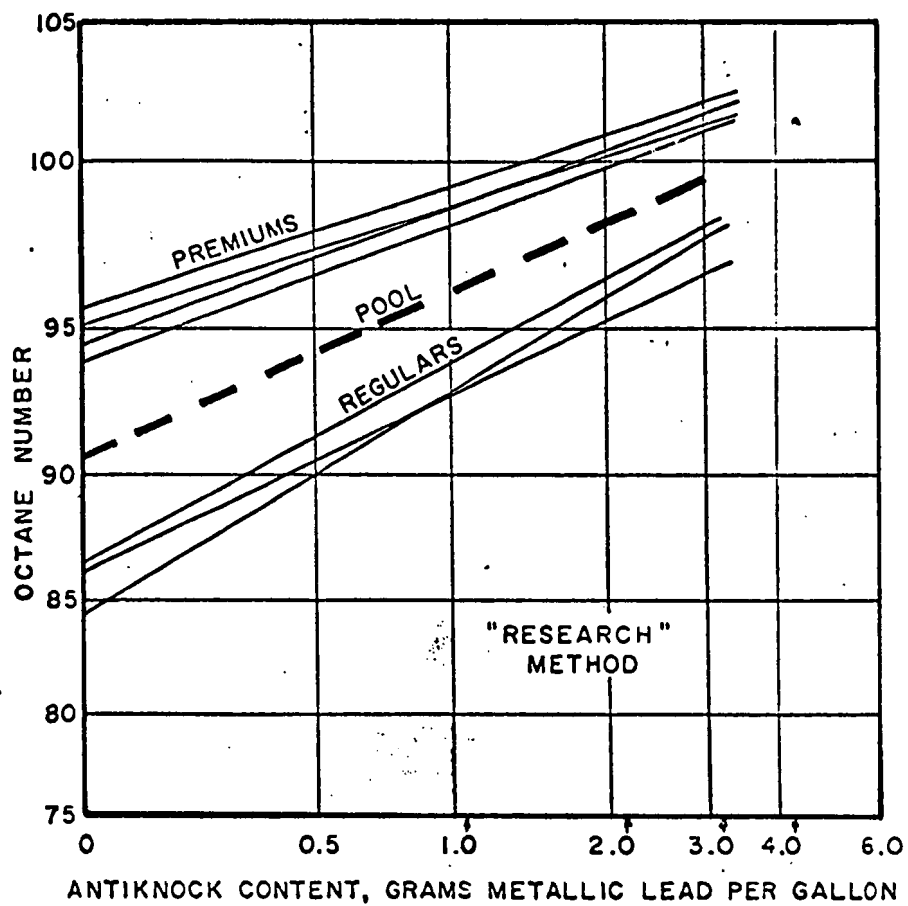


Figure 8-4. Typical "Blending" Properties of Southern California Motor Gasoline

Source: Reference (10).

TABLE 8-5. THE EFFECT OF LEAD REMOVAL IN MOTOR FUELS ON MOTOR VEHICLE PARTICULATE EXHAUST EMISSIONS IN FOUR-COUNTY AREA

Motor Vehicle Category	Projected Baseline Particulate Emissions Tons/Day		Particulate Emissions Reductions <sup>a</sup> Tons/Day	
	1977	1980	1977	1980
Light duty	40.4	35.8	4.4	1.4
Heavy duty	6.6	7.1	2.6	2.8
Motorcycles and other miscellaneous vehicles	7.0	7.7	2.8	3.1

<sup>a</sup>Emission reductions are based on 40% decrease attributable to all vehicles not equipped with catalytic oxidizers when operating on unleaded fuel. It was assumed that aeromatic content of fuel was essentially unchanged. The portion of light duty vehicle VMT for those vehicles equipped with catalytic oxidizer exhaust control was taken as 73% in 1977, and 90% in 1980.<sup>6</sup>

the supported assumption<sup>11</sup> that aeromatic content will not increase appreciably in the unleaded transition.

#### Cost of Unleaded Fuels

Many estimates have been made of the cost to remove lead. Costs for the immediate removal of all lead from gasoline while maintaining present octane levels have been estimated from 2 to 10 billion dollars, or a cost increase of 1 to 6 cents per gallon to the consumer. However because of lower octane requirements of the newer vehicles, additional investments in refineries and marketing equipment can be kept far below this estimate.<sup>9</sup> The cost of providing unleaded fuel in the total motor vehicle gasoline pool over the next 2 to 3 years would amount to approximately one tenth of a cent per gallon of gas.<sup>9</sup>

The cost of producing unleaded fuels depends heavily on restrictions limiting the aeromatic content. If aeromatic content can be varied to produce desired octane ratings in the unleaded fuels, costs would be minimal. Moreover, since lower octane fuels will be permissable in future motor fuels, unleaded fuels will not require substantial increases in aeromatic content.



It is significant to the economics of unleaded fuel that vehicle exhaust from a catalytic muffler shows little sensitivity to aeromatic fuel content. Particulate emissions from the catalytic oxidizers are typically composed of almost 100% sulfates and water, with very minor traces of carbonaceous particles present. Increased aeromatics are expected to affect gaseous hydrocarbon emissions significantly, since organics are essentially eliminated by the purposeful behavior of the oxidizing catalyst. These observations would suggest an arrangement of the vehicle gasoline pool in which higher content aeromatics would be used to obtain octane levels for vehicles equipped with catalytic mufflers, while low content aeromatic fuel would be provided for vehicles operating without the catalytic exhaust device. This motor fuel configuration might provide a more economic path to octane attainment, by permitting a higher overall aeromatic composition in the motor gasoline pool.

Another significant consideration in unleaded fuel economics are the tradeoff benefits due to vehicle maintenance savings. These savings are due principally to longer spark plug life, less oil contamination, and greater exhaust system life.<sup>9,10</sup>

Considering the above observations, it is apparent that the cost of the control option, complete removal of lead in fuels, can be implemented at less than the published estimates of .1¢ per gallon of gas (derived from Reference (9)). However, even at .1¢ per gallon, the cost of the fuel control option is relatively low.

TABLE 8-6. COST OF REMOVING ALL LEAD FROM MOTOR VEHICLE FUEL POOL (AS OPPOSED TO THE EPA PLAN REQUIRING PARTIAL REMOVAL BY 1977)

Year	Total Annual Cost Millions	Cost Per Ton of Particulates Removed
1977	1.7 <sup>a</sup>	\$475
1980	1.5 <sup>b</sup>	562

<sup>a</sup>Based on total VMT for Four-County Area of  $168 \times 10^6$  miles/day;<sup>6</sup> ave. vehicle gas mileage rate of 12.4 mi/gal;<sup>(13)</sup> increased cost of unleaded fuel .1¢/gal; and percentage of VMT by vehicles non-equipped with catalytic converter = 27%.<sup>(6)</sup>  
<sup>b</sup>Calculated same as (a) above except: VMT for 1980 =  $180 \times 10^6$  miles/day and percentage of VMT by vehicles without catalytic mufflers = 10%.<sup>(6)</sup>

#### 8.2.1.2 Other Gasoline Additives

Fuel additives are utilized to 1) maintain carburetor and engine cleanliness, 2) remove lead deposits, 3) inhibit corrosion and gum formation.

Additives used to maintain engines in clean condition have also been shown to cause some reductions in exhaust emissions.<sup>14</sup> Reduced emissions are most pronounced for older vehicles with very dirty engines. The most dramatic effects are obtained when fuel additives consumed by the vehicle are suddenly changed. The new cleaning action of the additive removes old deposits which were stable when contacted by the previous fuel composition. Hence short term increases in particulate emissions may be observed in this laboratory testing situation, however, with continued use of the additive, particulate emissions are seen to return to prior levels.

Most often additives have been utilized to modify deposits of lead in the engine. These additives consist of halogen scavengers, such as chlorine and bromine compounds. They react with lead to form lead bromide or lead chloride salts which emit as particulates in the exhaust. Use of these additives is especially effective for the scavenging of lead deposits on spark plugs, resulting in the prevention of spark plug misfire.

Additives are typically used in concentrations less than 100 ppm; and therefore can contribute only a few parts per million to the exhaust emissions. Moreover, the great majority of the carbon, hydrogen, nitrogen, and oxygen compounds of additives are burned with the fuel. Hence the direct effect of additives in exhaust emissions is minimal.

#### 8.2.1.3 Sulfur Content in Fuels

Emissions of sulfur compounds from motor vehicles have received little concern in the past. Most of the sulfur content in gasoline is removed in the refining process because of its interference with the effectiveness of lead additives. When sulfur is burned in the engine, the resulting emissions are predominantly  $\text{SO}_2$  in relatively minimal concentrations, accounting for about 13% of all  $\text{SO}_2$  found in the atmosphere of the Four-County Area.

New attention is now being drawn to the role of sulfur in motor vehicle emissions. Studies<sup>15,16</sup> have shown that vehicles equipped with oxidation

catalysts convert a substantial portion of the sulfur in the gasoline to sulfuric acid particles. In addition it has been discovered that particulate matter exhausting from an oxidation catalyst is effectively all sulfuric acid together with water droplets. Carbonaceous particulates and lead compounds which previously characterized exhausts from standard vehicles operating on leaded fuels, are no longer emitted when oxidation catalysts are employed. This changing character of exhaust emissions raises serious questions regarding the benefit of oxidation catalysts. The emission of sulfuric acid vapors directly into the atmosphere as high concentration sources near transportation corridors poses an important new health problem.

An obvious means of preventing emissions of sulfuric acid from catalytic oxidizer equipped vehicles, or  $\text{SO}_2$  from all vehicles, is to remove the sulfur from the fuel. The technology for drastic sulfur reduction of automotive gasoline is available (Section 3.2.1). Various oil companies claim proprietary technology which will reduce sulfur content to less than 100 ppm. Desulfurization to very low sulfur levels has been commercially practiced in pilot facilities, but because of limited applications for the very low sulfur fuels, the technology has not been employed extensively. Additional process equipment would be required to attain the degree of sulfur control sought.

#### Impact of Fuel Sulfur Removal

The impact of automotive fuel desulfurization to levels below 200 ppm on motor vehicle emissions is shown in Table 8-7. Desulfurization of the entire spectrum of vehicle motor fuels to less than 100 ppm sulfur content would result in particulate emission reductions of about 87% for vehicles equipped with the catalytic mufflers (Table 8-2 and 8-3). Sulfuric acid emitted from these vehicles would be reduced by about 99%. Prevention of  $\text{SO}_2$  emissions would vary from 25 to 60% depending on the vehicle category and the type of fuel.

