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These notes are designed to provide technical guidance to Caltrans personnel and other organizations involved in the preparation of air quality documents as part of the environmental process. They provide a ready reference and promote uniformity in performing air quality studies. These procedures and techniques discussed are meant to meet the requirements of appropriate Federal and State regulations.

Every effort has been made to cover every aspects of the problem that are within the scope of the Transportation Laboratory's expertise. As new procedures are developed and old ones modified, the changes will be incorporated into the manual and updates distributed to users. A form is included at the end of the manual for this purpose. Please submit this form to the Transportation Laboratory if you wish to be included on the mailing list for updates.

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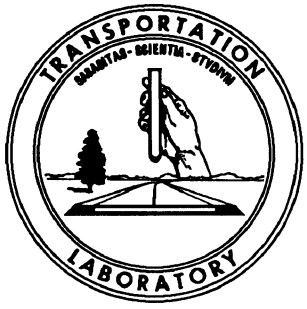

Air Quality

Technical Analysis Notes

Caltrans

State of California
Department of Transportation

State of California
Department of Transportation
Division of Construction
Office of Transportation Laboratory

AIR QUALITY

TECHNICAL ANALYSIS NOTES

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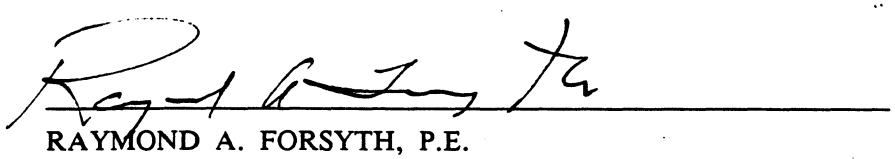

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Foreword

These notes are designed to provide technical guidance to Caltrans personnel and other organizations involved in the preparation of air quality documents as part of the environmental process. They provide a ready reference and promote uniformity in performing air quality studies. The procedures and techniques discussed are meant to meet the requirements of appropriate Federal and State regulations.

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1100 Introduction

Air quality impacts are generally assessed using one of three possible scales of analysis: microscale, mesoscale or macroscale. The dynamics of transport, dispersion and chemical transformation for a particular pollutant dictate the type of analysis most appropriate. For instance, ozone is formed as the result of a complex chain of chemical reactions involving nitrogen dioxide, hydrocarbons and sunlight. To model all the aspects of this problem, one must consider a relatively large, mesoscale region (usually the size of a typical metropolitan area). The acid rain problem can only be understood by considering an even larger, macroscale region often encompassing multiple states or nations.

While transportation facilities as a whole make significant contributions to both mesoscale and macroscale air quality problems, the impacts of a single project do not. Therefore, project-level air quality analyses need only consider impacts within the microscale region. This region is defined as the area within approximately 300 meters (1000 feet) of the transportation facility.

Carbon monoxide (CO) is considered the foremost microscale problem related to transportation sources. It is a relatively inert gas formed by the incomplete combustion of fossil fuels. Concentrations tend to peak during winter months near transportation facilities, especially where traffic volumes are high and speeds are low.

These notes provide basic guidance on the technical procedures involved in microscale CO analyses for typical highway projects. A microscale analysis involves estimation of "inputs" for the computerized prediction models, execution of a series of model "runs", and interpretation of the results.

BASICS

Introduction

The initial task of gathering input data is usually the most time consuming portion of the process. Four distinct types of information are needed:

1. Background Concentrations
2. Link/Receptor Geometry
3. Vehicle Emissions
4. Meteorology

Methods for developing input data for each of these categories will be discussed in subsequent sections of these notes. Instructions covering the use of the EMFAC7 and CALINE4 models are also included. These are the computer models used to predict composite vehicle emission factors and pollutant concentrations, respectively. A screening procedure for projects located in rural areas with minimal air quality problems is also presented.■■

1200 Air Quality Standards

Impacts are evaluated by comparing predicted air pollutant concentrations to the National Ambient Air Quality Standards (NAAQS) established by the Environmental Protection Agency (EPA). An impact is considered significant if the predicted concentration exceeds the NAAQS.

National standards have been established for the following air pollutants:

Ozone (O_3)
Carbon Monoxide (CO)
Nitrogen Dioxide (NO_2)
Sulfur Dioxide (SO_2)
Suspended Particulate Matter (PM_{10})
Lead (Pb)

Additional standards for these pollutants and several others have been adopted by the California Air Resources Board (CARB). Table 1200.1 summarizes both the National and California standards (1200-1). Note that the NAAQS are comprised of both primary and secondary standards. Primary standards are designed to protect public health, while secondary standards protect public welfare from known or anticipated adverse effects of air pollutants (e.g. reduced visibility or property damage). For our purposes, the significance of an impact will be based upon comparison with the more stringent primary standards.

The primary NAAQS and California Standards are based on medical studies which relate pollutant concentration and duration of exposure to morbidity and mortality rates for "at risk" populations. Because of this, the standard must specify both a concentration and an averaging time. As is apparent in Table 1200.1, higher concentrations can be tolerated when exposure (or averaging)

times are shorter. The averaging time plays a critical role in the modeling process.

The NAAQS for CO is established for two averaging times: 1-hour and 8-hours. These standards are not to be exceeded more than once per year. The procedures described in these notes are designed to estimate the second highest 1-hour and 8-hour annual CO concentrations (called the second annual maximum). If either of these values exceed the NAAQS, the impact is considered significant. This approach is often referred to as a "worst case" analysis. The fact that predictions are made for an assumed set of concurrent, worst case conditions guarantees a conservative estimate of the impacts.

The California CO Standards are not to be exceeded at any time. Technically speaking, an estimate of the first annual maximum would be needed to address this standard. However, the degree of resolution achievable by prediction models does not justify efforts to make this distinction.■■

Reference:

1200-1. California Air Resources Board, Aerometric Data Division, California Air Quality Data - Annual Summary Vol. XVIII , 1986

Table 1200.1 Ambient Air Quality Standards

		California Standards[1]	National Standards[2]	
POLLUTANT	AVERAGING TIME	CONCENTRATION	PRIMARY[3,4]	SECONDARY[3,5]
Oxidant[7] Ozone	1 hour 1 hour	0.10 ppm -	 0.12 ppm	 Same as Primary
Carbon Monoxide	8 hour 1 hour	9.0 ppm 20 ppm	9 ppm 35 ppm	Same as Primary
Nitrogen Dioxide	Annual Average 1 hour	- 0.25 ppm	100 ug/m^3 -	Same as Primary
Sulfar Dioxide	Annual Average 24 hour 3 hour 1 hour	 0.05 ppm 0.25 ppm	80 ug/m^3 365 ug/m^3 -	- - 1300 ug/m^3 -
Suspended Particulate Matter (PM_{10})	Annual Geometric Mean 24 hour	30 ug/m^3 50 ug/m^3	- -	- -
Suspended Particulate Matter	Annual Geometric Mean 24 hour	 -	75 ug/m^3 260 ug/m^3	60 ug/m^3
Sulfates	24 hour	25 ug/m^3	-	-
Lead	30 Day Average Calender Quarter	1.5 ug/m^3 -	 1.5 ug/m^3	 Same as Primary
Hydrogen Sulfide	1 hour	0.03 ppm	-	
Vinyl Chloride (Chloroethene)	24 hour	0.010 ppm	-	
Visibility Reducing Particles	1 observation	Visibility[6] < 10 miles with relative humidity < 70%	-	
APPLICABLE ONLY IN THE LAKE TAHOE AIR BASIN:				
Carbon Monoxide	8 hour	6 ppm	-	
Visibility Reducing Particles	1 Observation	Visibility[6] < 30 miles with relative humidity < 70%	-	

BASICS

Air Quality Standards

Table 1200.1 Ambient Air Quality Standards (Continued)

NOTES:

1. California standards, other than carbon monoxide, sulfur dioxide (1 hour) and particulate matter - PM_{10} are values that are not to be equaled or exceeded. The carbon monoxide, sulfur dioxide (1 hour) and particulate matter - PM_{10} standards are not to be exceeded.

2. National standards, other than ozone and those based on annual averages or annual geometric means, are not to be exceeded more than once a year. The ozone standard is attained when the expected number of days per calendar year with maximum hourly average concentrations above the standard is equal to or less than one.

3. All measurements of air quality are to be corrected to a reference temperature of 25°C and a reference pressure of 760 mm of Hg (1,013.2 millibar); ppm in this table refers to ppm by volume, or micromoles of pollutant per mole of gas.

4. National Primary Standards: The levels of air quality necessary, with an adequate margin of safety, to protect the public health. Each state must attain the primary standards no later than three years after that state's implementation plan is approved by the Environmental Protection Agency (EPA).

5. National Secondary Standards: The levels of air quality necessary to protect the public welfare from any known or anticipated adverse effects of a pollutant. Each state must attain the secondary standards within a "reasonable time" after the implementation plan is approved by the EPA.

6. Prevailing visibility is defined as the greatest visibility which is attained or surpassed around at least half of the horizon circle, but not necessarily in continuous sectors.

7. Measured as ozone.

1300 General Principles

Before addressing specific components of the microscale air quality analysis, it is important to introduce some general principles. The first principle deals with the so-called worst case assumption. As mentioned in the preceding section, impacts are evaluated by estimating or assuming worst case conditions for meteorology, traffic, and background concentration. These conditions must be concurrent. For example, it is incorrect to estimate an impact by combining peak afternoon traffic with worst case morning meteorology. To avoid confusion in this area, four specific time periods have been defined (1300-1):

	Time Period
MORNING	06:00 - 10:00
MIDDAY	10:00 - 17:00
EVENING	17:00 - 21:00
NOCTURNAL	21:00 - 06:00

The second principle helps define the scope of the analysis. It says that the estimated impacts must be project-related. This simply means that the analysis should only be based on time periods when the project is making significant contributions to nearby pollutant levels. For instance, high CO concentrations occurring at 02:00 should not be used in a project-level impact analysis because the project does not make a significant contribution at that time. A high nocturnal concentration is symptomatic of either a mesoscale air quality problem or a stationary source microscale problem. In either case, the transportation project does not make a significant contribution to the problem.

The third principle concerns level of effort. In gathering information for a microscale analysis, a balanced approach should be followed. Effort should not be squandered obtaining very precise estimates of one variable at the expense of another. Consideration should be given to the sensitivity of the model output to each input variable. Very little time should be spent estimating the value of variables to which the model is insensitive. The analyst should strive to optimize

BASICS

General Principals

the overall accuracy of the analysis by equalizing the level of effort spent on each variable in accordance with the model sensitivity.■■

Reference:

1300-1. W. Nokes and P. Benson, Development of Worst Case Meteorology Criteria, Caltrans, FHWA/CA/TL-85/14, November 1985.

2000 BACKGROUND CO

2100 OVERVIEW

2200 CARB/APCD DATA

2300 ON-SITE MONITORING

2310 Site Location

2320 Sampling Plan

2400 ROLLBACK FACTOR

BACKGROUND CO

Tables

Table 2320.1 Seasonal Max. Probabilities

2100 Overview

A project-level microscale analysis seeks to determine the impacts of a specific project on nearby receptors. This implies that we need only concern ourselves with the pollutant contribution from the project. However, since the significance of the impact is determined by comparison to the NAAQS, the total pollutant concentration at the receptor must be considered. This total concentration has both background and project-related components. The background component will include areawide mobile and stationary sources as well as contributions from nearby streets, intersections and parking facilities. Pollutants transported into the area from distant sources or emitted during earlier time periods may also add significantly to the background concentration.

The background concentration can be thought of as the mesoscale and macroscale components of the microscale analysis. When added to the modeled contributions from the project, a total concentration that can be compared directly to the NAAQS results:

BACKGROUND CO + PROJECT CO = TOTAL CO

There are several ways of arriving at a background concentration. The simplest is to assume a value that is conservative enough to be accepted by all. If this is not sufficiently accurate, an estimate can be based on the records of a nearby air quality monitoring station. These continuous monitoring stations are often unduly influenced by local sources, however, and may overpredict the actual background level. To overcome this problem, on-site monitoring designed specifically to measure background concentrations near the project may be necessary.■■

BACKGROUND CO

Overview

2200 CARB/APCD Data

CARB and local air pollution control districts (APCD) maintain a statewide network of continuous air quality monitoring stations. The data from these stations are used to determine whether regions have achieved attainment of the NAAQS. Most of these stations include hourly CO measurements as part of their database. The first and second-annual maximum 1-hour and 8-hour CO concentrations recorded at these stations are published by CARB in an annual summary (2200-1).

The highest second annual maximum reported over the last three years at a nearby, representative station may be used as an estimate of the background concentration. However, finding a nearby station that is representative of background conditions at a given project location is often difficult. Frequently, the stations are located near local "hot spots" and are, therefore, unrepresentative of background conditions. They do provide conservative estimates, however, that are accepted without question by reviewing agencies. Appendix 2A gives the first and second annual maximum CO concentrations at these stations for 1981 through the most recently published year. The location and exposure for all stations in the CARB summary that report CO concentrations are listed in Appendix 2B.

In District 4, the Bay Area Air Quality Management District's (BAAQMD) air quality data base has been combined with Caltrans data to produce maps showing isopleths of 1-hour and 8-hour worst case background CO concentrations (2200-2). These maps may be used in District 4 in lieu of the above procedure. To our knowledge, no other AQMD has developed similar guidelines.■■

BACKGROUND CO

CARB/APCD Data

References:

2200-1. California Air Resources Board, Aerometric Data Division, California Air Quality Data - Annual Summary.

2200-2. Bay Area Air Quality Management District, Air Quality and Urban Development Guidelines for Assessing Impacts of Projects and Plans, November 1985.

2300 On-Site Monitoring

The most dependable way to ascertain a background concentration for a given project is to initiate an on-site sampling program early in the project development process. Samples are collected by an automated bag sampling device. Bags are filled sequentially at a constant rate of flow, each bag representing a one-hour sample. Because of the inert behavior of CO, concentrations can be measured in the laboratory up to 3 days after the samples have been collected. Background sampling is recommended for projects located in urban areas that have not attained the NAAQS for CO. In such areas, project-specific background measurements under worst case conditions can be expected to be 15 to 25% lower than results from source-affected air quality monitoring stations.■■

2310 Site Location

Concentrations at background sites must represent the emissions from diverse activities and locations within a corridor. No single emissions source can dominate. The site should represent a single land-use category (e.g. residential, commercial, industrial, or rural) consistent with the planned development of the lands adjacent to the project. For example, background monitoring for a new alignment near an expanding urban core should be conducted in the developed zones nearest the project.

In cases where measurements are needed in a corridor containing an existing highway, background sites should be well removed from the immediate influence of the highway. The contributions from the existing facilities including proposed improvements will be determined by using computer models. Any contributions also accounted for in the background estimate will lead to overpredictions of the

total impact. The recommended minimum setback distance from existing facilities is:

$$d = ADT/100$$

where:

d = distance in meters
ADT = average daily traffic in vehicles/day.