The control option of fuel desulfurization to 100 ppm will prevent about 77% of all  $\text{SO}_2$  motor vehicle exhaust emissions projected for 1977. This would lower the total  $\text{SO}_2$  emission inventory for motor vehicle exhaust to 10.6 tons/day in 1977, as compared to 58.9 tons per day in the

TABLE 8-7. THE EFFECT OF AUTOMOTIVE FUEL DESULFURIZATION  
(100 ppm) ON MOTOR VEHICLE EMISSIONS IN FOUR  
COUNTY AREA

Motor Vehicle Category	Projected Baseline Emissions Tons/Day		Emissions Reductions Tons/Day	
	1977	1980	1977	1980
PARTICULATES				
Light duty	40.4	35.8	15.5	19.8
<u>SULFUR DIOXIDE</u>				
Light duty				
with catalyst	18.2	22.5	10.8	13.4
without catalyst	17.4	13.2	14.8	11.2
Heavy duty				
diesel	9.7	10.4	9.2	9.9
gasoline	.8	.9	.7	.8
Motorcycles & miscellaneous	-	-	-	-
TOTAL (SO <sub>2</sub> )	46.1	47.0	35.5	35.3
<p>1. The portion of light duty VMT for vehicles equipped with catalytic mufflers was taken as 73% in 1977, and 90% in 1980.<sup>6</sup></p> <p>2. SO<sub>2</sub> reductions are based on 85% reduction in gasoline sulfur content, and 95% in diesel fuel. For light duty vehicles equipped with catalytic mufflers it was assumed that 30% of the fuel sulfur is converted to sulfate (sulfuric acid) and the remainder is emitted as SO<sub>2</sub>.</p>				

1972 baseyear. As a control for particulate, drastic desulfurization is not as effective, accounting for a 40% reduction in motor vehicle exhaust particulates in 1977. Total particulate exhaust emissions would be 38.5 tons per day from motor vehicle sources in 1977, compared to 70.2 tons/day in the 1972 baseyear.

## Cost of Desulfurization

Desulfurization of automotive gasolines can be accomplished with facilities similar to those now employed to desulfurize low sulfur fuel blend stocks for fuel oil supply to electric utilities companies. However, in most installations, the operating severity of the equipment cannot be sufficiently increased for sulfur contents less than about .05%, hence it is necessary to construct new facilities for more complete desulfurization. In one process which has proven effective for essentially complete desulfurization, the Chevron Isomax, a wide range of distillates, from diesel up to 1100°F end point vacuum gas oil, are economically processed to sulfur contents less than 100 ppm. (As discussed in Section 3.2.1, the Isomax equipment can also be used to desulfurize the cracker unit feed stock, resulting in an effective control for SO<sub>2</sub> emissions from the cracker catalyst regenerator unit.) Several oil companies are now licensed to use the Isomax process. Because of its relatively widespread recognition in the literature, it has been considered here as candidate equipment for implementing desulfurization control.

The economics of motor vehicle emission control via the desulfurization route is portrayed in Table 8-8. The measure of desulfurization is about twice as cost effective as a control for SO<sub>2</sub> emissions than for particulate emissions. Taken as a joint control for emissions of particulates and SO<sub>2</sub>

TABLE 8-8. COST OF DESULFURIZATION OF VEHICLE FUELS  
FOR CONTROL OF EXHAUST EMISSIONS

Equipment	Capital Cost	Annual Opera- tion Cost Increase in Millions of	Total Annuali- zed Cost Dollars	Cost Per Ton of Emission Prevented			
				Particulates 1977	1980	SO <sub>2</sub> 1977	1980
Desulfurization facilities (8 VGO high severity Iso-max units of avg. capacity, 40,000 barrels/day)	80 <sup>b</sup>	13.8 <sup>c</sup>	21.8 <sup>d</sup>	\$3870	\$3100	\$1680	\$1690

<sup>a</sup>Based on daily fuel requirement for Four County Area of 320,000 barrels/day in 1977, and 345,000 barrels/day in 1980, as calculated from projected VMT and vehicle gasoline mileage averages.  
<sup>b</sup>Capital costs based on Reference (23) and Reference (24).  
<sup>c</sup>Operating cost based on cost of similar desulfurization facilities (Ref.22).  
<sup>d</sup>Based on 30 year equipment life @ 10%.

combined, the cost effectiveness is equivalent to \$1170/ton of SO<sub>2</sub> and particulate removed in 1977, and \$1085 per unit in 1980. Moreover it is also evident that desulfurization facilities utilized in an effort to prevent motor vehicle emissions are also integral to control efforts to prevent emissions from combustion equipment and refinery process equipment operational in the Four County Area. The various desulfurization schemes which have been examined as candidate emission control measures for a given targeted process (combustion, motor vehicles, refineries, aircraft) in this study, cannot be viewed as mutually exclusive measures. There is substantial overlap in the equipment requirements for the various desulfurization options identified in this study, and therefore the cost effectiveness of any of these measures analyzed independently of its side benefits does not provide a true credit of effectiveness. A synthesis of the individual desulfurization schemes and an analysis of their combined effectiveness, is presented in the Summary of this study.

### 8.2.2 Particulate Trap Devices

Evaluation of devices under development for removing particulate matter from vehicle exhaust is particularly difficult because measurement techniques have not been standardized. Hence the effectiveness of an exhaust particulate trap would depend substantially on the method used to measure it. This is exemplified by tests of the California Air Resources Board,<sup>25</sup> in which measurements of exhausts from vehicles equipped with catalytic converters indicated particulate emission rates of less than .02 gm/mile, about 10 times less than measured by other researchers studying similar exhaust emissions. The tests by the Air Resources Board did not permit the evaluation of the vapor constituent in the exhaust which normally precipitates into mist as it is discharged to ambient air. For vehicles equipped with catalytic converters, the vapor mist is the most significant particulate matter arising from the exhaust stream, being composed almost entirely of sulfuric acid and water. Because of the elevated temperatures of the exhaust stream, and the relatively small size of the sulfuric acid mist (.2 micron or smaller) when it condenses, the removal of particulate matter from the gas stream of vehicles equipped with oxidizing catalysts represents a very difficult task.

Several systems for removing particulate matter from exhaust gases have been under evaluation. These devices have typically been designed to manage particulate matter from vehicles with standard exhaust systems (without the oxidizing catalyst), principally as a trap for lead particulate. None of the systems tested to date have clearly demonstrated an effectiveness which would allow use of leaded gasoline with catalytic converters. The most extensive testing and development of particulate traps has been performed by Ethyl Corporation. The results of these efforts have provided particulate trapping systems which are effective as retrofit emission controls for incomplete control for lead emissions when employed in new vehicles.

Most of the proposed particulate traps consist of an agglomerator, an inertial separator, and a filter. The agglomerator unit is generally composed of beads or mesh, and provides a surface for mechanically agglomerating the particles into larger sizes. The inertial separator is generally a

cyclone or combination of cyclones used to spin out the particles at high velocity into a reservoir. A filter is often employed at the exit of the trapping unit to remove smaller particles remaining in the gas stream when exiting from the cyclone.

Preliminary data of commercial prototype retrofit units developed by Ethyl Corporation have shown that total particulate emissions in standard exhaust systems may be reduced by 70% with traps consisting of agglomeration and inertial reactions. Lead is reduced by more than 90%.<sup>4,26</sup> More sophisticated traps now being developed by Ethyl have shown ability to remove nearly all (95%) lead and particulate emissions in the standard exhaust system.<sup>27</sup> These higher efficiency systems are not engineered as retrofit units and have limited adaptability to in-use vehicles. They are intended for adaption to new vehicle designs whenever the vehicle is equipped with a conventional exhaust system. Since the traps are essentially mechanical collectors by nature, they are therefore ineffective as a control for vapors of sulfuric acid. Particulate traps for sulfuric acid vapors have been developed to a limited extent. The technology on sulfuric acid removal is discussed in the next section ( $\text{SO}_2$  Scrubbers).

There is currently substantial indication that very effective particulate trapping systems can be engineered and adapted to control exhaust emissions from both in-use and new motor vehicles which utilize standard exhaust systems. This indication is based on the apparent effectiveness of preliminary particulate trapping devices which have been constructed with limited budgets and within a very limited segment of the industry. A more substantial effort, supported by more certainty of the market for the trapping devices, would undoubtedly produce significant gains in effectiveness and costs over the existing control devices. It appears feasible that production of these units could be accomplished by 1977.

#### Impact of Particulate Traps on Motor Vehicle Emissions

The preventions of particulate emissions when motor vehicles are equipped with particulate traps is shown in Table 8-9. While particulate traps are not applicable to a major segment of the vehicle population (65% of light duty vehicles in 1977 and 90% in 1980), their installation on the remaining vehicle population can effect a 46% particulate emission prevention in 1977, and 35% in 1980.



TABLE 8-9. IMPACT OF PARTICULATE TRAPS ON PARTICULATE EMISSIONS FROM MOTOR VEHICLES IN FOUR-COUNTY AREA

Motor Vehicle Category	Projected Baseline Particulate Emissions		Prevention of Particulate Emissions	
	Tons/Day		Tons/Day	
	1977	1980	1977	1980
Light duty <sup>a</sup>				
with catalyst	20.2	25.8	0	0
without catalyst	20.2	10.0	16.2	8.0
Heavy duty	6.6	7.1	5.3	5.7
Motorcycles and miscellaneous	7.0	7.7	3.5 <sup>b</sup>	3.9 <sup>b</sup>
TOTAL	54.0	50.6	25.0	17.6

Notes:

1. It was assumed that vehicles non-equipped with catalysts would utilize leaded fuels, and that leaded fuels would be available through 1980.
2. Trap devices were assumed to be 80% efficient.

<sup>a</sup>Baseline light duty particulate emissions were segregated into catalyst and non-catalyst vehicles using emission factors from Reference (18) as applied in TRW Report #2.

<sup>b</sup>It was assumed that design of existing traps could be modified for retrofit adaption to motorcycles. To weight the portion of emissions in this category which are unlikely retrofit possibilities (such as lawn-mowers, tractors, earth moving equipment) by the year 1980, a 50% control efficiency was assumed.