2320 Sampling Plan

The sampling should take place during the winter for approximately 4 to 6 weeks. The highest 1-hour and 8-hour values recorded during this period are used as estimates of the second annual maximum background levels.(2300-1)

The sampling program should be designed so that enough days are measured to insure that the probability (P_m) of obtaining a seasonal maximum is around 0.93. P_m is calculated as:

$$P_m = 1 - (PW_1)(PW_2)(PW_3)....(PW_n)$$

where:

PW_1 = the probability from Table 2320.1 for the 1st sampled week.
PW_2 = " " " " " " " 2nd " "
PW_3 = " " " " " " " 3nd " "
PW_n = " " " " " " " last " "

For example:

If the tentative sampling plan called for measuring Monday through Friday for the last three weeks of November and the first two weeks of December then P_m would be:

$$P_m = 1 - (0.66)(0.66)(0.66)(0.49)(0.49)$$
$$\text{or } 1 - 0.07$$
$$P_m = 0.93$$

Values for P_m of less than 0.93 indicate a lower probability that the measured maximum value is equal to or less than the second annual maximum (possible under-prediction) while values greater than 0.93 have a greater probability that the highest measured value is the first annual maximum rather than the second (over-prediction).

Table 2320.1 Seasonal Max. Probabilities.

Days of the Week Sampled S M T W T F S	Month Sampled: October	November	December	January	February
* * *	0.94	0.80	0.68	0.89	0.97
* * *	0.93	0.79	0.66	0.89	0.97
* * *	0.92	0.76	0.62	0.87	0.97
* * * *	0.91	0.74	0.59	0.86	0.96
* * * *	0.90	0.71	0.55	0.84	0.96
* * * * *	0.88	0.66	0.49	0.81	0.95
* * * * * *	0.87	0.63	0.44	0.79	0.94
* * * * * * *	0 86	0.61	0.43	0.78	0.94

BACKGROUND CO

On-Site Monitoring

Reference:

2300-1. P. Benson, Measurement and Analysis of Ambient Carbon Monoxide Concentrations for Project-Level Air Quality Studies, FHWA/CA/TL-84-01, February 1984.

2400 Rollback Factor

Background concentrations obtained for a base year can be adjusted for possible changes in emissions if future year impacts are to be assessed. This is accomplished by means of a rollback factor, F_r. F_r is defined as the ratio of expected future year emissions to estimated base year emissions. In most urban areas, detailed inventories of current and projected emissions are available from the local AQMD. These inventories serve as input to the mesoscale models used to formulate regional plans for attainment of the NAAQS. Emissions, usually expressed in tons/day, are developed for "grid cells" used in the mesoscale model. A value for F_r can be computed as the ratio of the future to base year CO emissions for the grid cell(s) in the vicinity the project.

Since mobile emissions are by far the most important source of CO in urban areas, projected increases in vehicle miles traveled (VMT) and decreases in the composite vehicle emission factor (EF) can be used to estimate F_r in the absence of a gridded emissions inventory.

Values of F_r obtained from projections of averaged quantities as described above may not accurately characterize the ratio between base and future year emissions under the unique conditions likely to produce a worst case air quality impact. A study (2400-1) of seasonal maximum CO concentrations from 1971 to 1982 showed no significant correlation between predicted and observed values of F_r. Year-to-year variations in meteorology apparently had a much greater influence under these conditions. In light of these findings and the further consideration that improvements in fleet emissions are now leveling out, it is recommended that the use of F_r be discontinued except for special cases.■■

BACKGROUND CO

Rollback Factor

Reference:

2400-1. P. Benson, Measurement and Analysis of Ambient Carbon Monoxide Concentrations for Project-Level Air Quality Impact Studies, FHWA/CA/TL-84/01, February 1984.

3000 EMISSION FACTORS

3100 EMFAC7 MODEL INPUTS

- 3110 Year
- 3120 Ambient Air Temperature
- 3130 Vehicle Mix
- 3140 Percent Cold & Hot Starts
- 3150 Inspection & Maintenance Credit
- 3160 Altitude Correction
- 3170 Speed

3200 RUNNING EMFAC7

EMISSION FACTORS

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Table 3120.1	Worst Case CO Temperature
Table 3130.1	Vehicle Type Definitions
Table 3130.2	Time Period Adjustment Factors
Table 3130.3	Vehicle Mix
Table 3140.1	Urban Corridor Hot/Cold Starts
Table 3150.1	I/M Credits
Table 3160.1	MOBILE3 Ratio's of High Altitude to Low Altitude
Table 3160.2	EMFAC7 to MOBILE3 Vehicle Mix.

Figures

Figure 3110.1	CO Emissions vs Year
Figure 3140.1	Percent Cold Starts vs. v/V
Figure 3170.1	CO Emissions vs Speed

3100 EMFAC7 Model Inputs

The EMFAC7 model calculates the composite emission factors from a statistical mix of individual emission rates which are emitted from the exhaust, crankcase and evaporative systems of individual vehicles. These emission rates are modified by a number of factors which affect the composite emission factors including; operating mode, vehicle types, vehicle age distribution, speed, temperature etc. The following Sections discuss the necessary model inputs.■■

3110 Year

EMFAC7 estimates the composite emission factors from a 26 year mix of vehicle model years for any calendar year requested. Calculations are made for December 31st of the requested year and so will contain approximately three months of the following model year. For example, if emission factors are requested for the year 1995 the model output will be based on a mixture of 1970 through 1996 vehicles.

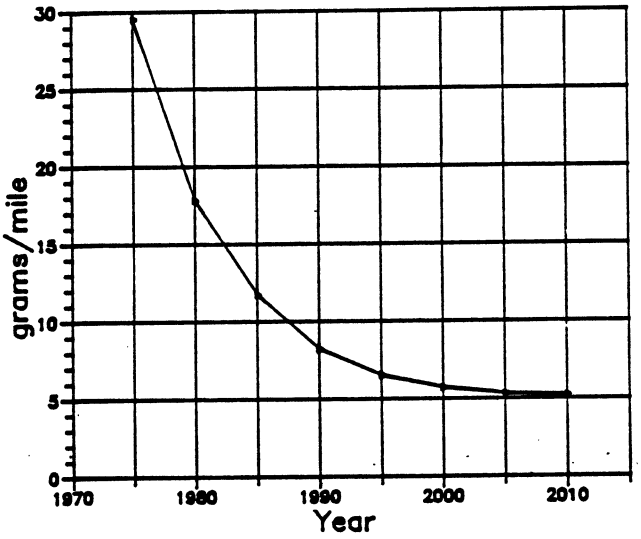
Users will usually need emission factors for the year of estimated completion of the project and the design year; this is generally 20 years, plus or minus, after project completion. In addition, intermediate year calculations may be needed for projects which involve stage construction, temporary alignments or other unusual features which may result in high CO concentrations during the interim years.

As can be seen in Figure 3110.1, there is very little change in emission factors after year 2005.■■

EMISSION FACTORS

EMFAC7 Model Inputs

Figure 3110.1 CO Emissions vs. Year.



3120 Ambient Air Temperature

The ambient air temperature has a significant effect on the emissions of vehicles, and is particularly dramatic for vehicles which are operating in the cold start mode. The lower the temperature, the greater the potential for incomplete combustion. Such conditions lead to higher emissions of CO and hydrocarbons. For a worst case 1-hour analysis the following procedure is adequate. For multihour analysis in areas with extremely low temperatures, it may be appropriate to vary the temperature with the time of day.

Procedure:

Add the appropriate temperature adjustment to the lowest January mean minimum temperature over a representative three-year period (3100-1).

Table 3120.1 Worst Case CO Temperature.

Time Period		Temperature Adjustment
Morning	(06:00-10:00)	+5 F°
Midday	(10:00-17:00)	+10 F°
Evening	(17:00-21:00)	+5 F°
Nocturnal	(21:00-06:00)	0 F°

Appendix 1 contains the National Weather Service California January mean minimum temperatures for 1984 through 1986. This period may be considered representative for the purposes of future year analysis.■■

3130 Vehicle Mix

Exhaust emissions standards for automobiles have been in effect in California since 1966. They have gradually become more stringent over the years and have been extended to include trucks and motorcycles.

The phased implementation of emissions standards means that vehicle emissions are directly correlated to vehicle age and vehicle type. To arrive at an accurate composite emission factor, vehicle age and type distributions must be considered. The vehicle age distribution is assumed to be relatively uniform throughout the state, and is, therefore, handled internally by the EMFAC7 model. The vehicle type distribution, however, can vary markedly from route to route. To account for this, percentages of the following six specific vehicle types are included as inputs to the model:

EMISSION FACTORS

EMFAC7 Model Inputs

Table 3130.1 Vehicle Type Definitions.

Vehicle Type	Gross Vehicle Weight (lb)
Light Duty Auto (LDA)	N/A
Light Duty Truck (LDT)	<6000
Medium Duty Truck (MDT)	6000 - 8500
Heavy Duty Gas Truck (HDGT)	>8500
Heavy Duty Diesel Truck (HDDT)	>8500
Motorcycle (MC)	N/A

Of these six inputs, the EMFAC7 model is most sensitive to the HDGT percentage. Because of this, the method we recommend focuses on the accurate prediction of the heavy duty truck (HDT) split. The method uses the Annual Average Daily Truck Traffic Report compiled by the Division of Traffic Engineering (3100-2), and applies factors derived from a 1985 report prepared for CARB (3100-3) and 1995 projections of diesel fuel usage for HDT (3100-4). The non-HDT split is derived from projections of vehicle miles traveled contained in Reference 3100-5. Time period adjustment factors are based on reference 3100-6.

The Annual Truck Traffic Report contains the average daily percentage of truck and non-truck traffic by route for the complete state system. It is based on a variety of sample truck counts including partial day, 24-hour and 7-day counts. The truck percentages are divided into four axle groups, from 2-axle to 5+-axle. The 2-axle classification includes 1 1/2-ton trucks with dual rear wheels and excludes all pickups and vans with only four wheels. This division is assumed to coincide with EMFAC7's HDT definition.

The user should extract truck percentages (by axle category) from the most recent annual report available for the appropriate route segment. Combined percentages for both HDT axle categories and non-HDT vehicles must then be determined. Since the axle category percentages are for HDT's only, they must be multiplied

by the total HDT percentage (in decimal form) to arrive at a combined percentage. The percent non-HDT is determined by simply subtracting the total HDT percentage from 100%.

Table 3130.2 gives the time period adjustment factors to apply to the combined daily averaged percentages determined above. Multiply each percentage by the corresponding factor that best fits the conditions of the analysis. For instance, for a morning period analysis of a freeway segment inbound to a central business district, multiply percent Non-HDT by 2.20, percent 2-Axle HDT by 1.35, etc.

Once all the five percentages have been adjusted, the results are summed and each adjusted percentage is divided by this sum and multiplied by 100 to arrive at the final adjusted HDT (by axle count) and Non-HDT percentage. To convert these five percentages to the six categories needed by EMFAC7, apply the equations given in Table 3130.3.

EMISSION FACTORS

EMFAC7 Model Inputs

Table 3130.2 Time Period Adjustment Factors.

URBAN AREAS

	Morning		Midday	Evening		Nocturnal
	Inbound	Outbound	Both	Inbound	Outbound	Both
Non- HDT	2.20	1.15	1.36	1.64	2.57	0.13
2- axle	1.35	1.71	1.74	1.78	1.58	0.23
3- axle	1.10	1.67	1.82	1.69	1.08	0.34
4- axle	0.84	1.50	1.55	1.05	1.06	0.52
5+- axle	0.98	1.06	1.23	0.91	1.12	0.89

NON-URBAN AREAS

	Morning	Midday	Evening	Nocturnal
	Both	Both	Both	Both
Non- HDT	1.36	1.53	1.79	0.16
2- axle	1.41	1.72	1.66	0.29
3- axle	1.47	1.54	1.39	0.44
4- axle	1.20	1.52	1.33	0.48
5+- axle	0.87	1.08	1.07	1.04

Table 3130.3 Vehicle Mix.

```
% LDA  = 0.80(% Non-HDT)
% LDT  = 0.14(    "    )
% MDT  = 0.05(    "    )
% HDGT = 0.50(% 2-Axle) + 0.25(% 3-Axle) + 0.10(% 4-Axle)
% HDDT = 0.50(% 2-Axle) + 0.75(% 3-Axle) + 0.90(% 4-Axle) + (% 5+-Axle)
% MC   = 0.01(% Non-HDT)
```

Example Vehicle Mix Calculation:

Problem: Calculate the morning vehicle mix for the following non-urban location data which has been extracted from the Annual Average Daily Truck Traffic report.

VEHICLE AADT TOTAL	TRUCK AADT TOTAL	TRUCK % TOT VEH	TRUCK AADT TOTAL BY AXLE 2	3	4	5+	% TRUCK AADT BY AXLE 2	3	4	5+	EAL 1-WAY (1000)	YEAR VER/ EST
22600	5039	22.3	1028	650	428	2933	20.4	12.9	8.5	58.2	1171	85E

STEP 1. Find the mix for the given AADT.

Non-HDT is equal to 100% minus the TRUCK % TOT

a. Non-HDT : 100% - 22.3% = 77.7%

The percent of each axle class is the TRUCK % TOT VEH times % TRUCK AADT BY AXLE divided by 100:

b. 2-Axle: 22.3%(20.4%) / 100 = 4.5%
c. 3-Axle: 22.3%(12.9%) / 100 = 2.9%
d. 4-Axle: 22.3%(8.5%) / 100 = 1.9%
e. 5+-Axle: 22.3%(58.2%) / 100 = 13.0%

sum = 100%

STEP 2. Adjust the mix for time of day.

Multiply the percent of each class from Step 1 by the non-urban, morning factors from Table 3130.2:

a. Non-HDT: 77.7%(1.36) = 105.7
b. 2-Axle: 4.5%(1.41) = 6.3
c. 3-Axle: 2.9%(1.47) = 4.3
d. 4-Axle: 1.9%(1.20) = 2.3
e. 5+-Axle: 13.0%(0.87) = 11.3

f. Sum the results: sum = 129.9

Normalize back to unity by dividing each class by the sum:

g. Non-HDT: 105.7 / 129.9 = 81.4%
h. 2-Axle: 7.8 / 129.9 = 4.9%
i. 3-Axle: 5.3 / 129.9 = 3.4%
j. 4-Axle: 2.9 / 129.9 = 1.8%
k. 5+-Axle: 16.0 / 129.9 = 8.7%

sum = 100%

STEP 3. Convert to the vehicle classes used in EMFAC7.

Substitute the percentages from Step 2 g-k into the equations in Table 3130.3

a. % LDA : 0.80 X 81.4% = 65.1%
b. % LDT : 0.14 X 81.4% = 11.4%
c. % MDT : 0.05 X 81.4% = 4.1%
d. % HDGT: 0.50(4.9%) + 0.25(3.4%) + 0.10(1.8%) = 3.5%
e. % HDDT: 0.50(4.9%) + 0.75(3.4%) + 0.90(1.8%) + 11.6% = 15.3%
f. % MC : 0.01 X 81.4% = 0.8%

sum = 100%

If construction of the project is expected to change the current vehicle mix, apply the same methodology to whatever truck/nontruck split is appropriate. If a future split by axle group is not available, prorate the existing split (from the annual report) over the projected truck fraction.

REMINDER:

For worst case CO analysis the % HDGT's is the most critical component of the vehicle mix.■■

3140 Percent Cold & Hot Starts

Fuel is not easily vaporized in a cold or partially warmed-up engine. To achieve an air-to-fuel mixture at the proper ratio for ignition, excess fuel must be used. Much of the unvaporized portion of this fuel passes into the exhaust as unburned or partially burned carbon compounds. For catalyst-equipped vehicles, the ability to deal with the resulting excess CO and hydrocarbon emissions is severely limited during start-up by the low efficiency of the cold catalytic converter.