Cost of Particulate Traps

Due to the very limited operating data available the economics of particulate traps are not well defined. Ethyl estimates they would be able to provide a trap with about 80% collection efficiency for the light duty vehicle at a cost of \$14.<sup>26</sup> The device would be incorporated into a muffler, and would be rated for a lifetime of 36,000 miles, with no periodic maintenance required. This amounts to a cost of approximately .03¢ per mile per vehicle. Table 8-10 summarizes the overall economics of an implementation measure to equip the Four-County Area with motor vehicle particulate traps.

TABLE 8-10. COST OF IMPLEMENTING PARTICULATE EMISSION CONTROL FROM MOTOR VEHICLES WITH PARTICULATE TRAPS, FOUR-COUNTY AREA

Year	Motor Vehicle Category	Initial Purchase & Installation Cost	Operating Cost	Annualized Cost	Cost per Ton of Particulate Emissions Prevented
Millions of Dollars					
1977	Light Duty (without catalyst)	23	-	9.3	\$1560
	Heavy Duty	.8	-	.3	160
	Motorcycles	4.7	-	1.9	1470
1980	Light Duty	9.0	-	3.7	2000
	Heavy Duty	.8	-	.3	150
	Motorcycles	5.0	-	2.0	1430

Notes:

1. It was assumed that motorcycles and heavy duty vehicles could be retrofitted.
2. The cost of retrofitting heavy duty vehicles and motorcycles was assumed to parallel the relative scale for typical muffler costs of each of the vehicle categories. The number of vehicles for retrofit in each category was determined from VMT of Reference (6) and average yearly mileage data.<sup>30</sup>

It is evident that particulate traps are competitive with fuel desulfurization as a method of particulate emission control, however the value of the character of particulate matter removed by the mechanical traps may not be of equal importance to the prevention of sulfuric acid emissions obtained with fuel desulfurization. In addition, the particulate traps will have decreasing effect as a control in the years ahead, as the proportion of vehicles with standard exhaust systems diminishes in favor of those equipped with the catalytic oxidizer.

The particulate trap control option appears to be most cost effective when applied to heavy duty vehicles, requiring \$160 for each ton of particulates collected. This advantage is due to the larger emissions

available for collection by the trap from the large volumes of exhaust emitted from heavy duty vehicles, particularly diesels.

### 8.2.3 SO<sub>2</sub> Scrubbers

Because the important discovery of the interaction of sulfur and oxidizing catalysts is relatively recent, and because of the uncertainty associated with the implementation of the catalytic control device, limited effort has been directed toward development of auxiliary hardware to circumvent the problem that sulfur poses for the catalytic controls. Perhaps the most promising equipment which has been developed to be responsive to the sulfur-catalyst problem is the molten carbonate scrubber-mufflers by Atomics International. Designed principally to remove lead vapors in the heated portion of the exhaust upstream of the catalytic converter, road tests have shown the scrubber also removes essentially all the sulfur oxides in the exhaust.<sup>28</sup> The unit operates on the basis that lead and sulfur compounds in vehicle exhaust are acidic and will react chemically with alkaline molten carbonate. In these reactions, lead vapor is converted to solid lead carbonates and oxides, and sulfur dioxide is reacted to metal sulfates.

The scrubber-muffler device is installed under the engine hood of the vehicle to utilize maximum heat from the engine exhaust. The exhaust heat reaches the 750°F melting point of the molten carbonate mixture rapidly. Figure 8-5 illustrates the design of the scrubber-muffler unit. The molten mixture is aspirated out the venturi suction tube into the gas stream to facilitate rapid acid-base reactions. The resulting carbonates and sulfates are retained by absorption on the mesh. Particulates are wetted and retained in the carbonate mixture. Test data<sup>29</sup> show the collection efficiency for particulates in the scrubber is about 90%, making the device both an effective particulate and SO<sub>2</sub> control for vehicles not equipped with the catalytic converter.

### Impact of SO<sub>2</sub> Scrubber on Motor Vehicle Emissions

The preventions of SO<sub>2</sub> and particulate emissions when motor vehicles are equipped with the Atomics International scrubber-muffler system are shown in Table 8-11. Because of the very effective control of SO<sub>2</sub> and particulates claimed by Atomics International, the overall emission control

TABLE 8-11. IMPACT OF SCRUBBER ON SO<sub>2</sub> AND PARTICULATE EMISSIONS FROM MOTOR VEHICLES IN FOUR COUNTY AREA

Motor Vehicle Category	Projected Baseline Emissions Tons/Day		Emission Preventions Tons/Day	
	1977	1980	1977	1980
PARTICULATES				
Light Duty				
with catalyst	20.2	25.8	18.1	23.2
without catalyst	20.2	10.0	17.2	8.5
Heavy Duty	6.6	7.1	5.6	6.0
Motorcycles and miscellaneous	7.0	7.7	5.9	6.6
TOTAL	54.0	50.6	46.8	44.3
SULFUR DIOXIDE				
Light Duty	35.6	35.7	33.8	33.9
Heavy Duty	10.5	11.3	10.0	10.7
Motorcycles and miscellaneous	-	-	-	-
TOTAL	46.1	47.0	43.8	44.6

Notes:

1. The scrubber was assumed to have an efficiency of 95% for SO<sub>2</sub> removal and 85% for particulate collection.
2. Since the scrubber removes SO<sub>2</sub> upstream of the catalytic oxidizer, conversions of SO<sub>2</sub> to sulfuric acid particulates does not occur. Particulates of other types are also removed by the scrubber. Hence it is assumed that particulate emissions from vehicles with the catalytic oxidizer will be controlled to 90% efficiency.
3. It was assumed that the scrubber-muffler unit could be adapted for retrofit on motorcycles and heavy duty vehicles.<sup>31</sup>

impact on the motor vehicle population is impressive. Serious reservation should probably be maintained relative to this preliminary analyses until further testing can be accomplished to confirm the very encouraging preliminary data.

### Economics of Scrubber-Muffler System

The cost to the consumer for the scrubber and muffler device has been estimated at \$35 for a factory installed device to \$45 for retrofit units. This compares to a typical muffler purchase and installation cost of approximately \$22.

Maintenance of the scrubber device consists of replacing the salt solution every 15,000 to 20,000 miles at a cost of \$10.<sup>28</sup> The life of the dual function scrubber and muffler is estimated at 50,000 miles.

The economics of implementing the installation of scrubber devices on the motor vehicle population as a pollution control measure is summarized in Table 8-12. It has been assumed that the scrubber can be engineered for adaptability to the motorcycle and the heavy duty vehicle without difficulty by the year 1977.<sup>31</sup> In the absence of any manufacturing cost estimates for these adapted retrofits, it was assumed their cost would parallel the relative scale of typical muffler costs for the given vehicle categories.

TABLE 8-12. COST OF EQUIPPING VEHICLE POPULATION WITH SCRUBBER DEVICE FOR CONTROL OF SO<sub>2</sub> AND PARTICULATE EMISSIONS, FOUR-COUNTY AREA, 1977

Motor Vehicle Category	Initial Purchase and Installation Cost	Annual Operation Cost	Annualized Cost	Cost Per Ton of Combined SO <sub>2</sub> and Particulate Emissions Prevented
Millions of Dollars				
Light Duty	138	39.7	76.0	\$3020
Heavy Duty	1.2	.6	1.3	231
Motorcycles & Miscellaneous	7.7	.6	1.8	835
TOTALS	146.9	40.9	79.1	\$2380

Notes:

1. Annual operation cost based on \$10/15,000 mi, and average annual vehicle mileage as follows: Light duty, 10,000; heavy duty, 25,000; Motorcycles, 4,000.
2. Capital costs annualized at 50,000 miles lifetime at 10% interest.

Because the unit has nearly equal effectiveness either as a particulate trap or for  $\text{SO}_2$  removal, it is applicable as an emission control for all the motor vehicle categories, whether they are equipped with catalytic oxidizers or not. Clearly the device is more cost effective for those vehicles not equipped with the device since more emissions would be prevented from these sources for an equivalent cost. The scrubber would be most cost effective for heavy duty vehicles from which the greatest potential of emission preventions exists.

#### 8.2.4 Fuel Substitution

Conversion to alternative fuels for use in motor vehicles is a control option which affects preventions of particulates,  $\text{SO}_2$ , hydrocarbons, and  $\text{NO}_x$  simultaneously. As discussed in Section 3.2.3, methyl-fuel is probably the most desirable of the fuel substitution alternatives. It can be used as an additive to current fuel stocks without special adaption, or can be used as a total motor fuel substitute with engine adaption. In either application, the resulting emission preventions are significant.

Existing engines can be converted to use methyl-fuel by decreasing the ratio of air to fuel consumed from 14 for gasoline to 6 for the methyl-fuel. In addition, exhaust recycling is required to deliver more heat to the carburetor. The impact of this conversion on vehicle exhaust emissions is illustrated by the test results shown in Table 8-13. Considerable research has demonstrated vehicle operation with the cleaner burning methyl-fuel produces substantial emission reductions. Studies have also shown that methyl-fuel may be handled with existing facilities, and can be used without requiring major hardware developments. It was also evident that greater performance and emission control can be accomplished from an engine designed specifically for methanol.<sup>32</sup>

Due to the relatively limited development performed to promote gasoline conversion to methyl-fuel, there are many uncertainties regarding its utility as a complete fuel substitute. A preliminary estimate for the cost of retrofitting in-use vehicles for the methyl-fuel conversion is \$100. At this cost, the methyl-fuel alternative is competitive with the catalytic oxidizer retrofit, given that methyl fuel itself is competitive costwise with gasoline (which it currently is). Because of the apparent

TABLE 8-13. EMISSIONS FROM A 1972 GREMLIN CONVERTED FOR METHANOL CONSUMPTION

<u>Fuel</u>	<u>Hydrocarbons</u>	<u>CO</u> gm/mile	<u>NO<sub>x</sub></u>
Gasoline	2.20	32.5	3.2
Methanol	.32	3.9	.35
1976 Federal Standards	.41	3.4	.40

The Gremlin was modified for use with methanol-fuel and equipped with a catalytic converter.

Source: Reference (5)

economic feasibility of this fuel conversion for motor vehicles, and the air quality benefits associated with the conversion, intensified investigations should be organized to ascertain the real near term and far term potential role of methanol as a motor vehicle fuel.

#### 8.2.5 Tire Options

A substantial portion of the particulate matter generated by motor vehicles may be attributed to tire wear. By 1980, it is estimated that tire wear will be responsible for 37% of all motor vehicle particulate pollution. Yet only minor efforts have been invested to characterize these emissions, and limited research has been performed to develop potential controls for their reduction.