EMFAC7 treats transient start-up emissions as a weighted component of the composite emission factor. Ambient temperature, vehicle soak time and fraction of vehicles in the start-up phase (defined as the first 505 seconds or 3.59 miles of operation) are the important variables in determining the transient emissions. The ambient temperature dictates the baseline temperature of the engine and catalyst at start-up. The colder the initial temperature of both engine and catalyst, the greater the excess emissions. The soak time is the elapsed time between engine operations. It determines the extent to which the system has cooled while the engine is off. Depending on the length of the soak and the type of vehicle (catalyst or noncatalyst), a start is categorized as either hot or

cold. The EMFAC7 user must input estimates of the percentage of vehicles in both the hot-start and cold-start modes of operation.

Warm-up of engine and catalyst is a continuous and relatively smooth process, dependent primarily upon the size of the engine and the rigor of the driving cycle. Transient emissions will be very high immediately following start-up, but will gradually decrease to zero by the time the engine achieves a stable operating temperature (3100-7, 3100-8). In urban corridors, more vehicles tend to be in the latter stages of the start-up phase because they are drawn from a larger area of potential trip origins. This skewed distribution tends to decrease the net excess start-up emissions for urban microscale applications. A correction can be applied to the percentage of hot/cold-starts to account for this effect (3100-9).

To compute the corrected percentage or fraction, c^ft, of vehicles in either the hot or cold transient modes, the following formula may be used:

$$c^ft = \frac{f_t v}{V}\left[R - W\left[\frac{3}{2} - \frac{W}{R} + \frac{W^2}{4R^2}\right] - 3r_a\left[1 - \frac{W}{R} + \frac{W^2}{3R^2}\right] + 3r_a^2\left[\frac{1}{R} - \frac{W}{2R^2}\right] - \frac{r_a^3}{R^2}\right] \qquad \text{eq(1)}$$

where:
c^ft = Corrected transient fraction.
f_t = Fraction of attracted vehicles in transient mode.
v = Number of vehicles attracted to the highway in vehicles per hour per mile.
V = Highway Traffic Volume in vehicles per hour.
W = Corridor 1/2 width in miles.
R = 3.59 miles.
r_a = Highway access distance.

If W equals R, and r_a is assumed to be zero, the equation simplifies to:

$$c^ft = \frac{f_t v R}{4V} \qquad \text{eq(2)}$$

The simplified form is appropriate for most freeway segments in heavily

urbanized corridors. The correction equation may be applied singly to aggregated traffic inputs, or separately to an appropriate split of traffic inputs. Separate application is recommended when there is asymmetry in either flow direction or corridor width. It is assumed that both peak hour mainline (V) and on-ramp volumes (used to calculate v) will be available from the project traffic report or that they can be reasonably estimated. If this information is not available, a value of 0.1 may be assumed for v/V for urban freeways.

If a specific estimate of the fraction of entering vehicles in transient mode (either hot or cold) is not available, the percentages in Table 3140.1 can be assumed for urban corridors.

Table 3140.1 Urban Corridor Hot/Cold Starts.

	f_t (%)	
	Hot-Starts	Cold-Starts
Peak	10	50
Off-peak	30	30

Figure 3140.1 illustrates the relationship between the v/V ratio and the adjusted percent cold starts for several values of f_t.

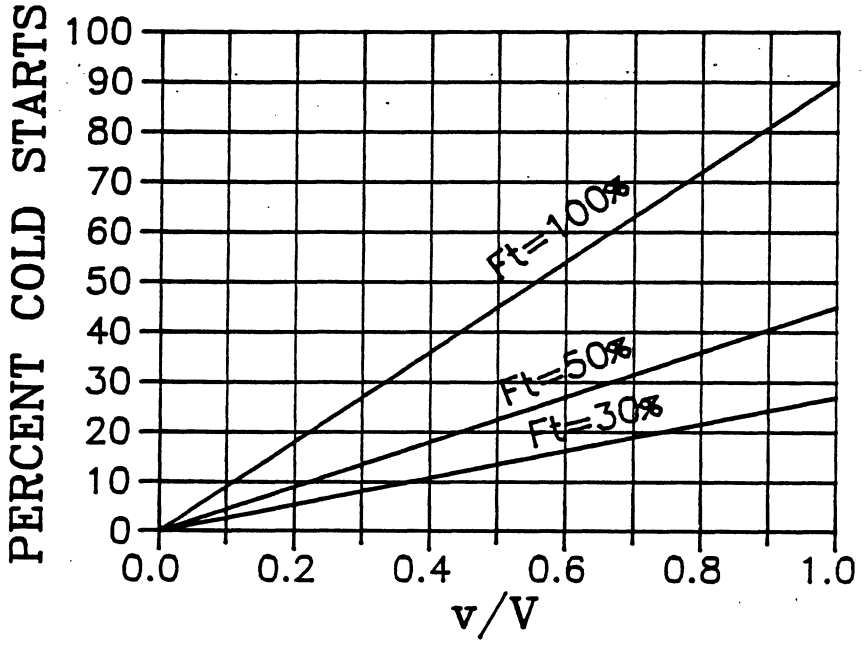
For special situations, these estimates may not apply. For instance, if all entering trips are generated within a narrow corridor such as a coastal strip, values approaching 100% cold-starts might be expected during peak hours. Conversely, if few trips are generated near the facility, the above estimates will be too high. For special circumstances consult the project engineer responsible for the traffic projections.

In the absence of the hourly traffic volumes necessary to calculate v/V, rough estimates of corrected percent cold starts for some generalized locations can be obtained from Figure 6220.1 of the Screening Procedure Section. These curves are derived for a morning commute route transecting rural and residential

communities. Percent hot starts can be assumed to be about one-fifth of the cold start values.

Another source of recommendations on cold start percentages is FHWA Technical Advisory T 6640.9. Remember that their recommendations do not account for the skewed distribution of transient emissions shown in equation 1.■■

Figure 3140.1 Percent Cold Starts vs. v/V



3150 Inspection and Maintenance Credit

For projects located in areas of the state covered by the biennial smog check program, emissions may be reduced for inspected vehicles by the following amounts (3100-10):

Table 3150.1 I/M Credits.

Pollutant	I/M Credit (for LDA & LDT only) 1984 and later years % Reduction	
CO	9.8 %	
TOG	12.3 %	
NO_x	0 %	
NO_x	3.9 %	(South Coast Air Basin Only)

The I/M credits are available in the Caltrans version of the EMFAC7 program on Timeshare and will be calculated if the users request them. The credit is applied only to the inspected vehicle types and thus the composite emission factors may show less decrease than the listed credits.■■

3160 Altitude Correction

Because the air is thinner at higher altitudes, automobile engines tend to operate at a lower air to fuel ratio leading to higher emission rates for CO and HC.

The EMFAC7 model does not contain any methodology for making adjustments to emission rates due to changes in elevation.

The current recommendation is that no altitude adjustment be made for projects where the average elevation is below 4000 feet. For projects above 4000 feet the

EMFAC7 emission factors should be adjusted by using the ratio of the MOBILE3 49 state low altitude and 49 state high altitude emission factors.

The values in Table 3160.1 may be used to adjust the EMFAC7 emission factors for high altitude projects in areas where the CO standards are not expected to be exceeded. Multiply the EMFAC7 emission factor by the appropriate ratio from the table.

Table 3160.1 MOBILE3 Ratio's of High Altitude to Low Altitude.

	0 % Cold Starts 0 % Hot Starts			20.6 % Cold Starts 27.0 % Hot Starts			100 % Cold Starts 0 % Hot Starts		
mph	1991	1996	2006	1991	1996	2006	1991	1996	2006
5	2.0	2.3	2.4	1.8	2.0	2.1	1.5	1.7	1.8
10	1.5	1.6	1.6	1.4	1.4	1.4	1.1	1.2	1.2
15	1.5	1.5	1.5	1.3	1.3	1.3	1.1	1.1	1.1
20	1.6	1.6	1.6	1.4	1.4	1.4	1.2	1.1	1.1
25	1.6	1.6	1.6	1.5	1.4	1.4	1.2	1.2	1.2
30	1.7	1.7	1.7	1.5	1.5	1.5	1.3	1.2	1.2
35	1.8	1.7	1.7	1.6	1.5	1.5	1.3	1.3	1.2
40	1.9	1.9	1.9	1.7	1.7	1.6	1.5	1.4	1.4
45	2.2	2.2	2.2	2.0	2.0	2.0	1.7	1.7	1.6
50	2.5	2.7	2.7	2.3	2.4	2.4	2.1	2.1	2.0
55	2.7	2.9	3.0	2.5	2.7	2.7	2.3	2.3	2.3

Ratio's derived by dividing the composite emission factors for Region=High by Region=Low for ambient temperature 30° F using the following vehicle mix:
LDGV = 69.5% LDDV = 2.0% LDGT1= 12.1% LDDT = 0.4%
LDGT2= 4.5% HDDV = 8.4% HDGV = 2.2% MC = 0.9%

For projects where a more accurate high altitude adjustment is needed use the following procedure:

a. Run EMFAC7 for the appropriate year, temperature, speed, % cold starts, % hot starts, and vehicle mix. Use the EMFAC7 Table 1 output, ESTIMATED TRAVEL FRACTIONS, (% VMT), to adjust the 6 vehicle types used in EMFAC7 to the 8 vehicle types used in MOBILE3 as follows:

Table 3160.2 EMFAC7 to MOBILE3 Vehicle Mix.

MOBILE3 Veh. Mix		EMFAC7 Veh. Mix
LDGV	=	%LDA X (%LDA_NCAT + %LDA_CAT) / 10000
LDGT1	=	%LDT X (%LDT_NCAT + %LDT_CAT) / 10000
LDGT2	=	%MDT X (%MDT_NCAT + %MDT_CAT) / 10000
HDGV	=	%HDG / 100
LDDV	=	%LDA X %LDA_DIESEL / 10000
LDDT	=	%LDT X %LDT_DIESEL / 10000
HDDV	=	%HDD / 100
MC	=	%MC / 100

Total = 1.000

b. Make two runs of MOBILE3, one for 49 state low altitude, and one for 49 state high altitude. Use the same temperature and speeds as used in the EMFAC7 run and the vehicle mix calculated in (a.) above. Make the MOBILE3 runs for 1 year later than the EMFAC7 runs (EMFAC7 calculates December 31 of the requested year, MOBILE3 calculates January 1).

c. Multiply the EMFAC7 emission factor by the MOBILE3 49-high and divide by the MOBILE3 49-low.■■

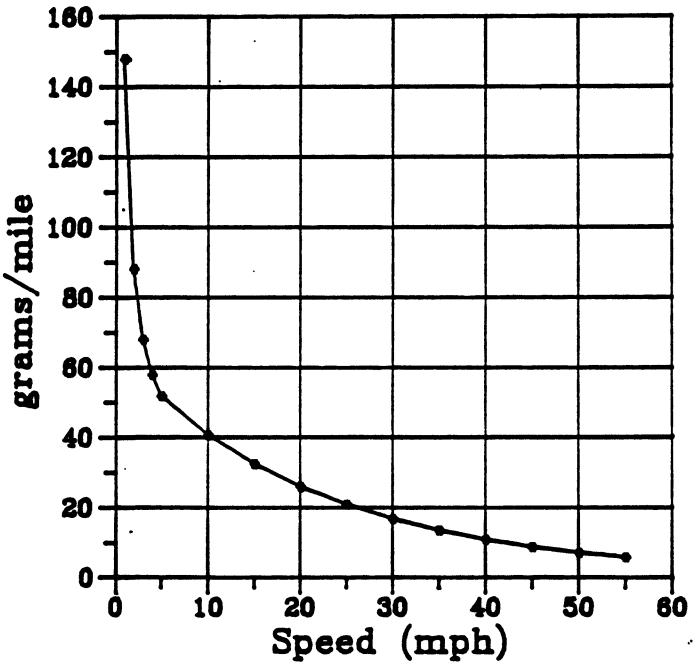
3170 Speed

CO emissions rates, in grams/mile, are high during engine idle mode and decrease as the engine speed is increased. The overall CO emission rate is influenced significantly by the amount of idle and low speed operation. As can be seen in Figure 3170.1, at lower speeds, changes of just a few mph can make radical changes in the emission factors. Fortunately this steep climb in emission

rates at low speeds is usually partially offset by an accompanying decrease in traffic volumes (levels of service E and F).

In congested urban corridors, the average vehicle speeds should be obtained from existing speed profiles, accepted traffic models or algorithms. It is expected that this information will be available from the appropriate district functional unit. For free flowing freeways or highways in rural settings, the posted speed limit may be used. In either case, the assigned vehicle speed should represent the average route speed (including idle time, accelerations, etc.) for the time period being considered (usually the peak hour).■■

Figure 3170.1 CO Emissions vs. Speed



EMISSION FACTORS

EMFAC7 Model Inputs

References:

3100-1. W. Nokes and P. Benson, Development of Worst Case Meteorology Criteria, Caltrans, FHWA/CA/TL-85/14, November 1985.

3100-2. E. Stoker, Annual Average Daily Truck Traffic on the California State Highway System, Caltrans, Division of Traffic Engineering, August 1985.

3100-3. Y. Horie and R. Rapoport, Assessment of Heavy-Duty Gasoline and Diesel Vehicles in California: Population and Use Patterns, California Air Resources Board, Contract No. A2-155-32, July 1985.

3100-4. J. Faucett Associates, California Freight Energy Demand Model, California Energy Commission, Contract No. 300-80-091, June 1983.

3100-5. California Motor Vehicle Stock, Travel and Fuel Forecast for the 1986 STIP Fund Estimate and the Statewide Transportation System Plan, Caltrans, Division of Transportation Planning, October 1985.

3100-6. 1967 Classified Vehicle Study, Caltrans, December 1970.

3100-7. T. P. Midurski and A. H. Castaline, Determination of Percentages of Vehicles Operating in the Cold Start Mode, Report EPA-450/3-77-023, U.S. Environmental Protection Agency, Research Triangle Park, 1977.

3100-8. K. J. Brodtman and T. A. Fuca, Determination of Hot and Cold Start Percentages in New Jersey, Report FHWA/NJ-84/001, New Jersey Department of Transportation, Trenton, 1984.

3100-9. P. E. Benson, Corrections to Transient Vehicle Fraction for Microscale Modeling, Presented at the 66th Annual Meeting of the Transportation Research Board, Washington, D. C., 1987.

3100-10. Sierra Research Inc., Evaluation of the California Smog Check Program, Submitted to the California I/M Review Committee, 1986.

3200 RUNNING EMFAC7

The Translab supports a version of EMFAC7C (3200-1) on the statewide VM/CMS timesharing system. The Translab's EMFAC7C includes the summary program ENV028 which creates composite emission factors based on the vehicle mix and the various percentages of each operating mode.

Before attempting to use the program, users should determine if the timeshare account that they are using has sufficient memory to run the program. Many timeshare accounts have a virtual machine size of only 1.5 meg (1536k) and this is not enough space to run EMFAC7. The virtual machine size can be checked from CMS by typing in the command:

```
CP QUERY VIRTUAL STORAGE   (or Q STOR for short)
```

The system will respond with the account's virtual machine size:

```
STORAGE = 04096K
```

Use VMSECURE to increase the virtual machine size if necessary. The exact amount of storage necessary to run EMFAC7 is dependent on the environment from which the program is invoked and it is suggested that if the user needs to increase his machine size that it be increased to 4 meg (4096k) which is the current maximum allowed. Remember that if a different machine size has been requested through VMSECURE the account must be logged off and then logged back on before the new machine size takes effect.

The program is run like any other Caltrans library program:

```
RUN EMFAC7C
```

The program will then display the input screen:

RUNNING EMFAC7

```
                              EMFAC7C
Title  EMFAC7C
Year   1987

Cold Starts   0    %
Hot  Starts   0    %
                Min Max Inc Min Max Inc Min Max Inc Min Max Inc
Temp.  (degF)   30_ 85_ 5__ ___ ___ ___ ___ ___ ___ ___ ___ ___
Speed  (mph)    5__ 55_ 5__ ___ ___ ___ ___ ___ ___ ___ ___ ___

Vehicle Mix  % LDA  100
             % LDT  0
             % MDT  0
             % HDG  0
             % HDD  0
             % MYC  0

Pollutants  CO     Y (y/n)     N I&M (y/n)
            HC     N (y/n)     N I&M South Coast Air Basin (y/n)
            NOx    N (y/n)
            Part.  N (y/n)

Message: Hit <<ENTER>> to Start or <<PF3>> to Quit
```

Change any of the default parameters as necessary before hitting the ENTER key to execute the program.

Valid input parameters and limitations are:

Title	any string of 1 to 64 characters.
Year	any For CO any year prior to 1965 will yield the same emission rates. For future years there is no change after 2020 and very little change after 2010. There is less than a 1% decrease in CO emissions between 2010 and 2020 and the 2010 emission factors can probably be used for any year after 2010.
Cold Start %	0 to 100%
Hot Start %	0 to 100% Note: Hot Stabilized is calculated as 100% - (ColdStart% + HotStart%)
Temp	0 to 110 deg F. A maximum of 12 temperatures per run starting at the minimum temperature and increasing by the increment amount through the maximum temperature.
Speed	0 to 60 mph A maximum of 29 speeds per run starting at the minimum and increasing by the increment amount through the maximum. Irregardless of user input, the program always calculates and outputs the emission factors for 26 mph for use in combining the cold and hot starts with the hot stabilized running emissions. Thus up to 29 speeds plus 26 mph can be output. Speeds below 5 mph (as well as 0 mph or idle) are calculated from the 5 mph rates and should be used with caution.
Vehicle Mix	Must total 100%.
Pollutants	Enter a 'y' in front of the pollutants that are to be output.
I&M	y = take Inspection & Maintenance credit for CO & HC.
I&M South Coast Air Basin	y = I&M credit for CO, HC & NOx.

Once the user hits <<ENTER>> the following messages will appear to let the user know that the program is running:

```
Entering WEIGHTS...
Entering EMFAC7C...
Entering ENV028A...
```

The output from the program is placed in the output file E7C LISTING O. If more than one run is made then each additional run is appended to the output file.

Users should group their runs so that all runs of the same year are made at the same time since rerunning the program with the same year does not require rerunning the WEIGHT program.

Upon exiting the program the message "E7C LISTING O not erased" will appear. The output file is left on the O disk so that the user may edit it as necessary.■■

RUNNING EMFAC7

Reference:

3200-1. Methodology to Calculate Emission Factors for On-Road Motor Vehicles, California Air Resources Board, Technical Support Division, Emission Inventory Branch, November 1986.

4000 DISPERSION MODELING

4100 CALINE4 MODEL INPUTS
- 4110 Site Geometry
  - 4111 Link Assignments
  - 4112 Mixing Zone Width
  - 4113 Receptor Locations
  - 4114 Surface Roughness (Z0)
- 4120 Meteorological Data
  - 4121 Mixing Height (MIXH)
  - 4122 Temperature
  - 4123 Wind Speed
  - 4124 Wind Direction
  - 4125 Stability Class
  - 4126 Sigma Theta
  - 4127 1-Hour Worst Case Met. Scenarios
- 4130 Input File Structure
  - 4131 CALINE4 Input Variables

Tables

Table 4115.1 Suggested Z0 Values
Table 4127.1 1-Hour Worst Case Met. Scenarios
Table 4131.1 CALINE4 Input Variables

4100 CALINE4 Model Inputs

CALINE4 is the latest in a series of line source air quality models developed by Caltrans. It is based on the Gaussian diffusion equation and employs a mixing zone concept to characterize pollutant dispersion over the roadway.

Historically, the CALINE series of models required relatively minimal input from the user. While CALINE4 uses more input parameters than its predecessor CALINE3, it must still be considered an extremely easy model to implement. For most applications, optional inputs can be bypassed and many other inputs can be assigned assumed worst-case values.■■

4110 Site Geometry

4111 Link Coordinates

The CALINE4 line source dispersion model represents the roadway as a series of straight line segments called links whose positions are defined by their endpoint coordinates (4100-1). A separate link must be defined whenever there is a significant change in roadway geometry (height, width or alignment), emission factor, or traffic volume. The following guidelines can be used to help establish the link network for a project.

1. Directional splits (i.e. separate links for opposite directions on a single route) are recommended for all multilane divided roadways.

2. Links should coincide with the centerline of the traveled way for all tangent sections.

DISPERSION MODELING
CALINE4 Model Inputs

3. For curved alignments, the deviation between the link and the traveled way centerline should not exceed 3 meters (10 ft).

4. No more than the minimum number of links consistent with Guideline 3 should be used to define a curved alignment.

5. The distance between any link endpoint and any receptor shall not exceed 10 kilometers (6.2 miles).

6. When a deviation from a tangent alignment occurs beyond 1 kilometer (0.6 mile) from the nearest receptor, no further link assignments are required in that direction.

7. The link network may extend beyond the limits of the project under consideration, but should not exceed the limits imposed by Guidelines 5 and 6.

8. Intersecting or paralleling arterials should only be included in the link network if their traffic volumes are significantly higher than the volumes on similar streets at the background site.

9. Ramps should only be modeled if their volumes warrant such detail and at least one receptor is located within 9 meters (30 ft) of the ramp.

10. Addition or deletion of one or more lanes (including auxiliary lanes) requires the assignment of a new link.

11. Depressed or elevated sections of roadway used for grade separation of two or more rights-of-way require the assignment of a new link. The endpoint of the new link should be located at the midpoint of the transition from the previous section.

12. Highway width and height inputs assume much less importance as link/receptor distances increase. Therefore, Guidelines 10 and 11 may be relaxed for sections of roadway with no adjacent receptors.

13. Assign a new link whenever there is a change in emission factor (usually attributable to a speed change) or traffic volume.■■

4112 Mixing Zone Width

CALINE4 treats the region directly over the roadway as a zone of uniform emissions and turbulence. The width of this "mixing zone" is defined as the width of the traveled way (traffic lanes - not including shoulders) plus 3 meters (10 ft) on either side. A median may be included in determining the mixing zone width if it is no wider than 10 meters (33 ft) and the differences in traffic volume and emission factor between directions are insignificant. This means that in most cases the mixing zone will be:

12 ft X No. of lanes + median width + 20 ft

REMINDERS:

a. If modeling parking lots, omit the extra 10 ft on each side.

b. Because of the added 10 ft on each side of the mixing cell, links will overlap when the median width is less than 20 feet. The model has no difficulty handling overlapping or superimposed links.■■

4113 Roadway Height

For each roadway link specified, CALINE4 requires an input for height. The height is defined as the vertical distance above or below the local ground level

or datum. The model cannot be used for roadway heights greater than 10 meters (33 ft) or less than -10 meters (-33 ft). Also, the model can only accept a single height input per link. Transitions in roadway height are handled by starting a new link.■■

4114 Receptor Locations

Enough receptor sites should be chosen to insure that the worst case condition is analyzed. The number of receptor sites for a project should normally not exceed 20 (the output limit for CALINE4). The locations of all receptors should be clearly indicated on a project map included in the physical environmental studies report.

Sites nearest the right-of-way where the general public or a portion thereof has continuous access are selected. These include residential yards, parks, playgrounds, buildings etc. Sensitive receptors such as schools, hospitals, child care centers, retirement and convalescent homes should always be included in the microscale analysis, even if they are not immediately adjacent to the right-of-way. Locations within the right-of-way (including pedestrian overcrossings, crosswalks, and sidewalks), agricultural lands not planned for development, parking lots, or any other locations where exposures are either transient or work-related should not be considered.

An effort should be made to select locations where the highest concentrations consistent with the 1-hour and 8-hour averaging times of the CO standard are anticipated. Sites located at the ends of long, tangent sections of highway will typically yield the highest concentrations because of the build-up of pollutants under parallel wind conditions.

Receptors height is referenced to the level of the terrain in the immediate

vicinity of the receptor. For outdoor exposures, a receptor height of 1.5 meters (5 ft) is recommended. For buildings, the height of the air intake should be used.

In the past, some analysts have chosen receptor locations at incremental distances from the highway right-of-way (e.g. 50, 100, 200 ft). This is only recommended in cases where a significant impact has already been determined at a worst case receptor and an estimate of the extent of the impact is needed.■■

4115 Surface Roughness (Z0)

Surface Roughness (Z0) affects the mechanical turbulence that is generated by the movement of air over the ground surface. As the surface roughness increases the amount of mechanical turbulence that is generated will also increase, thus enhancing the dispersion of pollutants near the ground. Use the following guidelines to estimate Z0:

1. Z0 is calculated as 15% of the average canopy height (cm).

2. Z0 should be limited to somewhere between 3 and 400 cm.

For example:
For a residential area with an average canopy height of approximately 20 ft, Z0 would be:

15%(20 ft)(30.48 cm/ft) = 91.44, or say 100 cm.

CALINE4 is not very sensitive to changes in surface roughness. Thus, a rough, order of magnitude estimate, based on the predominate land use is all that is needed in many cases. The following table may be used as a guide.■■

Table 4115.1 Suggested Z0 Values.

Land Use	Suggested Z0 (cm)
Open Ground	3
Single Family Residential	100
Parks	100
Multistory Apartments	400

4120 Meteorological Data

4121 Mixing Height (MIXH)

The mixing height algorithm is designed for modeling special nocturnal inversions. Unless you have information about local ground-based inversions, the mixing height algorithm should be bypassed by using an input of 1000 meters.■■

4122 Temperature

In CALINE4 temperature is used to convert model output in mass concentration (micrograms per cubic meter) to the volumetric concentration used for the NAAQS for CO (parts per million).

The temperature used should be consistent with the temperature used in running the emission factor model. See Section 3120 for guidance in selecting a temperature.

REMINDER:

The EMFAC model temperature input is degrees Fahrenheit (^{o}F), the CALINE4 input is in degrees Celsius (^{o}C).■■

4123 Wind Speed

Wind speed can have a very dramatic effect on CO concentrations, particularly for receptors located close to the roadway. The lower the wind speed, the higher the predicted concentration. In general, worst case CO modeling is usually done at or near the lowest wind speed that the model is capable of handling.

See AQTAN 4127 Worst Case Met. Scenarios, Table 4127.1, for recommended worst case 1-hour wind speeds.

REMINDER:

The lowest recommended wind speed for use in CALINE4 is 0.5 m/s. CALINE3's lower limit is 1.0 m/s (4100-2).■■

4124 Wind Direction

CALINE4 is capable of doing a worst wind angle search. Thus, for a worst case CO analysis the user need not be concerned with determining the prevalent wind direction from wind roses or other means. Simply code CALINE4 to do a worst wind angle search. This also allows the user to establish any convenient base for the coordinate system without concern for true north.■■

4125 Stability Class

Stability Class describes the potential of atmospheric conditions to disperse pollutants through the process of turbulent diffusion. A relatively stable atmosphere contains very little turbulence so that pollutant concentrations remain high. Unstable atmospheric conditions promote vertical mixing and, thus, lower

pollutant concentrations. The original Pasquill Stability Classifications (used in CALINE3) consisted of six classes; A, the most unstable, through F, the most stable. CALINE4 uses a modification of these stability classes to include vehicle-induced thermal effects. There are seven stability classes used in CALINE4, ranging from A through G. Because of the additions of mechanical and thermal vehicular turbulence calculations as well the addition of an independent horizontal dispersion algorithm (the sigma theta parameter), CALINE4 is not nearly as sensitive as CALINE3 to change in stability class.

See 4127 Worst Case Met. Scenarios, Table 4127.1, for recommended 1-hour stability classes and Tables 5300.1 and 5300.2 for recommended 8-hour stability classes.

REMINDER:
For CALINE3 the worst stability class is class F or (6).
For CALINE4 the worst is class G or (7).■■

4126 Sigma Theta

Sigma theta (SIGTH) is the standard deviation of the wind direction. It is used by CALINE4 to estimate the rate of horizontal dispersion of pollutants. High wind speeds tend to have low sigma theta values (wind vanes will tend to hold steady in one direction) while low wind speeds will have high sigma theta's (wind vanes will wander about). With receptors close to the roadway and parallel winds (a typical worst case scenario), changes in sigma theta can have a very dramatic effect on predicted concentrations. See 4127 Worst Case Met. Scenarios, Table 4127.1, for recommended sigma theta values.■■

4127 Worst Case Met. Scenarios

Table 4127.1 contains the 1-hour worst case recommendations for wind speed, sigma theta, stability class and delta temperature from reference 4100-3.■■

Table 4127.1 1-Hour Worst Case Met. Scenarios

1-HOUR

Time Period	Geographic Location	Wind Speed (m/s)	Sigma Theta (Deg.)	Stab. Class	Delta Temp. °F	Delta Temp. °C
MORNING (06:00-10:00)	Coastal	0.5	10	G	+5	+2.8
	Coastal Valley	0.5	20	G	+5	+2.8
	Central Valley	0.5	5	G	+5	+2.8
	Mountain	0.5	30	G	+5	+2.8
MIDDAY (10:00-17:00)	Coastal	1.0	25	D	+10	+5.6
	Coastal Valley	0.6	30	D	+10	+5.6
	Central Valley	0.5	20	D	+10	+5.6
	Mountain	0.9	30	D	+10	+5.6
EVENING (17:00-21:00)	Coastal	0.5	10	G	+5	+2.8
	Coastal Valley	0.5	10	G	+5	+2.8
	Central Valley	0.5	5	G	+5	+2.8
	Mountain	0.5	30	G	+5	+2.8
NOCTURNAL (21:00-06:00)	Coastal	0.5	5	G	0	0
	Coastal Valley	0.5	15	G	0	0
	Central Valley	0.5	10	G	0	0
	Mountain	0.5	20	G	0	0

Note: Add Delta Temp. to lowest Jan. mean min. temperature for the last three years

DISPERSION MODELING
CALINE4 Model Inputs

4130 Input File Structure

CALINE4 runs as a "batch program" . The user must first construct an input data file containing all of the necessary program inputs. Included at the end of this section are work sheets for construction of "simple, worst case CO" input data files with step by step notes on file structure, variable limits etc. These forms are intended to provide guidance to first time users of CALINE4 and do not include provisions for the more advanced problem types such as intersections, muli-hour runs etc.■■

4131 CALINE4 Input Variables

Table 4131.1 contains the CALINE4 input variables, their data type, the range of values that are normal for each variable. For numeric data, a representation of the type of output format that is used for the printed output so that the user can judge when an input may overflow/underflow an output field as well as determine the number of digits following the decimal point that should be used for input.■■