It has been suggested that replacement of standard bias-ply tires with radial tires would result in significant reductions in airborne tire matter. Radial tires constructed of fabric, steel, and fiberglass have demonstrated total tire wear (pounds of tire matter per mile) one-half the rate of standard bias-ply tires.<sup>33</sup> It should be noted, however, that the production rate of airborne tire matter is dependent on the rate at which suspendable particles of the tire materials are generated. It has been estimated that, under average conditions, 5 to 10% of all tire wear becomes airborne as suspended matter,<sup>34</sup> and that the remainder exists in the form of non-suspended particles deposited near the road. It is not clear whether a motor vehicle

population equipped with radial tires would emit the same fraction (5-10%) of its worn tire matter as suspendable particles. It is conceivable that the distribution of tire particles arising from wear of radial tires is in significant contrast to that characterizing the wear of the typical motor vehicle tire. Until additional research is performed to characterize the particulate matter arising from various types of motor vehicle tires operating under representative vehicle travel conditions, it will not be clear if atmospheric levels of airborne tire matter may be controlled by implementation of vehicle tire options.



## REFERENCES FOR SECTION 8.0

1. Environmental Protection Agency, "Air Programs; Approval and Promulgation of Implementation Plans," California Transportation Control Plan, Federal Register, December 12, 1973.
2. Personal communication with State of California Air Resources Board, Sacramento, California.
3. Environmental Protection Agency, "Regulations on Fuels and Fuel Additive," Environmental Reporter 121:0801, 1973.
4. G. Haas, D. Lenane, M. Brandt, Ethyl Corporation, "Composition, Size and Control of Automotive Exhaust Particulates," Journal of the Air Pollution Control Association, January, 1972.
5. G. Adelman, D. G. Andrews, "Exhaust Emissions from a Methanol-Fueled Automobile," Society of Automotive Engineers, paper 720693, August, 1972.
6. TRW Transportation and Environmental Operations, "The Development of a Particulate Implementation Plan for the Los Angeles Region," Report #2, Emission Inventories and Projections, prepared for the Environmental Protection Agency, June 1974.
7. Personal communication with Chevron Research Company, San Francisco, California.
8. Personal communication with Atlantic Richfield Corporation, Los Angeles, California.
9. United States Department of Commerce, "Automotive Fuels and Air Pollution," A Report of the Panel on Automotive Fuels and Air Pollution, March 1971.
10. Technical Advisory Committee to the California State Air Resources Board, "A Rational Program for Control of Lead in Motor Gasoline, March, 1970.
11. Sorem, S.S., "Automotive Fuels and Air Pollution," statement by Shell Oil Company to the Arizona Board of Health, November 20, 1970.
12. Derived from Reference (9).
13. Department of California Highway Patrol, "California Traffic Accident Summaries, 1972.
14. Kipp, H. L., Ingamells, J. C., "Ability of Gasoline Additives to Clean Engines and Reduce Exhaust Emissions," Society of Automotive Engineers Report 700456, Mid-year Meeting, Detroit, Michigan, May 18-22, 1970.

15. William Pierson, Robert Hammerle, Joseph Hummer, Research, Ford Motor Company, "Sulfuric Acid Aerosol Emissions from Catalyst-Equipped Engines, Society of Automotive Engineers, 740287, February 25 - March 1, 1974.
16. Morton Beltzer, Raymond Campion, William Peterson, Esso Research and Engineering Company, "Measurement of Vehicle Particulate Emissions," Society of Automotive Engineers, 740286, February 25 - March 1, 1974.
17. Personal communication with Shell Friedlander, California Institute of Technology, Pasadena, California.
18. Personal communication with ESSO Research and Engineering Company, Linden, New Jersey.
19. Joseph Hunter, "Studies of Catalyst Degradation in Automotive Emission Control Systems," Society of Automotive Engineers, 720122, January 10-14, 1972.
20. Personal communication with Environmental Protection Agency, Durham, North Carolina.
21. Personal communication with General Motors Automotive Research, Detroit, Michigan.
22. Statement of the Shell Oil Company, "Compliance with Title II (Auto Emission Standards) of the Clean Air Act, Hearings before the Committee on Public Works, United States Senate, November 5 and 6, 1973.
23. Steele, G., G. Gould, R. Roselius, W. Haunschild, "Clean Fuels Through New Isomax Technology," American Petroleum Institute 40-73, May 16, 1973.
24. Christensen, R., Chevron Research Company, "Low Sulfur Products from Middle East Crudes," National Petroleum Refiners Association, AM-73-38, April 1973.
25. California Air Resources Board, "Surveillance of Particulate Emissions From Mobile Sources, Project 5-4, Status Report 1, September 1973.
26. Dennis Lenane, Ethyl Corporation Research and Development Department, Letter of Data Transmittal to J. Sommers, Environmental Protection Agency, June 7, 1973.
27. Personal communication with Ethyl Corporation Research and Development, Ferndale, Michigan.
28. Aerospace Corporation, Final Report: "An Assessment of the Effects of Lead Additives in Gasoline on Emission Control Systems Which Might be Used to Meet the 1975-76 Motor Vehicle Emission Standards," Distributed by NTIS, U. S. Department of Commerce, November, 1971.

29. Atomics International, North American Rockwell, "Evaluation of a Device to Remove Lead and Particulates from Automobile Exhaust," A Technical Proposal to the Division of Motor Vehicle Research and Development, National Air Pollution Control Administration, AI-70-51P, August, 1970.
30. TRW Transportation and Environmental Operations, "Air Quality Implementation Plan Development for Critical California Regions," prepared for Environmental Protection Agency, July 1973.
31. Personal communication with Atomics International, Canoga Park, California.
32. Synthetic Fuels Panel, "Hydrogen and Other Synthetic Fuels," Atomic Energy Commission, September 1972.
33. Personal communication with General Tire and Rubber Company, Rubber Research and Development Division, Akron, Ohio.
34. William Pierson, Wanda Brachaczek, Research, Ford Motor Company, "Airborne Particulate Debris from Rubber Tires," August 1973.

## 9.0 ORGANIC SOLVENTS

Organic solvents are used extensively in the dry cleaning of clothes, surface coating operations, printing, degreasing, and a variety of other related activities. The role of organic solvent usage in atmospheric pollution, the current emission control technology being applied to its use, and the alternative pollution control measures which may be applied to achieve further emission preventions are discussed in the following sections.

### 9.1 BASELINE EMISSIONS AND CONTROLS

TABLE 9-1. ROLE OF ORGANIC SOLVENT EMISSIONS IN  
ATMOSPHERIC POLLUTION OF FOUR-COUNTY AREA

Percentage of Total Emissions in Four-County Area		
<u>Year</u>	<u>Particulates</u>	<u>Reactive Hydrocarbons</u>
1972	4	2
1977	3	3
1980	3	3

Source: Reference (1).

The role of organic solvent operations in atmospheric pollution in the Four County Region is illustrated above. There are essentially no SO<sub>2</sub> or NO<sub>x</sub> emissions yielded by these operations. Particulate emissions from organic solvent sources are projected to maintain the same relative status with respect to the overall Four County emissions totals for the next few years. However, reactive hydrocarbon emissions from organic solvent sources are expected to develop an increasing prominence in the Four County emissions total inventory. This is because additional emission controls scheduled for organic solvent operations will not keep pace with the overall decrease in the total hydrocarbon emission inventory.

Most of the emissions originating from the use or manufacture of organic solvents occur from the process of natural or forced evaporation.

For example, when architectural coatings are applied with solvents, the solvents evaporate into the atmosphere as the coating forms a film. In dry cleaning operation of clothes, the solvents are removed by heat, or forced evaporation. In general, the emissions from these activities are hydrocarbon vapors, of varying reactivity depending on the nature of the solvents used. With the federal promulgation of air program implementation plans for the State of California, release of solvent vapors to the atmosphere will be prevented by stricter emission controls for dry cleaning and degreasing operations. The user of solvents in those operations may choose to comply with the regulation by applying emission control hardware, or by selection of a non-photochemically active solvent.

The federal emission controls are directed at attaining the oxidant ambient air standards, and therefore control stipulations for the use of organic solvents address the prevention of reactive hydrocarbons. The scheduled controls do not significantly affect particulate emissions, as can be seen in Table 9-2.

TABLE 9-2. EMISSIONS FROM ORGANIC SOLVENT OPERATIONS  
IN FOUR-COUNTY AREA

Year	Tons/Day	
	Particulates	Reactive Hydrocarbons
1972	8	21.0
1977	8.5	14.9
1980	8.7	15.4

Table 9-3 provides an itemized characterization of the various emission sources resulting from the use of organic solvents in Los Angeles County. The data was extracted from the Emission Inventory File now in development by the Los Angeles County Air Pollution Control District. It is evident that painting operations in spray booths account for an overwhelming portion (85%) of the particulate emissions resulting from organic solvent use. This is due to the fact that emissions from other organic solvent operations are controlled with higher collection efficiency, while emissions from spray booths are typically controlled to

TABLE 9-3. CHARACTERIZATION OF EMISSION SOURCES ARISING FROM ORGANIC SOLVENT OPERATIONS IN LOS ANGELES COUNTY, 1972

Equipment & Operation	Emission Control Utilized	No. of Permits	Particulate Emissions lb/day	
			Actual	Preventions
Paint spraying device	Spray booth, paint & solvent	4227	4830.1	348.3
" " "	" " high solids paint	3	6.4	0
" " "	" " high water paint	4	14.4	0
" " "	" " styrenated resins	48	14.8	0
" " "	Control, powder coating	8	.5	0
" " "	Spray booth, ceramic	24	62.4	431.8
" " "	" " metalizing	12	12.9	17.4
" " "	" " paint & solvent	64	33.5	0
" " "	" " styrenated resins	3	.9	0
" " "	" " ceramic	11	79.3	0
" " "	" " other	12	6	0
Brake lining & bonding	Incineration control, dir. flame	1	.2	0
Coating - baking	None	785	232	0
" " "	Incineration control, dir. flame	116	186	870
" " "	" " catalytic	6	5.1	8.6
" " drying	None	265	233	0
Spraying device	Direct flame	26	54.4	486.1
" " "	Dry filter, baghouse	1	.4	3.6
" " "	Scrubber	2	4	0
Tank, asphaltic dip	Scrubber	7	1.2	.8
" paint dip	None	142	32.5	0
" plastic dip	None	17	.2	0
" misc. dip	None	57	6.5	0
" " "	Dry filter, other	1	.3	15.7
Continuous organic coating & drying	None	52	3	0
" " " "	Incineration control, dir. flame	11	0	0
" " " "	Scrubber	1	8	72
Degreaser, tri Chloroethylene	None	206	0	0
" other	None	509	1	0
Dry cleaning, petrol.	None	126	.6	0
" " synthetic & other	None	774	.2	0
" " " "	Dry Filter, other	1	.6	5.4
" " " "	" " baghouse	6	6.4	47.6
Flexograph	None	96	0	0
" " "	Incineration, direct flame	5	0	0
Letter press	None	14	0	0
Lithograph	None	11	0	0
" " "	Incineration, direct flame	8	9.6	341.7
Rotogravure	None	19	0	0
Paint, blending	None	18	40.8	0
" " "	Baghouse	5	4	44
" reaction	Scrubber	1	.1	.9
" baking	None	1	4	0
Flow coater	None	76	70.9	0
" " "	Incineration control, dir. flm	6	0	0
Rollercoater	None	88	1.5	0
" " "	Incineration control, dir. flm	26	1.5	10.6
" " "	Mist collector	1	.1	.7
Misc. solvent Convey.	Vapor balancing/gas blanketing	1	3.4	0
Varnish, shellac, cook.	Incineration, direct flame	5	24.2	221.8