Table 4131.1 CALINE4 Input Variables

Run Time & Misc. Variables

Variable	Description	Type	Units	Range	Print Format
JOB	Job title	Char.	-	0 to 40 Chars.	
ZO	Aerodynamic Roughness Coefficient	Real	cm	3 to 400 cm	###.
NR	Number of Receptors	Int.	-	1 to 20	
NL	Number of Links	Int.	-	1 to 20	
SCAL	Scaling Factor	Real	m/UU*		
LC	Link Name Option	Int.	-	0 or 1	
RC	Receptor Name Option	Int.	-	0 or 1	
RTYP	Run Type	Int.	-		
	1 = Standard Run		-		
	2 = Multi-Run		-		
	3 = Worst-Case Wind Angle		-		
	4 = Multi-Run + Worst-Case Wind Angle (2 + 3)		-		
	5 = Last Run of Multi-Run		-		
VPHCOD	Change Traffic Volume Code	Int.	-	0 or 1	
EFLCOD	Change Emission Factor Code	Int.	-	0 or 1	
INTCOD	Change Intersection Parameters Code	Int.	-	0 or 1	
METCOD	Change Meteorology Code	Int.	-	0 or 1	
RUN	Run Title	Char.	-		

*UU = User Units

Pollutant Variables

Variable	Description	Type	Units	Range	Print Format
PTYPE	Pollutant Type:	Int.	-	1 - 4	
	1 = CO				
	2 = NO_2				
	3 = Inert Gas				
	4 = Particulate				
NAME	Pollutant Name	Char.	-	0 to 30 Chars.	
MOWT	Molecular Weight	Real	-		
VS	Settling Velocity	Real	cm/sec	>= 0 (0 for CO)	##.#
VD	Deposition Velocity	Real	cm/sec	>= 0 (0 for CO)	##.#
O3	Ambient O_3 Concentration	Real	ppm		#.##
NOA	Ambient NO Concentration	Real	ppm		#.##
NO2A	Ambient NO_2 Concentration	Real	ppm		#.##
KR	NO_2 Photolysis Rate	Real	1/s		#.###

Emissions & Traffic Variables

Variable	Description	Type	Units	Range	Print Format
VPHL	Hourly Traffic Volume	Real	vph		#####
EFL	Composite Emission Factor	Real	gm/v-m	> 0	###.#

DISPERSION MODELING

CALINE4 Model Inputs

Table 4131.1 CALINE4 Input Variables (continued)

Geometric Variables

Variable	Description	Type	Units	Range	Print Format
RCP	Receptor Name	Char.	-		
XR, YR	Receptor Coordinates	Real	UU*		######
ZR	Receptor Height Coord.	Real	UU*		###.#
LNK	Link Name	Char.	-		
TYP	Link Type 1 = At-Grade 2 = Depressed 3 = Fill 4 = Bridge 5 = Parking Lot 6 = Intersection	Int.	-		
XL1, YL1	Begin. Link Coordinates	Real	UU*		#####
CC	Link Continuation Code	Int.	-	0 or 1	
XL2, YL2	End. Link Coordinates	Real	UU*		#####
HL	Link Height	Real	UU*	-10m to +10m	##.#
WL	Link Width	Real	UU*	>= 1 lane +3m+3m	##.#
MIXWR	Canyon/Bluff Mixing Width - Right	Real	UU*	>= WL/2 (0=None)	###.
MIXWL	Canyon/Bluff Mixing Width - Left	Real	UU*	>= WL/2 (0=None)	###.

*UU = User Units

Intersection Variables

Variable	Description	Type	Units	Range	Print Format
STPL	End link to stop line distance	Real	UU*		####
DCLT	Deceleration time	Real	sec		###.
ACCT	Acceleration time	Real	sec		###.
NCYC	Number of vehicles/cycle/lane	Int.	-		####
NDLA	No. of delayed vehicles/cycle/lane	Int.	-		###
VPHO	Hourly depart volume	Real	vph		#####
EFI	Composite idle emission factor	Real	gm/v-m	> 0	##.##
IDT1	Vehicle idle time at stopline	Real	sec		###.
IDT2	Vehicle idle time at end queue	Real	sec		###.
SPD	Cruise speed	Real	mph		###.

*UU = User Units

Meteorology Variables

Variable	Description	Type	Units	Range	Print Format
BRG	Wind direction	Real	deg	0^{o} to 360^{o}	###.#
U	Wind Speed	Real	m/s	>= 0.5 m/s	###.#
CLAS	Stability Class	Int.	-	1(A) to 7(G)	
MIXH	Mixing Height	Real	m	>= 5m	####.
SIGTH	Sigma Theta Std. Dev. of Wind Dir.	Real	deg	5^{o} to 60^{o}	####.
AMB	Ambient Concentration	Real	-		##.#
TEMP	Temperature	Real	^{o}C		##.#

References:

4100-1. P. E. Benson, CALINE4 - A Dispersion Model For Predicting Air Pollution Concentrations Near Roadways, Caltrans, FHWA/CA/TL-84/15, November 1984.

4100-2. P. E. Benson, CALINE3 - A Versatile Dispersion Model for Predicting Air Pollutant Concentrations Near Roadways, Caltrans, FHWA/CA/TL-79/23, November 1979.

4100-3. W. Nokes and P. Benson, Development of Worst Case Meteorology Criteria, Caltrans, FHWA/CA/TL-85/14, November 1985.

DISPERSION MODELING

CALINE4 Model Inputs

CALINE4 WORKSHEET 1

Surface Roughness (ZO)

Land use	Approx. ZO (m)
Open Ground	3
Single Family Residential	100
Park	100
Multi-story Apts	400
CBD	300
(or 15% average canopy height)	

Notes:

(f) Formatted Record.

Unformatted records should have at least 1 blank between numbers.

Pollutant Type No. (PTYP)
1 = CO 3 = Inert Gas
2 = NO_2 4 = Particulate

CALINE4			
DIST	CO	RTE	PM
DESCRIPTION			

① **Job Title**

② **PTYP & Pollutant Name**

1,C,O, (f)

③ ZO	MOWT	VS	VD	NR	NL	SCAL	LC	RC
.	28.	0.	0.			0.3048	1	1

	④ Receptor Description	⑤ Receptor Coordinates X	Y	Z
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				

STEP ① Enter Title Line. (40 char max.)

STEP ② Enter Pollutant Type Number & Pollutant Name.
This line is a "formatted record", the PTYP number must be in column 1.

STEP ④ Enter Receptor descriptions for all receptors.
1 to a line, 8 characters max.

STEP ⑤ Enter the Receptor X, Y, & Z coordinates.
1 set per line.

STEP ③ Enter a line containing:

ZO Surface Roughness
MOWT Molecular Weight of pollutant (CO=28)
VS Settling Velocity (use 0.)
VD Deposition Velocity (use 0.)
NR Number or Receptors (1 - 20)
NL Number of Links (1 - 20)
SCAL Scaling Factor (feet = 0.3048, meters = 1)
LC Link Description Code (1 = user description, 0 = program)
RC Reception Description Code (1 = user description, 0 = program)

DISPERSION MODELING

CALINE4 Model Inputs

CALINE4 WORKSHEET 2

	CALINE4			
STEP 6 Enter Link Descriptions (12 char. max.)	DIST	CO	RTE	PM
	DESCRIPTION			
STEP 7 Enter link type # (TYP), coordinates (XL1, YL1, XL2, YL2), height (HL), width (WL), right & left mixing walls, (MIXWR, MIXWL) & continuation code (CC).				

Notes:

(f) Formatted Record.

Unformatted records should have at least 1 blank between numbers.

Link Type #'s (TYP)
1 = At Grade
2 = Depressed
3 = Fill
4 = Parking Lot
5 = Intersection

* NOTE: When the Continuation Code on the previous link is set to 1 then omit XL1 & YL1

TYP	XL2	YL2	HL	HW	MIXWR	MIXWL	CC

⑥

A	B	C
D	E	F
G	H	I
J	K	L
M	N	O
P	Q	R

S T

⑦

	Link Type #	Link Coordinates				Link Height	Link Width	Distance to Canyon Wall Right	Distance to Canyon Wall Left	Continuation Code*
	TYP	XL1	YL1	XL2	YL2	HL	WL	MIXWR	MIXWL	CC
A										
B										
C										
D										
E										
F										
G										
H										
I										
J										
K										
L										
M										
N										
O										
P										
Q										
R										
S										
T										

DISPERSION MODELING

CALINE4 Model Inputs

CALINE4 WORKSHEET 3

SUGGESTED WORST CASE 1-HR MET. SCENARIOS	MORNING 06:00-10:00 U	CLAS	SIGTH	MIDDAY 10:00-17:00 U	CLAS	SIGTH
COASTAL	0.5	7(G)	10	1.0	4(D)	25
COASTAL VALLEY	0.5	7(G)	20	0.6	4(D)	30
CENTRAL VALLEY	0.5	7(G)	5	0.5	4(D)	20
MOUNTAIN	0.5	7(G)	30	0.9	4(D)	30
	EVENING 17:00-21:00 U	CLAS	SIGTH	NOCTURNAL 21:00-06:00 U	CLAS	SIGTH
COASTAL	0.5	7(G)	10	0.5	7(G)	5
COASTAL VALLEY	0.5	7(G)	10	0.5	7(G)	15
CENTRAL VALLEY	0.5	7(G)	5	0.5	7(G)	10
MOUNTAIN	0.5	7(G)	30	0.5	7(G)	20

CALINE4			
DIST	CO	RTE	PM
DESCRIPTION			

STEP (8) Enter a line containing the run type code (RTYP), four change codes, and run title. This line is a "formatted record". RTYP must be in col. 1, VPHCOD in col. 2, etc.

STEP (9) Enter the hourly traffic volumes for each link.

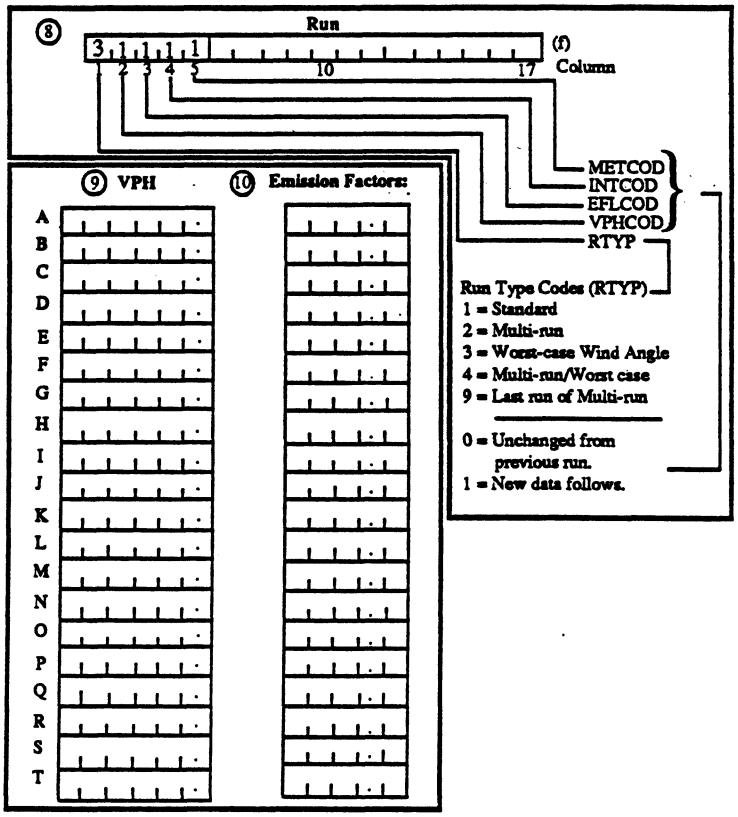
STEP (10) Enter the Emission Factors for each link.

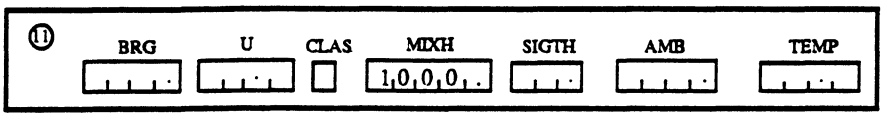
STEP (11) Enter a line containing :

- BRG Wind direction
- U Wind speed in m/s (min.=0.5 m/s)
- CLAS Stability Class # (1=A to 7=G)
- MIXH Mixing Height (m)
- SIGTH Sigma Theta, standard deviation of wind direction
- AMB Ambient Level
- TEMP Temperature (°C)

LAST. For additional runs return to STEP (8) For example, to future traffic, code re-run the same problem with
VPHCOD = 1
EFLCOD = 1
INTCOD = 0
METCOD = 0
STEP 8 line: 31100BUILD 2010
Repeat STEPS 9 & 10.

Notes: (f) Formatted Record.
Unformatted records should have at least 1 blank between numbers.





5000 EIGHT-HOUR ANALYSIS

5100 INTRODUCTION

5200 PERSISTENCE FACTOR

5300 MULTIPLE HOUR RUN

EIGHT-HOUR ANALYSIS

Tables

Table 5200.1	Suggested Eight-Hour Persistence Factors
Table 5300.1	Recommended 8-Hour Worst Case Met. - Case 1
Table 5300.2	Recommended 8-Hour Worst Case Met. - Case 2

5100 Introduction

Changes in meteorology and traffic over time invariably cause peak 8-hour CO concentrations to be less severe than peak 1-hour values. Shifts in wind speed and direction alter transport and enhance horizontal dispersion. Temperature changes have a direct effect on the composite emission factor. Daily fluctuations in traffic (e.g. volume, speed, % cold starts) change the overall emissions. It is extremely unlikely that peak 1-hour conditions for all these variables will prevail for a full eight hours.

One way to predict peak 8-hour concentrations is to execute a multiple-hour run. The procedure for doing this is described in the CALINE4 report (5100-1). The approach requires hourly data for meteorology, traffic and emissions.

The persistence factor can be used as an alternative approach to the multiple-hour run. It is expressed as a ratio of the 8-hour to 1-hour second annual maximum CO concentrations. One simply multiplies the predicted 1-hour value by the persistence factor to obtain an estimate of the corresponding 8-hour value. Use of the persistence factor is not appropriate when there are significant differences in the distribution of hourly traffic volumes between project alternatives.■■

EIGHT-HOUR ANALYSIS

Introduction

Reference:

5100-1. P. E. Benson, CALINE4 - A Dispersion Model For Predicting Air Pollution Concentrations Near Roadways, Caltrans, FHWA/CA/TL-84/15, November 1984.

5200 Persistence Factor

The persistence factor is defined in these guidelines as a ratio between the 8-hour and 1-hour second annual maximum CO concentrations measured at a continuous monitoring station. It incorporates the persistence of both meteorological variables and emissions. The 1-hour and 8-hour measurements may occur on the same day or separate days, but must be chosen from the same calendar year (5200-1). The maximum ratio over the most recent three years for which information is available is used. Persistence factors extracted from the California Air Resources Board Annual Summaries for 1981 through the most recently published year are given in Appendix 2A.

If no nearby representative monitoring station exists, use the following:

Table 5200.1 Suggested Eight-Hour Persistance Factors.

Persistence Factor	Land Use Category
0.6	Rural and suburban.
0.7	Urban locations.
0.8	Urban sites with a recognized tendency for persistent stagnant meteorological conditions and/or persistent traffic congestion.■■

EIGHT-HOUR ANALYSIS

Persistence Factor

Reference:

5200-1. W. Nokes and P. Benson, Development of Worst Case Meteorology Criteria, Caltrans, FHWA/CA/TL-85/14, November 1985.

5300 Multiple Hour Run

Circumstances may arise that preclude the use of a persistence factor. The best example of this is a situation in which two project alternatives with traffic peaks of similar magnitude, but different duration, must be compared. Since the traffic volumes and emission factors for the 1-hour analysis are similar, the difference between the predicted 1-hour CO concentrations will be small. If a single persistence factor is applied to these 1-hour values, the difference between the 8-hour values will also be small. Yet, the project alternative with the longer traffic peak should yield a significantly higher 8-hour CO concentration.

To handle this kind of problem effectively, a standard set of worst case 8-hour meteorological scenarios can be used in conjunction with the CALINE4 multiple hour run option. Table 5300.1 represents scenarios typical of persistent low wind speeds. Table 5300.2 represents scenarios typical of persistent wind direction. The scenarios are categorized by time of day and geographic location. The "peak" conditions are assumed to persist for three hours and include all or a portion of the traffic peak. The "off-peak" conditions are assumed to persist for the remaining five hours. Computer runs should be made for the appropriate scenario from both tables, with the highest result being reported. As with the 1-hour analysis, the worst case wind angle option should be used. Corrections for wind direction variability are made through the sigma theta parameter.■■

EIGHT-HOUR ANALYSIS

Multiple Hour Run

Table 5300.1 Recommended 8-Hour Worst Case Met. - Case 1

Case 1: Persistent Low Wind Speed

Time Period	Geographic Location	PEAK(1) Wind Speed (m/s)	PEAK(1) Sigma Theta (Deg.)	PEAK(1) Stab. Class	PEAK(1) Delta Temp.(3) °F	PEAK(1) Delta Temp.(3) °C	OFF-PEAK(2) Wind Speed (m/s)	OFF-PEAK(2) Sigma Theta (Deg.)	OFF-PEAK(2) Stab. Class	OFF-PEAK(2) Delta Temp.(3) °F	OFF-PEAK(2) Delta Temp.(3) °C
MORNING (06:00-10:00)	Coastal	0.5	45	G	+5	+2.8	1.5	30	D	+10	+5.6
	Coastal Valley	0.5	45	G	+5	+2.8	1.0	45	D	+10	+5.6
	Central Valley	0.5	45	G	+5	+2.8	0.5	45	D	+10	+5.6
	Mountain	0.5	45	G	+5	+2.8	1.5	30	D	+10	+5.6
MIDDAY (10:00-17:00)	Coastal	0.5	45	G	+5	+2.8	1.5	30	D	+10	+5.6
	Coastal Valley	0.5	45	G	+5	+2.8	1.0	45	D	+10	+5.6
	Central Valley	0.5	45	G	+5	+2.8	0.5	45	D	+10	+5.6
	Mountain	0.5	45	G	+5	+2.8	1.5	30	D	+10	+5.6
EVENING (1700:21:00)	Coastal	0.5	45	G	+5	+2.8	0.5	45	D	+5	+2.8
	Coastal Valley	0.5	45	G	+5	+2.8	0.5	45	D	+5	+2.8
	Central Valley	0.5	45	G	+5	+2.8	0.5	45	D	+5	+2.8
	Mountain	0.5	45	G	+5	+2.8	0.5	45	D	+5	+2.8

(1) Use Peak values for 3 of the 8 hours.
(2) Use Off-Peak values for the remaining 5 hours.
(3) Add Delta Temp. to lowest January mean minimum temperature for the last three years.

EIGHT-HOUR ANALYSIS

Multiple Hour Run

Table 5300.2 Recommended 8-Hour Worst Case Met. - Case 2

Case 2: Persistent Wind Direction

Time Period	Geographic Location	PEAK(1) Wind Speed (m/s)	PEAK(1) Sigma Theta (Deg.)	PEAK(1) Stab. Class	PEAK(1) Delta Temp.(3) °F	PEAK(1) Delta Temp.(3) °C	OFF-PEAK(2) Wind Speed (m/s)	OFF-PEAK(2) Sigma Theta (Deg.)	OFF-PEAK(2) Stab. Class	OFF-PEAK(2) Delta Temp.(3) °F	OFF-PEAK(2) Delta Temp.(3) °C
MORNING	Coastal	1.0	20	G	+5	+2.8	2.0	20	D	+10	+5.6
(06:00-10:00)	Coastal Valley	1.0	20	G	+5	+2.8	2.0	20	D	+10	+5.6
	Central Valley	0.5	20	G	+5	+2.8	1.0	20	D	+10	+5.6
	Mountain	1.0	20	G	+5	+2.8	2.0	20	D	+10	+5.6
MIDDAY	Coastal	1.0	20	G	+5	+2.8	2.0	30	D	+10	+5.6
(10:00-17:00)	Coastal Valley	1.0	20	G	+5	+2.8	2.0	45	D	+10	+5.6
	Central Valley	1.0	20	G	+5	+2.8	1.0	45	D	+10	+5.6
	Mountain	1.0	20	G	+5	+2.8	2.0	30	D	+10	+5.6
EVENING	Coastal	1.0	20	G	+5	+2.8	1.0	20	G	+5	+2.8
(1700:21:00)	Coastal Valley	1.0	20	G	+5	+2.8	1.0	20	G	+5	+2.8
	Central Valley	1.0	20	G	+5	+2.8	1.0	20	G	+5	+2.8
	Mountain	1.0	20	G	+5	+2.8	1.0	20	G	+5	+2.8

(1) Use Peak values for 3 of the 8 hours.
(2) Use Off-Peak values for the remaining 5 hours.
(3) Add Delta Temp. to lowest January mean minimum temperature for the last three years.

EIGHT-HOUR ANALYSIS

Multiple Hour Run

Reference:

5200-1. W. Nokes and P. Benson, Development of Worst Case Meteorology Criteria, Caltrans, FHWA/CA/TL-85/14, November 1985.

6000 MICROSCALE CO SCREENING PROCEDURE

6100 PROCEDURE
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  - 6131 Year
  - 6132 Speed
  - 6133 Temperature
  - 6134 Cold Start Adjustment
  - 6135 Inspection & Maintenance Credit
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MICROSCALE CO SCREENING PROCEDURE

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Table 6130.2	Cold Start Factors
Table 6130.3	Cold Start Curves
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Figure 6140.1	Receptor Distance & Link Width
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Figure 6140.2B	Dispersion Factors - Sigma Theta 10^{o}
Figure 6140.2C	Dispersion Factors - Sigma Theta 30^{o}
Figure 6160.1	Example 1
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Figure 6220.1	Corrected Percent Cold Starts
Figure 6220.2	Transient Trip Area

MICROSCALE CO SCREENING PROCEDURE

6100 Procedure

This section is intended to update the CO MICROSCALE SCREENING PROCEDURE contained in the Guidelines and Technical Procedures for Assessing the Air Quality Impact of Transportation Projects, issued July 30, 1984, which was based on the CALINE3 dispersion model and the EMFAC6D emission factor model. This latest procedure is based on the CALINE4 dispersion model, the EMFAC7C emissions model and includes the benefits of recent work in estimating cold start mode transient emissions.

The screening procedure is a relatively simple analysis technique to determine if a proposed project is likely to pose a threat to air quality. It is aimed primarily at projects with low traffic volumes in relatively undeveloped and unpopulated areas. In these cases, predicted concentrations from the proposed project as well as the background concentrations should be low enough so that impacts can be conservatively estimated and still meet air quality standards. If the predictions from the screening procedure exceed the standards, then a more detailed analysis is called for. The screening procedure should not be used for projects located in heavily urbanized area.■■

6110 Introduction

The microscale analysis is composed of two elements, the background CO level and the project contribution. Background CO is generally defined as that part of the ambient CO concentration that is attributable to areawide and local sources not specifically modeled in the microscale analysis. The project contribution is estimated from three components; an estimate of the number of vehicles (peak hour traffic volumes); a dispersion factor (how rapidly does the CO from the traffic on the highway disperse); and an emission factor (how much CO is emitted by the average vehicle as it passes by). The sum of the background and

project contributions is then compared with the ambient air quality standards to see if the proposed project would have a significant impact.

Separate calculations should usually be made for the year of completion of the project and for the design year (usually 20 years after completion) for all alternatives, including the no-build alternative.■■

6120 Background CO Levels

The first step is to estimate the 1-hour worst case background CO concentration that exists in the vicinity of the proposed project. The preferred method is to use recently measured data (within the last three years) from a nearby location which is representitive of the background concentrations and is not influenced by project traffic. However, such data is seldom available. Another source of CO data is the annual air quality summaries published by the California Air Resources Board. The CO data has been extracted from the annual summaries and are presented in Appendix 2A. Users of these data will note that the majority of the stations are influenced (sometimes heavily) by nearby traffic sources and thus, are not particularly good background sites.

Determine the 1-hour background CO from one of the following:

- Monitored data - Predicted 1-Hour 2nd max. from the OBSMAX computer program for a nearby site.
- CARB Summary Data - Highest 2nd annual max. of the last three years for a representative site.
- Assumed Value (not for urban locations) - Recommended values:
  - 3 ppm - Uninhabited or very sparsely populated areas.
  - 6 ppm - Isolated communities and small towns. (Under 20,000 population)
  - 10 ppm - Small isolated cities. (Under 50,000 population)

Once the existing background CO level has been determined, the same value should be used for future years calculations. Since the direction of future CO levels is highly uncertain and can vary widely by location depending on changes in vehicle emissions, growth of VMT, etc., there are no reliable trends which can be used to adjust the present levels to future years.■■

6130 Emission Factor

The emission factor is the composite emission rate ,usually expressed in grams per vehicle mile, used to characterize the combined effect of vehicle operating mode, types of vehicles, temperature, speed, year, altitude and other variables. Table 6130.1 contains selected hot stabilized running emission factors for a typical vehicle mix for various temperatures, speeds and years. Table 6130.2 has the additional emissions for vehicles in cold start mode. The composite emission factor is estimated by using a weighted combination of the values from these two tables.

The factors in Tables 6130.1 and 6130.2 are low altitude factors. For project locations above 4,000 ft elevation, the emission factors should be adjusted for high altitude. See AQTAN-3160 for guidance.■■

6131 Year

With the passage of time, the number of vehicles on the road that meet the more stringent emission standards of recent years increases and the composite emission factors decrease. As can be seen in Table 6130.1, emission factors change very little after the year 2000. This is because no further major decreases in emission

rates for new cars are being contemplated, and by the year 2000 there will be very few vehicles on the road that don't meet the current standards.

Make CO calculations for the year of completion of the project and for 20 years after completion for both 'Build' and 'No-Build' alternatives.■■

6132 Speed

For CO the lower the speed the higher the emission rate in grams/mile. As can be seen in Table 6130.1, the change in emission rates for low speeds can be quite dramatic so that low speeds should be estimated carefully. Accurate estimation at the higher speeds is not as critical.

Estimate the average speed for the peak hour. Make sure that the speed selected is compatible with level of service for the peak hour.■■

6133 Temperature

CO emissions increase as temperature decreases. With the latest emissions model, EMFAC7, the hot stabilized running emissions, the cold start emissions and the hot start emissions are all temperature-dependent.

Use the lowest January mean minimum temperature for three representative years, add 5^{o} as a time of day adjustment and round off to the nearest 5^{o}.

Appendix 1 contains the National Weather Service California station January mean minimum temperature data for 1984 through 1986. Find the January mean minimum temperature for the station closest to your project and use the adjusted temperature shown in the last column.■■

MICROSCALE CO SCREENING PROCEDURE

Table 6130.1 Stabilized Running Emissions

100% Hot Stabilized Running Emissions (g/m)

Year	mph	Temperature (°F) 20	25	30	35	40	45	50	55	60
1990	5	53.1	50.0	47.1	44.5	42.0	39.8	37.8	35.9	34.2
	10	38.4	35.9	33.7	31.6	29.7	28.0	26.4	24.9	23.6
	15	29.4	27.5	25.7	24.1	22.6	21.2	20.0	18.8	17.7
	20	23.2	21.6	20.2	18.9	17.7	16.6	15.6	14.7	13.9
	25	18.5	17.3	16.1	15.1	14.1	13.3	12.5	11.7	11.0
	30	14.9	13.9	13.0	12.2	11.4	10.7	10.1	9.5	8.9
	35	12.2	11.4	10.6	10.0	9.4	8.8	8.3	7.8	7.4
	40	10.1	9.4	8.9	8.3	7.8	7.4	6.9	6.6	6.2
	45	8.5	8.0	7.5	7.1	6.7	6.3	6.0	5.7	5.4
	50	7.4	7.0	6.6	6.2	5.9	5.6	5.3	5.1	4.8
	55	6.6	6.2	5.9	5.6	5.3	5.1	4.9	4.6	4.4
1995	5	42.1	39.1	36.4	34.0	31.7	29.7	27.8	26.1	24.5
	10	31.9	29.5	27.4	25.4	23.7	22.0	20.5	19.2	17.9
	15	24.9	23.0	21.3	19.8	18.3	17.1	15.9	14.8	13.8
	20	19.7	18.2	16.9	15.6	14.5	13.5	12.5	11.6	10.9
	25	15.8	14.6	13.5	12.5	11.6	10.8	10.0	9.3	8.7
	30	12.7	11.8	10.9	10.1	9.4	8.7	8.1	7.5	7.0
	35	10.4	9.6	8.9	8.2	7.6	7.1	6.6	6.2	5.7
	40	8.5	7.9	7.3	6.8	6.3	5.9	5.5	5.1	4.8
	45	7.1	6.6	6.1	5.7	5.3	5.0	4.7	4.4	4.1
	50	6.1	5.6	5.3	4.9	4.6	4.3	4.1	3.8	3.6
	55	5.3	4.9	4.6	4.3	4.1	3.8	3.6	3.4	3.2
2000	5	36.6	33.8	31.3	29.0	26.9	25.0	23.2	21.6	20.1
	10	28.4	26.2	24.2	22.3	20.7	19.1	17.7	16.5	15.3
	15	22.4	20.6	19.0	17.5	16.2	15.0	13.9	12.8	11.9
	20	17.8	16.4	15.1	13.9	12.8	11.9	11.0	10.2	9.4
	25	14.3	13.1	12.1	11.1	10.3	9.5	8.8	8.1	7.5
	30	11.5	10.6	9.8	9.0	8.3	7.7	7.1	6.6	6.1
	35	9.3	8.6	7.9	7.3	6.8	6.2	5.8	5.4	5.0
	40	7.6	7.0	6.5	6.0	5.6	5.2	4.8	4.4	4.1
	45	6.3	5.8	5.4	5.0	4.6	4.3	4.0	3.7	3.5
	50	5.3	4.9	4.6	4.3	4.0	3.7	3.4	3.2	3.0
	55	4.6	4.3	4.0	3.7	3.5	3.2	3.0	2.9	2.7
2005 & later	5	34.8	32.1	29.6	27.4	25.3	23.4	21.7	20.2	18.7
	10	27.1	24.9	23.0	21.2	19.5	18.1	16.7	15.5	14.3
	15	21.4	19.7	18.1	16.7	15.4	14.2	13.1	12.1	11.2
	20	17.1	15.7	14.4	13.3	12.2	11.3	10.4	9.6	8.9
	25	13.7	12.6	11.6	10.6	9.8	9.0	8.3	7.7	7.1
	30	11.0	10.1	9.3	8.6	7.9	7.3	6.7	6.2	5.7
	35	8.9	8.2	7.6	7.0	6.4	5.9	5.5	5.1	4.7
	40	7.3	6.7	6.2	5.7	5.3	4.9	4.5	4.2	3.9
	45	6.0	5.6	5.1	4.8	4.4	4.1	3.8	3.5	3.3
	50	5.1	4.7	4.3	4.0	3.7	3.5	3.2	3.0	2.8
	55	4.3	4.0	3.7	3.5	3.2	3.0	2.8	2.6	2.5