Source: Los Angeles County Air Pollution Control District Computer Emission Inventory File

low efficiencies. The average emission level from a typical paint spray booth is relatively small, such that in the majority of cases Rule 66, which limits total discharge of organic materials from a given piece of equipment to less than 15 pounds of organic materials per day, is not violated. In addition, the emissions are well diluted, so as to comply with Rule 52 which limits the concentration of particulate matter arising from a source according to the volume discharge, and so as also to comply with the visible emissions and nuisance rules (No. 50 and 51). Table 9-4 summarizes clearly the important role that paint spraying operations play in atmospheric pollution from organic solvent emission sources in the Four County Area (the distribution relationships of Table 9-3 have been used to proportion the Four County Area emissions totals).

TABLE 9-4. EMISSIONS FROM PAINT SPRAY BOOTHS AND "OTHER" ORGANIC SOLVENT OPERATIONS, FOUR-COUNTY AREA, 1972

Operation	No. of Permits	Particulate Emissions Tons/Day		Efficiency of Control
		Actual	Preventions	
Paint spraying in spray booth	4482	6.8	1.1	13.5%
"Other"	3470	1.1.2	2.8	70.8%
TOTAL	7952	8.0	3.9	32.8%

Paint spray booths consist of an enclosure in which paint spraying is conducted. The spray is directed toward a vented wall with a ventilation rate of about 100 to 150 feet per minute per square foot of vent opening. There are basically three types of devices used to capture the paint spray before the ventilation fan exhausts the booth air to the atmosphere. They are: 1) dry baffle plates, 2) arrestors or filters, or 3) a water wash. Baffle plates capture paint spray particles with low efficiency, and are generally used as the most economic route for protection of the spray booth operator and prevention of nuisance emissions. Arrestors or filter paper provide collection of paint particles with efficiencies up to 98%. Where filters are not practical for continuous painting operations, water washes may be used with collection efficiencies of 95%.

## 9.2 ALTERNATIVE CONTROLS

Since paint spraying in spray booths accounts for 85% of all emissions from organic solvent activities, it follows that it shall be the target for additional controls. Other organic solvent emission sources will not be considered as likely candidates for additional control since 1) they are already controlled to 70% efficiency, and 2) they only account for about 1 ton/day of particulate emissions.

Consultation with spray booth manufacturers revealed the most frequently used spray booth is about 12 feet wide by 7 feet high at the venting entry, and is usually equipped with a dry baffle collector. It was estimated that 80% of the booths in Los Angeles are of this general description.<sup>2</sup> To improve the efficiency of the 4482 spray booths (Table 9-4) operating with county permits, two retrofits are feasible: an arrestor filter mat, or a water wash. In many instances the water wash is the more economic route as servicing requirements are very minimal, while filters must be replaced regularly when utilized under continuous spray operations.

### Impact of Retrofitting Spray Booths with Water Wash

The emission preventions obtained by retrofitting the present population of paint spray booths in the Four County Area with a water wash is shown in Table 9-5. This control measure can yield a 77% overall prevention of particulate emissions arising from organic solvent usage.

TABLE 9-5. EFFECT OF RETROFIT WATER WASH CONTROL ON EMISSIONS FROM PAINT SPRAY BOOTHS

	Baseline Particulate Emissions	Particulate Emission Reductions
Year	Tons/Day	
1977	8.5	6.5
1980	8.7	6.7

1. Reductions calculated on basis of 90% reduction, assuming a particulate distribution with 60% of particles under 10 micron size.



Based on an average retrofit cost of \$2800 per spray booth,<sup>2,3</sup> annualized to \$280 per year at 10% interest, the total annualized cost for the entire population of retrofits is \$1.6 million. This amounts to a cost effectiveness of \$724 per ton of particulate emissions removed from the atmosphere.

#### REFERENCES FOR SECTION 9.0

1. TRW Transportation and Environmental Operations, "The Development of A Particulate Implementation Plan for the Los Angeles Region," Report #2, Emission Inventories and Projections, June, 1974.
2. Personal Communication with Binks Company, Los Angeles, and De Vilbiss, Los Angeles.
3. Personal Communication with Joy Manufacturing, Los Angeles.

## 10.0 METALLURGICAL PROCESSES

Operations characterizing the metallurgical industry consist primarily of metal separation processes. The processes are carried out in various types of melting furnaces, which yield high-temperature effluents requiring air pollution control. The following discussion provides a characterization of the emissions arising from present operations in the metallurgical industry, the air pollution control methods being utilized to manage these emissions, and alternative control measures which may be employed to yield further emission control.

### 10.1 BASELINE EMISSIONS

The principal emissions produced during metallurgical operations are particulates and SO<sub>2</sub>. The role of these emissions in total atmospheric pollution of the Four County Area is shown in Table 10-1. In future years, the metallurgy industry is expected to be responsible for about 5% of all particulate emissions, and about 3% of the SO<sub>2</sub> emission inventory.

TABLE 10-1. ROLE OF METALLURGICAL INDUSTRY EMISSIONS IN ATMOSPHERIC POLLUTION OF FOUR-COUNTY AREA

Year	Percentage of Emissions in Four County Area		
	Particulates	SO <sub>2</sub>	NO <sub>x</sub>
1972	6	3	-
1977	5	3	-
1980	5	3	-

Source: Reference (1)

Emissions of the metallurgy industry are generated from the melting of metals and ores in furnaces. As the feed in the furnace is melted, combustibles such as grease, oil and burner fuel are burned and emitted along with refining emissions which consist of oxide fumes of the metal constituents in the furnace melt mixture. The quantities of emissions generated

by furnace operation depends mainly on the specific melting process. The total emissions deriving from activity of all metallurgical furnaces in the Four County Area is tabulated in Table 10-2. Emissions from incomplete combustion constitute a small portion of the furnace effluents, as can be seen by the relatively minor quantities of  $\text{NO}_x$  generated.

TABLE 10-2. EMISSIONS FROM METALLURGICAL OPERATIONS IN FOUR-COUNTY AREA

<u>Year</u>	<u>Particulates</u>	<u>SO<sub>2</sub></u>	<u>NO<sub>x</sub></u>
1972	12.3	13.0	.5
1977	13.4	15.0	.6
1980	14.0	15.9	.5

Source: Reference (1)

## 10.2 EMISSIONS CONTROLS

A detailed itemization of emission sources and emission control equipment of the metallurgical industry is presented in Table 10-3. It is evident that substantial effort has already been employed to achieve a high rate of particulate collection efficiency. The basic control equipment generally consists of either a baghouse or an electrical precipitator. A critical aspect of the successful control of furnace dust and fumes is the hooding design. Various hooding configurations are employed depending on the layout and shape of the furnace, and the volume of effluent to be managed. The most difficult design problem concerns the provision of adjustability for the hood to facilitate furnace charging and access. For the hood to remain effective it must be positioned to allow continuous capture of emissions arising during the charging process.

It is estimated by the Los Angeles Air Pollution Control District that about 92% of all particulate emissions generated from metallurgical operations are prevented from entering the atmosphere.<sup>2</sup> This degree of control is reflected in the itemization of source controls in Table 10-3. However, with regard to emissions of  $\text{SO}_2$ , there are virtually no controls applied.

SO<sub>2</sub> emissions arise almost solely from lead refining, in which a substantial amount of sulfur is present in various forms in the charge to the furnace. The melting of the charge oxidizes the sulfur compounds resulting in emission of SO<sub>2</sub>.

There are a vast number of furnaces utilized in which no emission control system has been incorporated. These furnaces are relatively small, and the effluents which are diluted and discharged to atmosphere by the hooding capture systems do not constitute a violation of air pollution regulations. Nevertheless, these "uncontrolled" emissions account for 58% the air pollution from all metallurgy operations. Table 10-4 provides a characterization of these small furnaces and their role in emissions from metallurgical operations.

TABLE 10-3. CHARACTERIZATION OF FURNACE CONTROL EFFECTIVENESS, FOUR-COUNTY AREA, 1972

Type of Furnace Control	No. of Permits	Particulates Emitted from Control System	Particulates Prevented from Emitting	Control Efficiency
None	1782	7.2	0	0
Baghouse	483	4.7	128	96.4
Precipitator, Scrubbers, & Afterburners	224	1.4	3.9	90.7
TOTALS	2489	12.3	132	91.5

1. Figures above were computed by applying the composite distribution derived from Table 10-3 to the total metallurgy emission inventory for Four County Area.

### 10.3 ALTERNATIVE CONTROLS

There are probably very few basic equipment modifications which would enable significant improvements in particulate collection efficiencies for those furnaces equipped with control systems. However it has been found that baghouses have on numerous occasions been inadequately maintained, resulting in poor collection efficiencies (less than 90%).<sup>3,4</sup> Baghouse filters must be designed to be compatible with the effluent gas temperatures, and condensation should be avoided or filters will saturate causing increased pressure drop and exhaust air flow. Bags must be shaken regularly as furnace fumes tend to agglomerate on the fibers. It is conceivable that significant performance improvements could be affected in furnace emission control systems if stricter industrial maintenance practices were implemented. However it would be extremely difficult to assess the benefits of such a program without extensive investigations of prevailing emission rates and maintenance procedures. It is noted however, that the emission inventory itemization of Table 10-3 credits baghouse installations with a composite control effectiveness of 96.4% (this is based on estimates derived, for the most part, from theoretical calculations, and not field measurements), which, it would seem, already presumes a high degree of maintenance consciousness.

The vast number of furnaces which currently are not equipped with emission control devices can be best retrofitted with baghouse installations in most instances. Baghouse operating temperature is an important consideration, and often temperature control must be provided for by installing extra equipment such as convection cooling columns, or thermal insulation.

Lead melting operations are presently equipped with baghouse emission control systems, but this equipment has no substantial effect on SO<sub>2</sub> pollution. Several candidate SO<sub>2</sub> removal processes may be employed at the baghouse effluent to obtain preventions of SO<sub>2</sub> emissions by 90%. These controls have been discussed in Section 3.2.2.

#### Impact of Alternative Controls on Metallurgical Emissions

The air pollution control benefits of retrofitting baghouse control systems to furnaces which currently are vented directly to the atmosphere is shown in Table 10-5. The retrofit measure will provide a 56% reduction in total particulate matter emitted by metallurgical melting operations.

TABLE 10-4. CHARACTERIZATION OF EMISSION SOURCES ARISING FROM METALLURGICAL OPERATIONS IN LOS ANGELES COUNTY, 1972

Equipment & Operation	Emission Control Utilized	No. of Permits	SO <sub>2</sub> Emissions lb/day		Particulate Emissions lb/day	
			Actual	Preventions	Actual	Preventions
Aluminum Pot	None	4	0	0	6.0	0
Lead and type metal "	None	188	0	0	170.6	0
" " " "	Incinerator Direct Flame	8	0	0	15.6	6.3
" " " "	Dry Filter, Baghouse	34	0	0	209	2237
" " " "	Scrubber	1	0	0	.3	.2
Time Solder "	None	3	0	0	.1	0
Zinc & Kirksite "	None	59	0	0	101	0
" " " "	Direct Flame	1	0	0	1.0	9.4
" " " "	Baghouse	1	0	0	1.0	8.6
Zinc & Kirksite Retort "	"	18	0	0	35.4	807.4
" " " "	Scrubbers	1	0	0	2.9	142.9
Aluminum Reverberatory/Open Hearth	None	87	.3	0	.4527	0
" " " "	Direct Flame	2	0	0	49.6	279.2
" " " "	Baghouse	7	0	0	630.2	1536.5
Brass, Bronze, Copper Reverb./Open Hearth	"	3	0	0	528	25873
Iron-Steel " " "	None	9	0	0	103.8	0
" " " "	Electric precipitator	3	0	0	216	2808
Lead Type Metal " "	Baghouse	4	620.8	336.0	20.6	1220
Zinc & Kirksite " "	None	4	0	0	39.4	0
" " " "	Baghouse	7	0	0	20.5	283.5
Aluminum Rotary	"	1	0	0	2.4	477.6
Brass (yellow) "	None	1	.2	0	.32	0
Brass, Bronze, Copper "	Baghouse	6	163.2	0	99.3	1616.7
Lead & Type Metal "	"	1	0	0	2.9	141.1
Zinc & Kirksite "	"	3	0	0	27.5	628.5
Aluminum Sweating Ops	None	1	0	0	2	0
" " " "	Baghouse	5	0	0	12.7	411.6
Lead & Type Metal ""	"	6	3348	0	37.2	3758
Tin & Solder ""	Direct Flame	2	0	0	5.0	44.6
" " " "	Baghouse	1	4.0	2.4	2.5	121.5
Zinc & Kirksite ""	"	7	0	0	524.8	1193
Misc. Metals ""	None	1	0	0	.9	0
" " " "	Baghouse	1	0	0	14.9	729.1
Brass (yellow) other Metal Ops.	"	1	0	0	1.9	94.1
Iron - Steel " " "	"	3	0	0	72	1368
" " " "	None	1	0	0	4.2	0
" " " "	None	1	14.4	0	20.6	0
Core Baking	None	85	.1	0	5.2	0
" " " "	Incineration Contr. Dir. Flm	8	0	0	.1	1.2
Galvanizing	None	6	0	0	23.2	0
Tank, chrome plating or stripping	None	104	0	0	10.3	0
" " " "	Mist collector	17	0	0	8.8	77.6
" " " "	Scrubber	60	0	0	9.6	65.0
Aluminum Crucible	None	50	0	0	63.3	0
Yellow Brass "	None	35	0	0	323.3	0
" " " "	Dry Filter, Baghouse	7	0	0	21.6	38.8
Brass, Bronze, Cop. "	None	96	49.4	0	645.6	0
" " " "	Dry Filter, Baghouse	17	0	0	75.2	543.7
Iron - Steel "	None	1	0	0	.2	0

TABLE 10-4. (CONTINUED) CHARACTERIZATION OF EMISSION SOURCES ARISING FROM METALLURGICAL OPERATIONS IN LOS ANGELES COUNTY, 1972

Equipment & Operation	Emission Control Utilized	No. of Permits	SO <sub>2</sub> Emissions lb/day		Particulate Emissions lb/day	
			Actual	Preventions	Actual	Preventions
Lead & Type Metal, Crucible	None	4	0	0	14.0	0
Magnesium "	None	1	0	0	1.6	0
Tin & Solder "	None	5	0	0	8.6	0
Zinc & Kirksite "	None	5	0	0	6.4	0
Misc. Metals "	None	2	0	0	2.2	0
Brass, Bronze, Copper	Dry Filter, Baghouse	1	0	0	26.4	1317.6
Cupola & Blast						
Iron - Steel " "	None	1	0	0	1.8	0
" " " "	Dry Filter, Baghouse	13	0	0	476.6	6381
Lead & Type Metal " " "	" " " "	1	696	18504	62.4	5938
" " " "	None	1	336	0	18	0
Aluminum Elec. Arc	None	1	.2	0	7.2	0
Iron - Steel " "	None	10	0	0	316.1	0
" " " "	Dry Filter, Baghouse	16	0	0	1204	13138
Misc. Metals " "	?	3	0	0	.3	0
Aluminum Elec, Inductive/resist	None	20	0	0	46.2	0
Yellos Brass " " "	None	3	0	0	20.8	0
" " " "	Dry Filter, Baghouse	13	0	0	109.5	838.5
Brass, Bronze, Cop. " "	" " " "	31	0	0	224.2	1494
" " " "	None	9	0	0	71.4	0
Iron - Steel " " "	None	41	0	0	193.2	0
" " " "	Dry Filter, Baghouse	19	0	0	7.3	175.6
Lead & Type Metal " " "	None	1	0	0	.8	0
Misc. Metals " " "	None	1	0	0	1.4	0
" " " "	Baghouse	2	0	0	1.4	0

Source: Los Angeles County Air Pollution Control District Computer Emission Inventory File.

TABLE 10-5. EFFECT OF BAGHOUSE RETROFIT ON UNCONTROLLED PARTICULATE EMISSIONS FROM FURNACES IN FOUR-COUNTY AREA

<u>Year</u>	Baseline Particulate Emissions	Particulate Emission Reduction
	Tons/Day	
1977	7.8	7.5
1980	8.2	7.9

1. Reductions based on baghouse collection efficiency of 96%.

The impact of retrofitting lead processing furnaces with SO<sub>2</sub> cleanup systems is shown in Table 10-6. The add-on SO<sub>2</sub> removal systems require pretreatment of the effluent for particulate removal, hence they must be sized to manage the effluent of the baghouses. In furnace emission control applications, the baghouse effluent volumes are often several times that of the furnace itself due to the dilution air used to cool the hot fumes and prevent condensation or rapid agglomeration of matter on the baghouse filter fabric. Based on substantial studies now being carried out to assess the performance of SO<sub>2</sub> cleanup systems, it is estimated that 90% of the SO<sub>2</sub> pollutions generated by metallurgical activities can be eliminated.

TABLE 10-6. EFFECT OF RETROFITTING SO<sub>2</sub> CLEANUP SYSTEMS TO LEAD REFINING FURNACE EFFLUENTS IN FOUR-COUNTY AREA

<u>Year</u>	Baseline SO <sub>2</sub> Emissions	SO <sub>2</sub> Emission Prevention
	Tons/Day	
1977	15.0	13.5
1980	15.9	14.3



### Cost of Emission Controls:

The cost of retrofitting uncontrolled pollutant emissions of SO<sub>2</sub> and particulates from melting furnaces in the Four County Area is shown in Table 10-7. Several assumptions were necessary in the derivation of the cost figures, and the estimates are preliminary at best. However, the magnitude of the cost effectiveness closely parallels the cost of other similar pollution control systems which are well documented in the literature, and in other sections of this report. Treatment for SO<sub>2</sub> removal from the effluent of lead melting furnaces is about ten times more cost effective than particulate collection from the small uncontrolled furnaces scattered about the Four County Area.

TABLE 10-7. COST OF RETROFIT CONTROL ALTERNATIVES FOR METALLURGICAL FURNACE EMISSIONS, FOUR-COUNTY AREA, 1977

Control Option	No. of Furnaces Requiring Retrofits	Purchase and Instal-	Annual Operating	Annualized	Cost Per Ton of Pollutant Emissions Prevented
		lation Cost	Cost	Cost	
Millions of Dollars					
Baghouse	1782	18.6 <sup>a</sup>	1.5 <sup>b</sup>	3.4	\$1242
SO <sub>2</sub> Cleanup System	12	4.0 <sup>c</sup>	.1 <sup>d</sup>	.5	\$ 101

1. Annualized cost based on 30 year lifetime @ 10% interest.

<sup>a</sup>In absence of detailed equipment inventory, several assumptions were made: 1) hood size of 5 ft<sup>2</sup> assumed for capture of fumes over furnace @ 150 fpm = 750 scfm per unit, 2) multiplicity of lead furnaces assumed at each site, such that one baghouse would serve approximately four furnaces for the average case. 444 baghouses are needed to handle 3000 scfm each, 3) cost is based on Ref.(6), plus 20% additional for ducting installation.

<sup>b</sup>Reference (6).

<sup>c</sup>SO<sub>2</sub> removal systems were sized by 1) average emission load (420 lb/day) of 12 permits shown in Table 10-3, adjusted to official APCD total SO<sub>2</sub> metallurgical emission inventory to give 1000 lb/day per permit (which slightly exceeds Rule 53, Allowable Sulfur Concentration); 2) typical baghouse effluent volume for lead smelting operation<sup>3</sup> as 3.3 scfm per lb/day of emissions processed. Hence total baghouse effluent volume to be treated by SO<sub>2</sub> removal system for Four County Area in 1977 = 100,000 scfm, for approximately 30 separate permits, 3) capital costs based on Envirotech Double Alkali SO<sub>2</sub> Scrubber System<sup>7</sup> (\$4.0 million per 100,000 cfm of effluent processed).