MICROSCALE CO SCREENING PROCEDURE

Table 6130.2 Cold Start Factors

Additional Emissions for Vehicles in the Cold Start Mode (g/m)

Year	mph	Temperature (°F) 20	25	30	35	40	45	50	55	60
1990	5	272	247	222	200	178	158	139	121	103
	10	203	184	166	150	134	119	104	91	77
	15	159	144	130	117	105	93	82	71	61
	20	126	114	103	93	83	74	65	56	48
	25	100	91	82	74	66	59	52	45	38
	30	80	73	66	59	53	47	41	36	31
	35	64	58	53	48	43	38	33	29	25
	40	52	47	43	38	34	30	27	23	20
	45	42	38	34	31	28	25	22	19	16
	50	34	31	28	25	23	20	18	15	13
	55	28	25	23	21	18	16	14	13	11
1995	5	201	185	169	154	138	123	108	94	79
	10	156	144	132	120	108	96	85	73	62
	15	124	115	105	95	86	77	68	58	49
	20	99	92	84	76	69	61	54	47	39
	25	80	73	67	61	55	49	43	37	32
	30	64	59	54	49	44	39	35	30	25
	35	51	47	43	39	36	32	28	24	20
	40	41	38	35	32	29	26	22	19	16
	45	33	31	28	26	23	21	18	16	13
	50	27	25	23	21	19	17	15	13	11
	55	22	20	18	17	15	13	12	10	9
2000	5	180	167	153	140	126	112	99	85	71
	10	143	133	122	111	100	89	78	68	57
	15	115	106	98	89	80	72	63	54	45
	20	92	85	78	71	64	57	50	43	36
	25	74	68	63	57	52	46	40	35	29
	30	59	55	50	46	41	37	32	28	23
	35	48	44	40	37	33	30	26	22	19
	40	38	35	33	30	27	24	21	18	15
	45	31	28	26	24	22	19	17	14	12
	50	25	23	21	19	17	15	14	12	10
	55	20	18	17	15	14	12	11	9	8
2005 & later	5	173	161	148	135	122	109	95	82	68
	10	138	128	118	108	97	87	76	65	55
	15	111	103	95	86	78	70	61	52	44
	20	89	83	76	69	63	56	49	42	35
	25	71	66	61	56	50	45	39	34	28
	30	57	53	49	45	40	36	32	27	23
	35	46	43	39	36	33	29	25	22	18
	40	37	34	32	29	26	23	20	18	15
	45	30	28	26	23	21	19	16	14	12
	50	24	22	21	19	17	15	13	11	10
	55	19	18	17	15	14	12	11	9	8

6134 Cold Start Adjustment

The percentage of vehicles that are in the cold start mode is one of the most sensitive emission factor parameters and the most difficult to estimate accurately. Vehicles operating in the hot start mode (engine restarted after less than one hour off for vehicles with catalytic converters) are just as difficult to estimate. Fortunately the emission factor program is relatively insensitive to changes in the percent of vehicles in the hot start mode and, for screening procedure purposes, can be accounted for by using conservative estimates of cold starts.

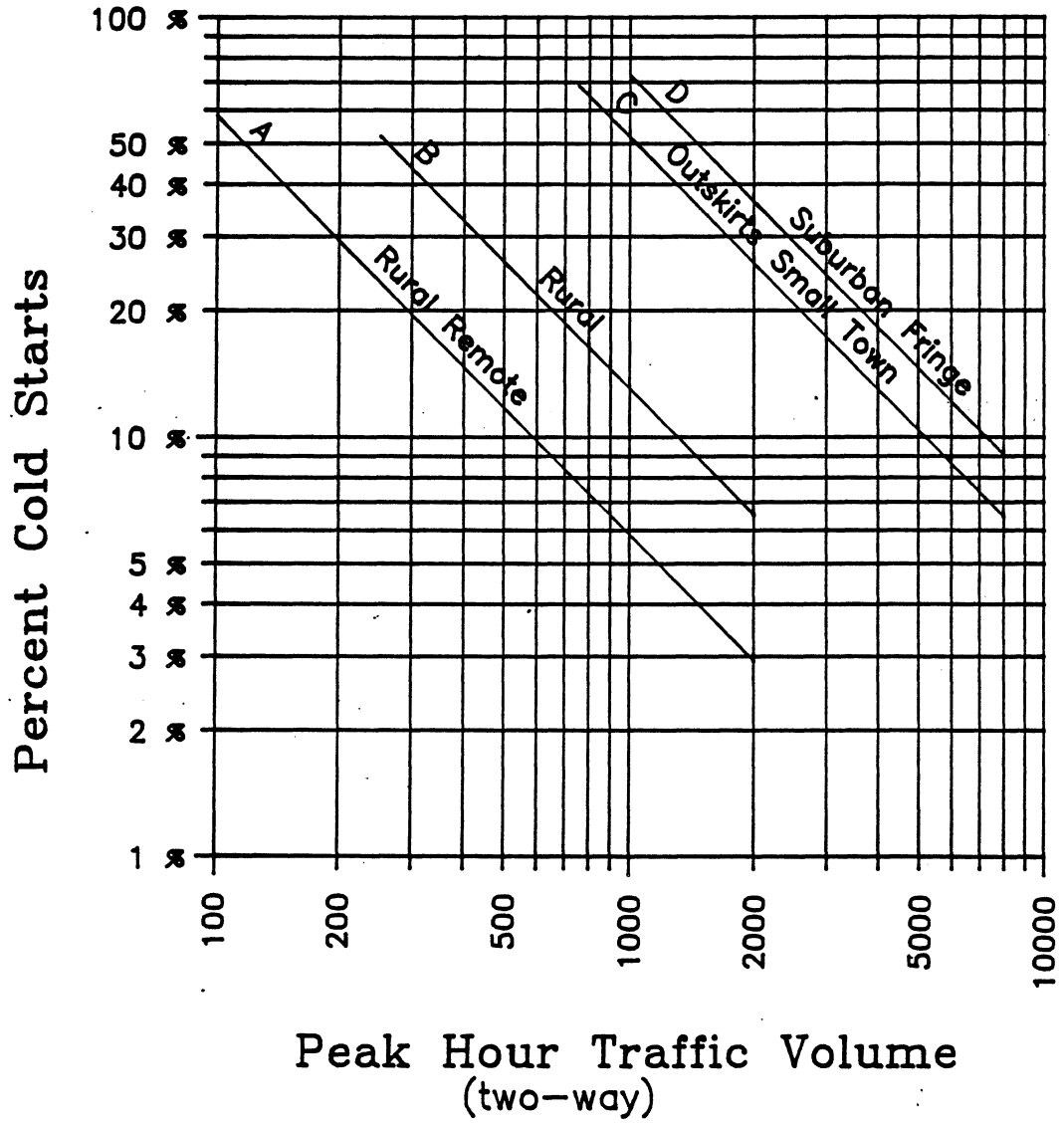
The curves shown in Figure 6130.1 are an attempt to relate population densities to cold start trip generation. Use Table 6130.3 to determine which curve best fits the project location. Since cold start trips can originate from more than 3 1/2 miles in each direction from a project, the selection of the cold start curve should be based on a very broad estimation of the surrounding land use.■■

Table 6130.3 Cold Start Curves

Highway Location	Use Curve	Household Density (Households/Acre)
Rural - Remote Location - 2 lanes, Scattered development, few crossroads, 1 house every 10 acres.	A	0.1
Rural - 2 lanes, Cross roads every mile or 1/2 mile, parcels of 3 to 5 acres.	B	0.2
Outskirts of small town - 2/4 lanes, Small subdivisions mixed with large undeveloped areas.	C	1
Suburban fringe - 4 lanes, residential with large areas undeveloped, highway access limited in some spots.	D	2 & greater

MICROSCALE CO SCREENING PROCEDURE

Figure 6130.1 Percent Cold Starts



6135 Inspection & Maintenance Credit

For projects that are located in areas of the state that are covered by the biennial smog check program, a reduction in emissions can be made. For the traffic mix assumptions used in Tables 6130.1 & 6130.2, a reduction of approximately 10% may be used. This reduction can be accounted for in the screening procedure by multiplying the final emission factor by 0.9.■■

6136 Final Composite Emission Factor

The final composite emission factor is derived from:

$$EF = [\ SRE + (\ CSF)(\ \%CS\ /\ 100)]\ X\ IM$$

where:
EF = final composite Emission Factor
SRE = hot Stabilized Running Emission from Table 6130.1
CSF = additional Cold Start Emissions from Table 6130.2
%CS = the percent of vehicles in the Cold Start mode from Figure 6130.1
IM = Inspection & Maintenence credit,
either 1.0 or 0.9 (see Section 6135)■■

6140 Roadway Contribution

The CO contribution from the roadway is estimated by taking the emissions rates (in grams per mile) and a dispersion factor to predict the concentration in (in parts per million). The dispersion factor is a function of the highway geometry, receptor location and meteorological conditions. The dispersion factor curves in Figures 6140.2A, B and C are based on typical at-grade highway geometry and appropriate worst case meteorological conditions for the various project locations.■■

MICROSCALE CO SCREENING PROCEDURE

6141 Receptor Location

The receptor site which yields the highest CO concentration outside the right-of-way should be the site chosen. Determine the receptor distance (RD) by measuring the perpendicular distance from the right-of-way line to the outside edge of the nearest lane. See Figure 6140.1 for examples.■■

6142 Highway Width

The width of the highway has a direct relationship to the CO concentration at the receptor. A wider highway means that the initial vehicle emissions are spread over a wider area so that initial concentrations are lower given equal traffic volumes.

Measure the highway width (HW) from the outside edge of the traveled way to the outside edge of the opposite traveled way. This distance should include any left turn lanes, medians etc. Interpolation between the various HW curves may be necessary to account for the median width.

For projects involving wide medians (greater than 35 ft) separate calculations should be made for each direction of travel. Make a calculation for each direction using directional traffic and sum the roadway CO contributions from both directions before adding in the background. The example shown at the bottom of Figure 6140.1 illustrates how to measure RD and HW for each calculation.

Note: for those users who are familiar with the CALINE3/CALINE4 inputs, do not add an extra 3 meters (10 ft) to both sides of the link widths, it has been accounted for in the dispersion factor curves.■■

6143 Project Location

It has been found that the most likely worst case meteorological regimes vary with location within the state. The three sets of dispersion factors in Figures 6140.2A, B and C reflect these differences. Users will find that the dispersion factors for the Central Valley are lower than the Coastal areas and that the Coastal area factors are lower than the Mountain. The lower dispersion factors indicate less horizontal spreading of pollutants (i.e. a lower sigma theta) and result in higher CO concentrations.

Location	Sigma Theta	Use
Central Valley or don't know	5^{o}	Figure 6140.2A
Coastal or Coastal Valley	10^{o}	Figure 6140.2B
Mountain	30^{o}	Figure 6140.2C

The dispersion factor should be estimated from the appropriate figure using the receptor distance (RD) and highway width (HW).■■

MICROSCALE CO SCREENING PROCEDURE

Figure 6140.1 Receptor Distance and Link Width

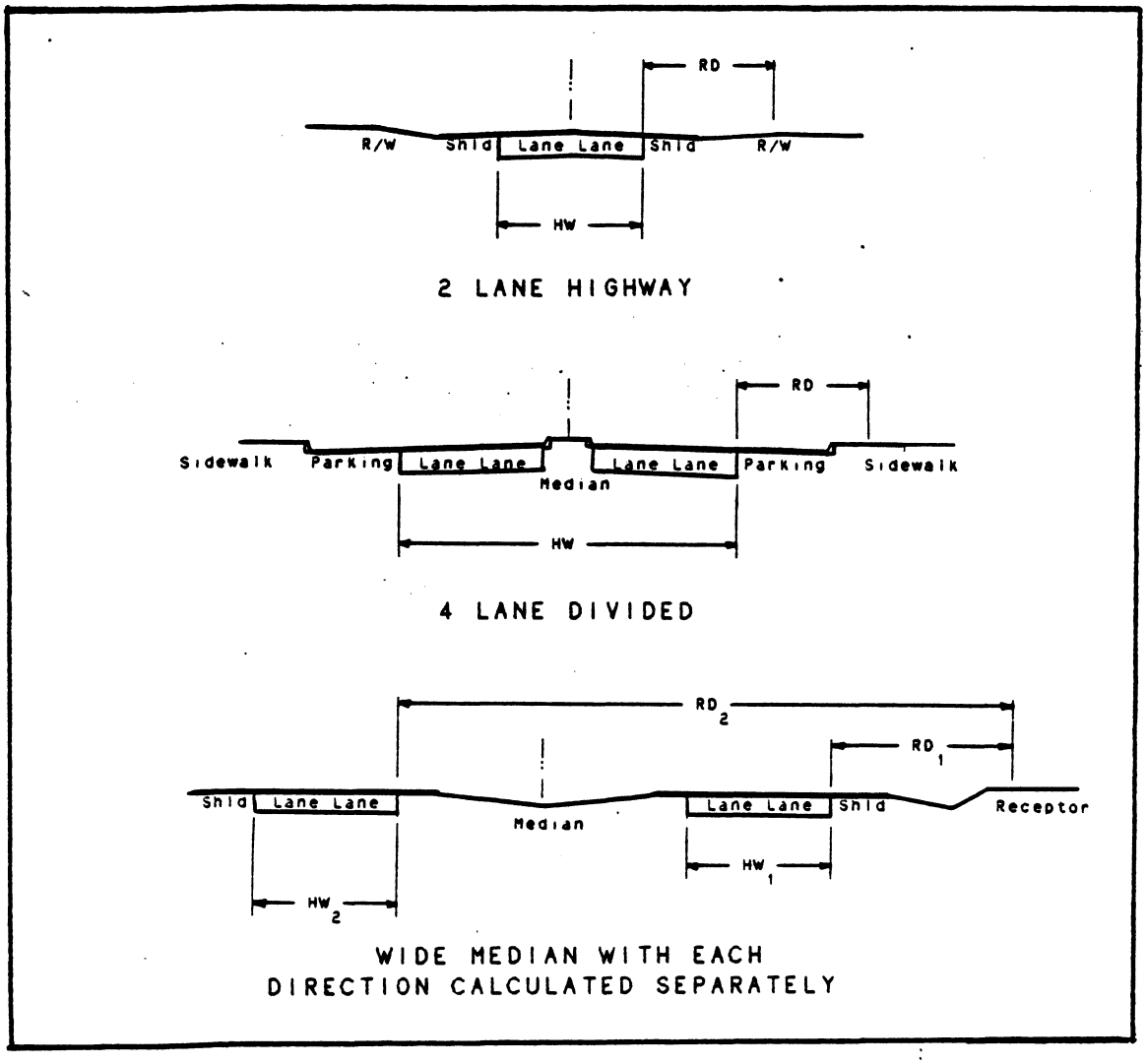
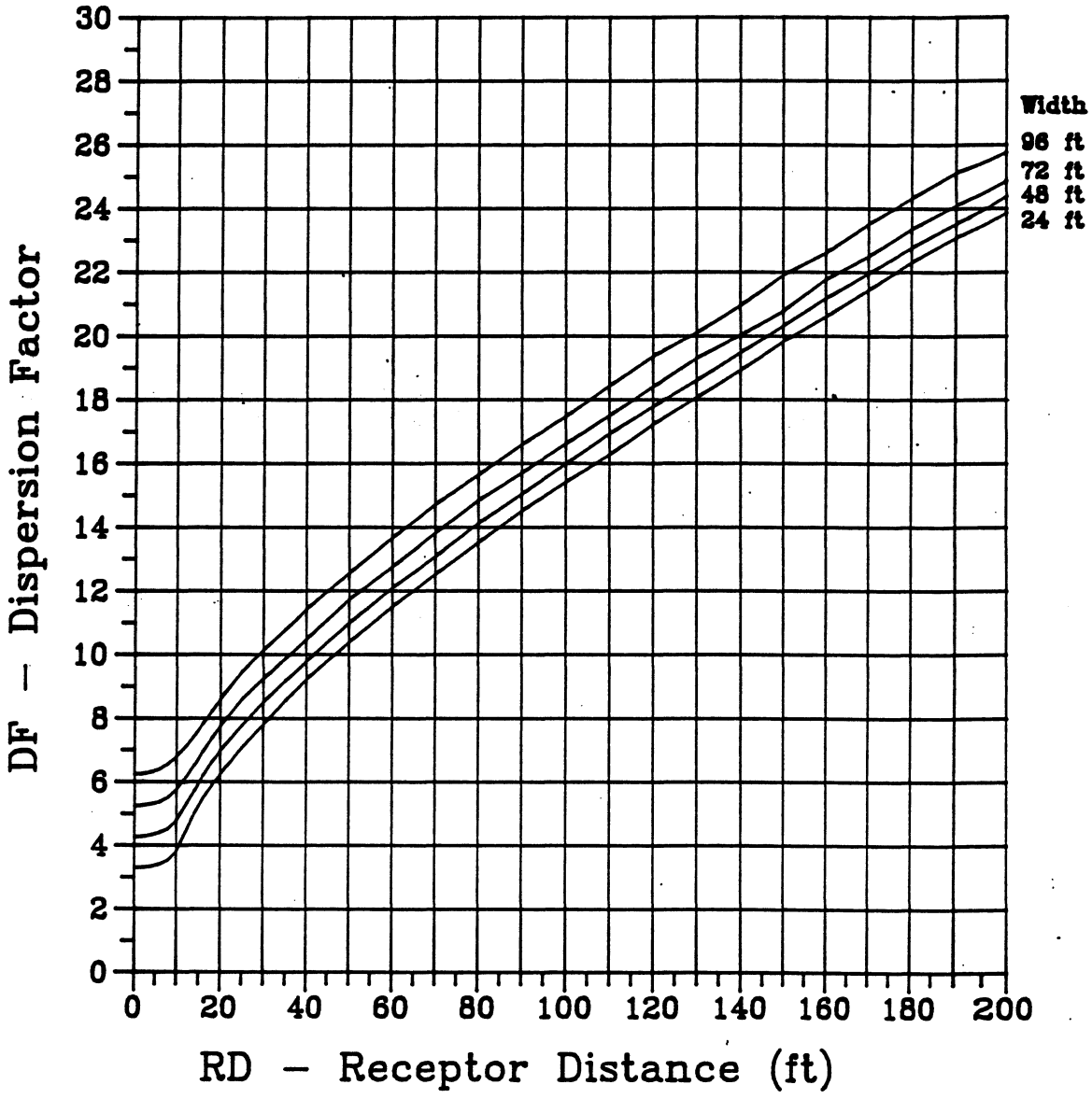