<sup>d</sup>Reference (7).

#### REFERENCES FOR SECTION 10.0

1. TRW Transportation and Environmental Operations, "The Development of a Particulate Implementation Plan for The Los Angeles Region," Report #2, Emission Inventories and Projections, June 1974.
2. Air Pollution Control District, County of Los Angeles, "Profile of Air Pollution Control," 1971.
3. Los Angeles County Air Pollution Control District, "Air Pollution Engineering Manual," Document AP-40, Environmental Protection Agency, May 1973.
4. Personal communication with Los Angeles County Air Pollution Control District.
5. Personal communication with Arthur D. Little Company, New York.
6. U. S. Department of Health, Education, and Welfare, National Air Pollution Control Administration, "Control Techniques for Particulate Air Pollutants."
7. Personal communication with Envirotech Emission Control Division, San Mateo, California.

## 11.0 CHEMICAL PROCESSING INDUSTRY

Emissions produced by the chemical processing industry originate from a wide variety of equipment categories such as resin kettles, varnish cookers, sulfur scavenger plants, acid plants, detergent manufacturing equipment, glass manufacturing plants, food processing plants, electroplating equipment, and others. The emissions arising from the use of this equipment, and the air pollution control methods being utilized to manage these emissions, are discussed in the following sections.

### 11.1 BASELINE EMISSIONS

The principal emissions arising from chemical processing activities are particulates and  $\text{SO}_2$ . The role of these emissions in total atmospheric pollution of the Four County Area is shown in Table 11-1. In future years the chemical industry is projected to be responsible for about 4% of all particulate emissions, and only 2% of the  $\text{SO}_2$  emission inventory. Emissions of  $\text{SO}_2$  are expected to be reduced dramatically by 1977 owing to the impact of Rule 53.2 of the Los Angeles Air Pollution Control District. Rule 53.2 will provide for reduction of  $\text{SO}_2$  emissions from the vent gas of sulfur recovery plants.  $\text{SO}_2$  removal processes are presently being applied in Los Angeles to reduce these emissions below 500 ppm.

TABLE 11-1. ROLE OF CHEMICAL PROCESSING INDUSTRY IN  
ATMOSPHERIC POLLUTION OF FOUR-COUNTY AREA

Year	Percentage of Emissions in Four County Area	
	Particulates	$\text{SO}_2$
1972	4	22
1977	4	2
1980	4	2

Source: Reference (1)

The total emissions deriving from chemical processing operations is tabulated in Table 11-2.

TABLE 11-2. EMISSIONS FROM CHEMICAL PROCESSING OPERATIONS IN FOUR-COUNTY AREA, TONS/DAY

Year	Particulates	SO <sub>2</sub>	NO <sub>x</sub>
1972	9.2	97	.4
1977	9.7	10	.5
1980	10.1	10	.5

## 11.2 EMISSION CONTROLS

A detailed itemization of emission sources and emission control equipment for particulate emissions of the chemical processing industry is presented in Table 11-3. It is apparent that appreciable effort has already been invested to achieve a high rate of particulate collection efficiency. Particulate control devices being used consist of mechanical collectors, wet scrubbers, electrostatic precipitators, filters, and incinerators. Table 11-3 shows that the Los Angeles Air Pollution Control District estimates that about 97% of all particulate emissions generated by chemical processing operations are prevented from entering the atmosphere.

The principal source of SO<sub>2</sub> emissions from the chemical industry are sulfur recovery plants which process the offstream acid gases at oil refineries. The acid gases are processed by the recovery plants to obtain sulfur and vent gases. Previously these vent gases were incinerated and discharged through a stack to the atmosphere. The concentration of SO<sub>2</sub> in these stack gases varied between 2000 and 20000 ppm. The SO<sub>2</sub> from the stacks of these plants are now being controlled by new available technology (see Section 3.2.2) to a stack discharge concentration of less than 500 ppm. SO<sub>2</sub> removal processes have now been applied successfully to most recovery plants in Los Angeles, but in some instances inadequate control systems were initially installed, causing delays in the compliance schedule. Scheduled equipment replacements or improvements will insure compliance before 1977.

## 11.3 ALTERNATIVE CONTROLS

The control equipment inventory of Table 11-3 illustrates the substantial degree of control (reflecting the best available technology) which has been accomplished over particulate emissions from the

chemical industry in Los Angeles County. It is presumed (in the absence of suitable data for confirmation) that a similar level of particulate emission control has been accomplished throughout the remainder of the Four County Area, since the process emission regulations are fairly consistent for the various counties. With respect to the emissions of  $\text{SO}_2$  the newly adopted regulations for sulfur recovery plants are especially stringent, requiring commitment of oil refineries to utilization of expensive control equipment still in its infant stages of development. These controls are to be implemented throughout Los Angeles County, which contains all sulfur recovery plants within the Four County Area. Owing to the impact of  $\text{SO}_2$  and particulate regulations in the Four County Area, it would not appear that significant additional emission reductions can presently be achieved with reasonable available technology. Hence, no alternative control measures have been identified for the chemical processing industry.

TABLE 11-3. CHARACTERIZATION OF PARTICULATE EMISSION SOURCES ASSOCIATED WITH CHEMICAL PROCESSING OPERATIONS IN LOS ANGELES COUNTY, 1972

Equipment & Operation	Emission Control Utilized	No. of Permits	Particulate Emissions lb/day	
			Actual	Preventions
Plastic & Virus, Extrusion	None	1	.8	0
" " "	Dry Filter, Baghouse	1	6	54
Plastic & Virus, Rolling	None	1	12	0
" " "	Incineration Direct Flame	1	34	51
Plastic & Virus, Reaction	None	2	18	0
" " "	Dry Filter, Other	1	2.4	237.6
" " "	Scrubber	1	24	216
Plastic & Virus, Organic Add.	None	10	.9	0
" " "	Direct Flame	1	15.8	0
Plastic & Virus, Baking	None	1	8	0
Plastic & Virus, Coaling	None	2	.8	0
Plastic & Virus, Size Reduction	None	7	21.5	0
" " "	Baghouse	4	5.7	127.1
Plastic & Virus, Size Class.	Baghouse	3	16.8	40.8
Polyester, Garnetting	None	1	4	0
" " "	Baghouse	2	5.2	15.2
Polyester, Organic Addition	Scrubber	3	2.2	.2
Polyethylene Blending	None	2	.8	0
" Conveying	None	1	1.2	0
" Packaging	Dry Filter, Other	1	.2	2.2
" Pelletizing	Incineration Flare	1	.2	239.8
Polystyrene, Extrusion	Floating Roof	2	2.4	237.6
" Pelletizing	Dry Inertial Separator	1	2.4	237.6
Polystyrene, Organic Addition	None	4	7.2	0
Polystyrene, Size Reduction	Baghouse	1	8	792
Polyvinyl acetate, Reaction	None	2	.8	0
Polyvinyl acetate Organic Add.	None	5	6.7	0
Polyvinyl chloride, Blending	None	4	12.3	0
" " "	Baghouse	3	5.4	45.8
Polyvinyl chloride, Conveying	None	8	112	0

TABLE 11-3 (CONTINUED) CHARACTERIZATION OF PARTICULATE EMISSION SOURCES  
ASSOCIATED WITH CHEMICAL PROCESSING OPERATIONS IN  
LOS ANGELES COUNTY, 1972

Equipment & Operation	Emission Control Utilized	No. of Per- mits	Particulate Emissions lb/day	
			Actual	Preven- tions
Polyvinyl chloride, Conveying	Dry Inertial Separator	1	6.4	87.6
Polyvinyl chloride Drying	Direct Flame	1	4	0
" "	Baghouse	4	177.6	8393
Polyvinyl chloride Extrusion	"	1	2	18
Polyvinyl chloride Pelletizing	Scrubber	1	24	99.2
Polyvinyl chloride Size Reduction	Baghouse	1	.6	5.4
Polyvinyl chloride Storage other	None	13	102.2	0
" "	Baghouse	3	72	3528
Detergents Cleaners Blending	Dry Inertial Separator	1	2.9	54.7
" "	Scrubber	12	42	318
Detergent Cleaners Conveying	None	13	101.2	0
" "	Dry Filter Baghouse	11	108.5	1529.7
Detergents Cleaners Drying	None	4	27.2	0
" "	Baghouse	2	10.3	388.1
" "	Dry Inertial Separator	1	24	2376
" "	Electrical Precipitator	1	260	15340
" "	Scrubber	4	832	110519
Detergents Cleaners Packaging	None	2	1.4	0
" "	Dry Filter Other	1	.9	8.1
" "	" " Baghouse	2	8	792
" "	Scrubber	1	2	18
Detergents Cleaners Pelletizing	" Baghouse	1	12	1188
Detergents Cleaners Reaction	None	8	86.8	0
" "	Baghouse	1	8.2	811.8
" "	"	3	48.8	311.2
Detergents Cleaners Inorganic Addition	Compres. & Condensation	1	144	1296
" "	Incineration, Direct Flame	1	24	216
" "	Dry Filter, Other	1	6	234
" "	Scrubber	3	24	216
Detergents Cleaners Size Reduction	"	1	4	76
Detergents Cleaners Size Classification	"	1	.8	15.2
Detergents Cleaners Storage, Other	None	19	3.1	0

TABLE 11-3 (CONTINUED) CHARACTERIZATION OF PARTICULATE EMISSION SOURCES  
ASSOCIATED WITH CHEMICAL PROCESSING OPERATIONS IN  
LOS ANGELES COUNTY, 1972

Equipment & Operation	Emission Control Utilized	No. of Per- mits	Particulate Emissions lb/day	
			Actual	Preven- tions
Detergents Cleaners Storage, Other	Baghouse	1	8	72
Dross Size Class.	None	1	24	0
Synthetic Fertilizer Blending	Baghouse	2	22.9	2263
" "	Scrubber	1	20.7	870.3
Synthetic Fertilizer Conveying	Baghouse	3	44	436
Flux Blending	None	1	1.5	0
Foams, Plastic, Rubber Blending	"	2	2.4	0
Foams, Plastic, Rubber Packaging	"	1	2.3	
Foams, Plastic, Rubber Size Reduction	"	1	8	
Polyurethane, Blending	"	1	.1	0
" "	Dry Filter, Baghouse	1	.8	79.2
Polyurethane Organic Addition	None	3	8	0
Rubber Synthetic Blend.	"	14	408.2	0
" " "	Dry Filter, Other	3	31.2	520.8
" " "	" " Baghouse	2	8.4	279.6
Rubber Synthetic Con- veying	" " "	4	60.8	1107.2
Rubber Synthetic Reac- tion	Furnace or Boiler Firebox	1	12	0
" " "	Scrubber	1	120	360
Rubber Synthetic Cooking	"	4	24	72
Rubber Synthetic Size Reduction	None	4	6.8	0
" "	Incineration Dir. Flame	1	.6	0
Sulfur Conveying	None	9	7.8	0
" Oxidation	Incineration Flame	1		
" "	Dry Filter, Baghouse	1	.2	.8
Sulfur Size Reduction	None	1	24	0
Sulfur Size Class.	None	1	8.4	0
Sulfuric Acid, Adsorption	"	2		
Sulfuric Acid, Conveying	"	3		
" "	Furnace or Boiler Firebox	2		
" "	Scrubber	1	.2	.2
Sulfuric Acid Reaction	None	1		
Sulfuric Acid Storage, Other	"	35		



TABLE 11-3 (CONTINUED) CHARACTERIZATION OF PARTICULATE EMISSION SOURCES  
ASSOCIATED WITH CHEMICAL PROCESSING OPERATIONS IN  
LOS ANGELES COUNTY, 1972

Equipment & Operation	Emission Control Utilized	No. of Per- mits	Particulate Emissions lb/day	
			Actual	Preven- tions
Sulfuric Acid Storage, Other	Scrubber	2	.4	7.2
Ethylene, Adsorption	None	1	1.0	0
Ethylene Separation	"	1	3.4	0
Organic Chemicals, Misc. Blending	"	11	8	0
Organic Chemicals, Misc. Conveying	Baghouse	1	1	99
Organic Chemicals, Misc. Drying	None	2	1.4	0
Organic Chemicals, Misc. Reactions	"	2	24	0
Organic Chemicals, Organic Addition	Direct Flame	1	.7	0
" "	Baghouse	2	.4	2.6
Rubber Blending	"	1	8.4	18
" Extrusion	None	1	1.6	2.9
" "	Baghouse	1	.1	2.9
Rubber, Size Class.	Direct Flame	1	.2	1.4
Plastic Curing	None	99	123.7	0
" "	Incineration Dir. Flame	5	.2	1.4
Plastisol Curing	None	20	69.7	0
" "	Scrubber	1	1.8	8
Rubber Curing	None	5	0	0
Acid (organic) Blending	"	2	1.4	0
Acid (organic) Conveying	"	2	16	0
Acid (organic) Oxidation	Adsorption	1	2.4	0
Acid (organic) Storage, Other	Scrubber	2	.4	.4
Acid (inorganic) Blending	None	2	8	0
" "	Scrubber	1	4	124
Acid (inorganic) Storage, Other	None	6		
" "	Adsorption	10	.1	0
Acid (inorganic) Treating	Scrubber	1		
Adhesives, Blending	None	14	39.1	0
" "	Dry Filter Baghouse	7	59.9	1242.1
Adhesives Organic Addition	None	1	2.5	0
Alums Conveying	"	1	16	0
Ammonium Sulfate, Conveying	Baghouse	1	1.6	158.4
Ammonium Sulfate Conveying	Scrubber	1	2.4	216

TABLE 11-3 (CONTINUED) CHARACTERIZATION OF PARTICULATE EMISSION SOURCES  
ASSOCIATED WITH CHEMICAL PROCESSING OPERATIONS IN  
LOS ANGELES COUNTY, 1972

Equipment & Operation	Emission Control Utilized	No. of Per- mits	Particulate Emissions lb/day	
			Actual	Preven- tions
Boron Compounds, Pkg.	None	2	1.2	0
" " "	Dry Filter, Other	1	.8	4
Boron Compounds Storage, Other	Baghouse	1	192	35808
Carbon Black Activated Conveying	None	5	43.6	0
" " "	Baghouse	1	2.4	237.6
Carbon Blk. Act. Drying	Incineration Dir. Flame	1	.5	4.3
" " " Dump.	Baghouse	1	.2	23.8
" " " Pkg.	"	2	2	3.6
Carbon Black Activated Size Reduction	"	2	4	68
Carbon Black Activated Size Classification	"	1	.2	8.8
Chemical (inorganic) Blending	None	11	8.8	0
" " "	Dry Filter, Other	1	15.2	136.8
" " "	" " Baghouse	3	2.9	33.9
" " "	Scrubber	1	.2	1.8
Chem. (inorg.) Convey.	None	10	82.7	0
" " "	Baghouse	4	87.2	3037
" " " Drying	None	2	245	0
" " "	Scrubber	1	13.5	121.5
" " " Pkg.	None	1	27	0
" " "	Scrubber	1	4	0
" " " Reaction	None	5	50.5	0
" " "	Scrubber	2	4	16
Chemical (inorganic) Inorganic Addition	"	2		
Chemical (inorganic) Size Reduction	Dry Filter, Other	1	.2	23.8
" " "	Baghouse	4	8.6	794
Chemical (inorganic) Size Classification	None	1	24	
" " "	Baghouse	1	.4	5.6
Coal Tar Fluridization	Incineration Dir. Flame	1	14.4	705.6
Cosmetics, Blending	Baghouse	20	14.1	1279
Detergents & Cleaners Blending	None	17	19.5	0
" " "	Adsorption	1	.8	.8
" " "	Dry Filter, Other	2	3	27
" " "	Baghouse	12	7.2	104.8
Pharmaceuticals, Blend.	Dry Filter, Baghouse	11	8.3	35.1
" " "	Scrubber	1	.2	1.6
" " " Dry.	None	7	.9	0
" " "	Baghouse	1	.2	15.7
" " " Reaction	Scrubber	1	.8	7.2
" " " Size Reduct.	Baghouse	9	2.9	13.3
" " "	Scrubber	1	1.6	0

TABLE 11-3 (CONTINUED) CHARACTERIZATION OF PARTICULATE EMISSION SOURCES  
ASSOCIATED WITH CHEMICAL PROCESSING OPERATIONS IN  
LOS ANGELES COUNTY, 1972

Equipment & Operation	Emission Control Utilized	No. of Per- mits	Particulate Emission lb/day	
			Actual	Preven- tions
Phthalic anhydride, Distillation	Scrubber	1	.7	143.3
Phthalic Anhydride, Refining	Baghouse	1	6	594
Phthalic Anhydride, Oxidation	Incineration, Dir. Flame	1	235.6	9365
Phthalic Anhydride, Storage Other	None	10	3.1	0
Phosphoric acid, React.	Mint Collector	1	76.8	235.2
" " Oxidat.	None	1	192	
Phosphates Blending	Scrubber	2	2.4	41.6
" " Conveying	None	2	6	0
" " "	Dry Filter, Other	2	8.4	312
" " "	" " Baghouse	1	40	0
" " Drying	Scrubber	1	16	144
" " Packaging	None	2	48	0
" " Reaction	None	2	48	0
" " Size Reduct.	Baghouse	1	.1	.7
" " Storage, Other	"	1	48	0
Pigments, Blending	None	10	18.1	0
" " "	Baghouse	1	.5	149.5
" " Conveying	None	1	2	0
" " Drying	"	1	2	0
" " Packaging	"	2	2.7	0
" " Size Reduct.	"	8	14.1	0
" " Stor. Other	Baghouse	1	.3	59.7
Plastic & Resins Blend.	None	23	42.1	0
" " " "	Baghouse	8	153.2	211.6
" " " "	Dry Inertial Separation	2	24	72
" " " "	Scrubber	2	2.3	20.3
" " " Convey.	None	4	24.5	0
" " " "	Dry Filter, Other	1	7	0
" " " "	" " Baghouse	5	52.4	1307.6
" " " "	Dry Inertial Separation	1	31.2	592.8
" " " Drying	None	3	5.6	0
Gypsum, Storage Other	None	1	7.2	0
Hydrocarbon Misc. Blendi	"	4	12	0
Hydrocarbon Misc. Con- veying	"	51	537.6	0
Hydrocarbon Misc. Cracking Catalytic	Incineration Control Flare	2		
Hydrocarbon Misc. Storage, Other	Inciner. Furn. or Boil. Fire- box	1		
Hydrocarbon Misc. Treating	None	3		
Hydrogen Manuf. Reaction	"	1	2.4	0
Hydrogen sulfide Distillation	"	7		

TABLE 11-3 (CONTINUED) CHARACTERIZATION OF PARTICULATE EMISSION SOURCES  
ASSOCIATED WITH CHEMICAL PROCESSING OPERATIONS IN  
LOS ANGELES COUNTY, 1972

Equipment & Operation	Emission Control Utilized	No. of Per- mits	Particulate Emission lb/day	
			Actual	Preven- tions
Hydrogen sulfide Distillation	None	2		
Hydrogen sulfide Treating	None	6		
Ink, Blending	Scrubber	1	2	6
Insecticides, Blend.	None	5	9.2	0
" "	Dry Filter, Baghouse	1	4	36
" "	Scrubber	2	4.8	92.7
" Conveying	Baghouse	2	.7	6.5
" Pelletizing	"	2	.6	17.4
" "	Dry Inertial Separator	1	.1	63.9
" Reaction	Scrubber	1	48	432
Keton, Organic Addition	Furnace or Boiler Firebox	2	22	0
Lead Oxide, Blending	Baghouse	3	1.2	24.8
" " "	Scrubber	5	11.6	92.4
" " Conveying	None	4	29	0
" " "	Baghouse	16	134.8	2412.7
" " Packaging	None	1	2.4	0
" " "	Baghouse	4	3.5	41.2
" " Oxidation	"	3	26.4	785.4
" " Inorganic Addition	"	1	1.1	10.1
Lead Oxide, Size Reduction	None	1	2	0
Lead Oxide, Size Classification	Baghouse	2	15.8	142.6
Lead Oxide, Storage Other	"	4	29.8	998.2
Maleic Anhydride Storage Other	None	5	3.5	0
Napthenic acids, Conveying	"	2		
Napthenic Acids, Separation	Furnace or Boiler Firebox	2		
Perfume & Cologne Blending	None	3	5	0
Totals			6665	278919

Source: Los Angeles County Air Pollution Control District Computer Emission  
Inventory File.