Figure 6140.2A Dispersion Factors - Sigma Theta 5°

CENTRAL VALLEY



MICROSCALE CO SCREENING PROCEDURE

Figure 6140.2B Dispersion Factors - Sigma Theta 10°

COASTAL OR COASTAL VALLEY

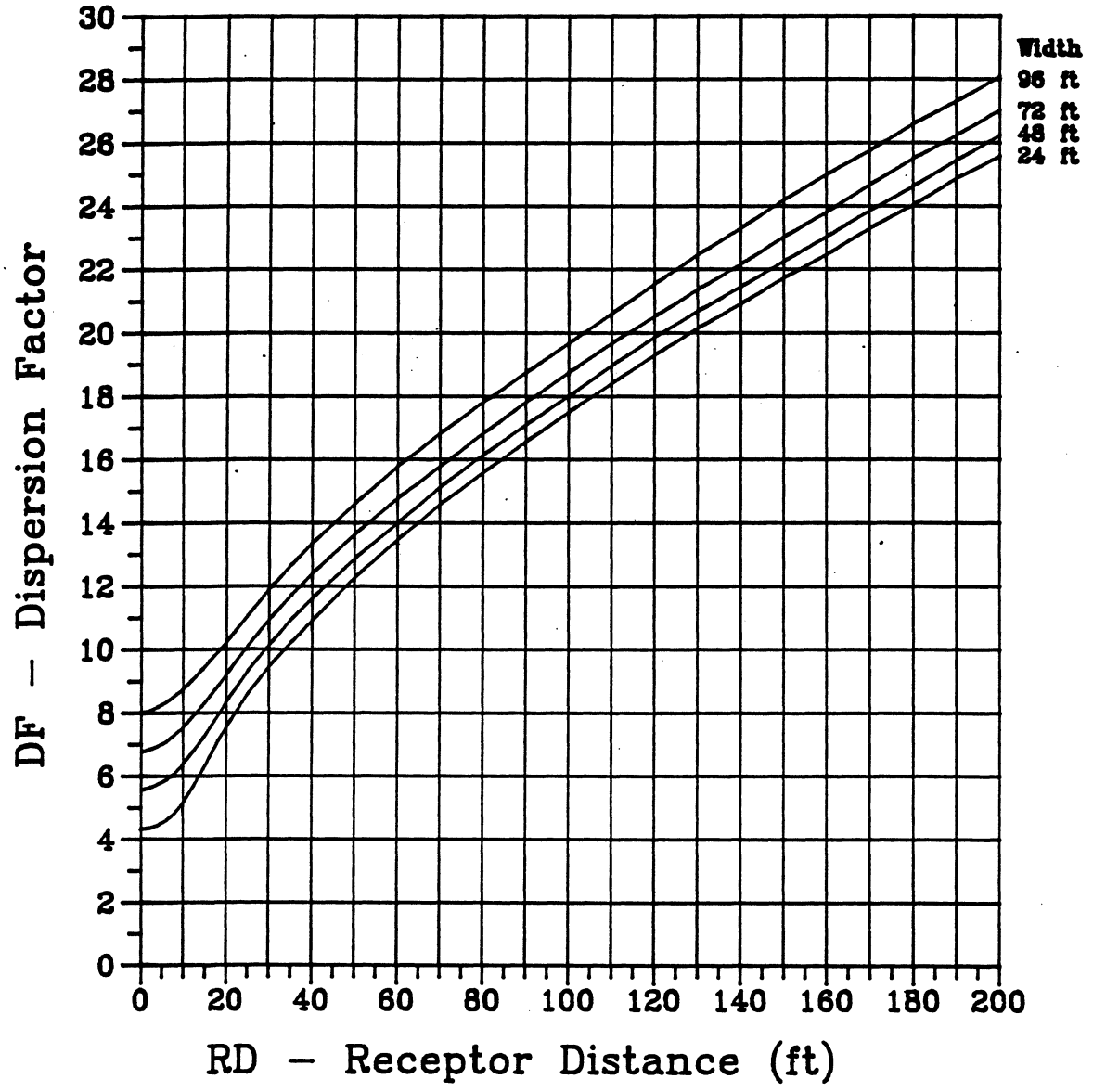
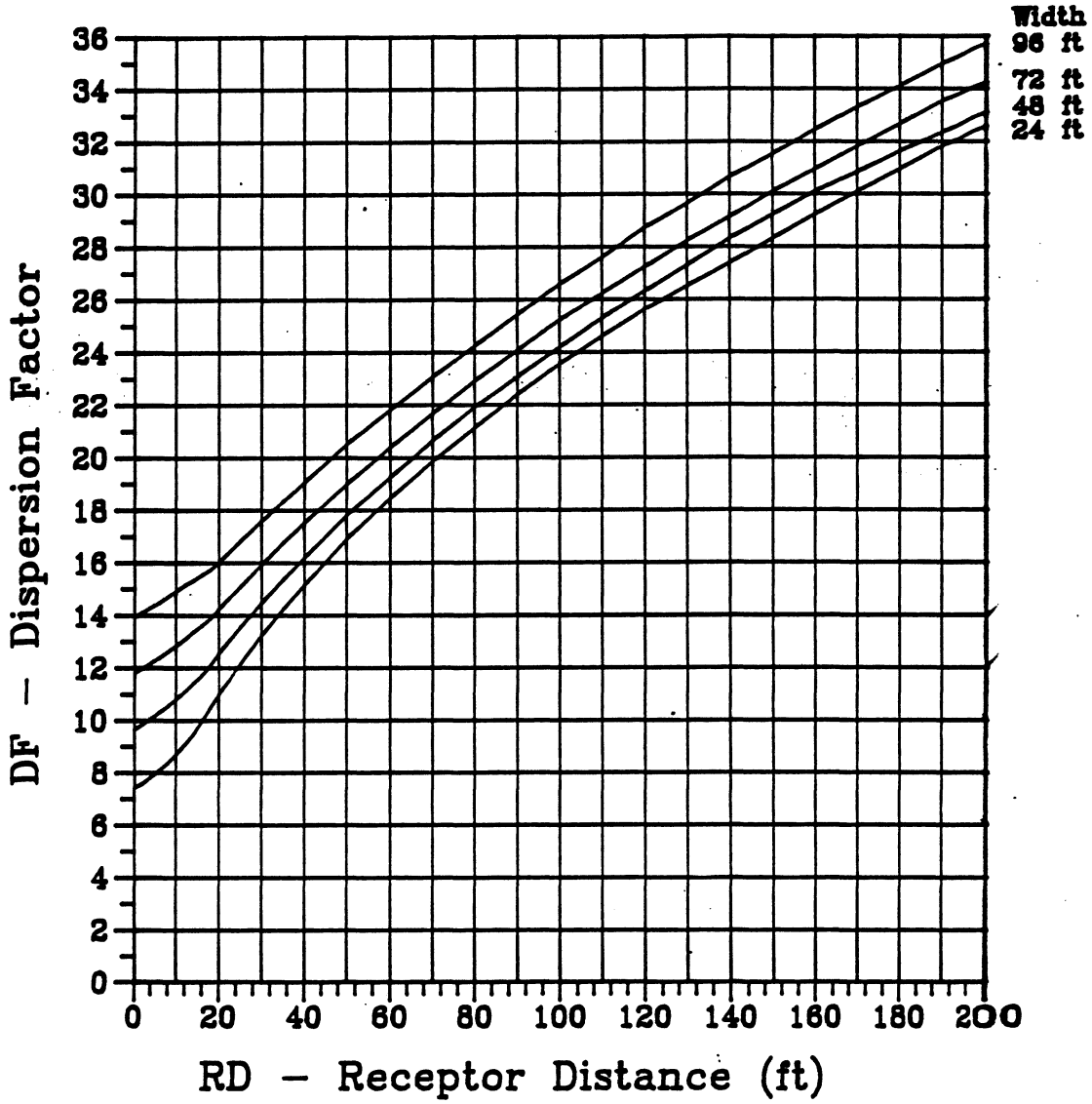


Figure 6140.2C Dispersion Factors - Sigma Theta 30°

MOUNTAIN



MICROSCALE CO SCREENING PROCEDURE

6144 Peak Hour Traffic Volume

Since the predicted concentrations are almost directly proportional to the traffic volumes, every effort should be made to obtain accurate peak hour traffic forecasts.

If the project peak hour traffic volumes are not known they may be estimated by:

- Use 10% of the Average Annual Daily Traffic (AADT) for the year of interest.
- If the AADT for the year of interest is not known, then the following table of capacities may be used as a guide. Users should keep in mind that for many rural highways actual peak hour volumes seldom approach capacity.■■

Table 6140.1 Highway Capacities.

PEAK HOUR TRAFFIC VOLUMES

2 LANES	2-way Peak Hour Volume (vph)	Speed (mph)
Rural - Level Terrain	2500	45-50
Rural - Rolling Terrain	2000	40-50
Rural - Mountains	1400	35-45

MORE THAN 2 LANES	Peak Hour Volumes per Lane Heavy Direction	Light Direction	Speed
Rural - Level Terrain	1500	1000	30-40
Rural - Rolling Terrain	1400	900	
Rural - Mountains	1200	800	
Suburban	1800	1200	
Urban	2000		
Urban - Major Commute	2100		

6145 Roadway Calculation

The roadway concentration is calculated by multiplying the peak hour traffic volume times the emission factor and dividing by the dispersion factor multiplied times 1000. When a wide median or lopsided directional split in traffic exists, make separate calculations for each direction with the appropriate directional traffic and dispersion factor.■■

$$RC = \frac{(VPH)(EF)}{(DF)(1000)}$$

Where:
VPH = peak hour traffic Volume in vehicles per hour
EF = final composite Emission Factor (from Section 6136)
RC = Roadway Contribution in ppm
DF = Dispersion Factor (from Figure 6140.2A, B or C)

6150 Results

6151 Predicted Maximum One-Hour Ambient CO Concentration

Once the CO contribution from the roadway (RC) has been estimated, it is simply added to the 1-hour background to yield a predicted worst case ambient CO concentration.

$$CO_1 = RC + Background_1$$

When seperate calculations are made for each direction of travel the ambient CO concentration becomes:

$$CO_1 = RC_{(near\ lanes)} + RC_{(far\ lanes)} + Background_1$$■■

MICROSCALE CO SCREENING PROCEDURE

6152 Predicted Maximum Eight-Hour Ambient CO Concentration

The predicted worst case 8-hour CO is calculated by multiplying the predicted worst case 1-hour concentration by an 8-hour persistence factor of 0.7.

$CO_8 = CO_1$(Persistence factor)■■

6153 Comparison with Standards

The applicable ambient air quality standards for CO are:

1-Hour CO Standards		
National(1)	35	ppm
State(2)	20	ppm
8-Hour CO Standards		
National(1)	9	ppm
State(2)	9.0	ppm (6 ppm for Lake Tahoe area)

(1) National ambient air quality standards for CO are not to be exceeded more than once per year.

(2) State ambient air quality standards for CO are not to be equaled or exceeded.

If the predicted CO concentrations are below both the 1-hour and 8-hour ambient air quality standards, then the effects of the project on air quality can be judged to be insignificant. In those cases where either standard is exceeded, a more detailed analysis based on site specific data should be performed.■■

6160 Examples

Example 1.

It is proposed to widen a section of Route 12 in San Joaquin County just west of Lodi from 2 lanes to 4 lanes. The right-of-way is 100 ft, predicted 1990 peak hour volume is 2000 vph at 40 mph. Find the predicted maximum CO concentrations for 1990 - Build.

Step 1. Background CO.
There are no measured data nor any CARB stations in the vicinity of the proposed project; therefore an assumed value of 6 ppm is selected.

Step 2. Emission Factor.
2a. Year. 1990.
2b. Temperature. From Appendix 1, San Joaquin County, the screening procedure temperature for Lodi is 40^{o}.
2c. Speed. 40 mph.
2d. Peak Hour Traffic Volume. 2000 vph.
2e. Hot Stabilized Running Emission. From Table 6130.1 the SRE for 1990, 40^{o} at 40 mph is found to be 7.8.
2f. Cold Start Factor. From Table 6130.2 the CSF is 34.
2g. % Cold Starts. From Table 6130.3 it is determined that curve C (Outskirts of small town) best fits the land use near the proposed project. From Figure 6130.1 the percent cold starts for 2000 vph for curve C is approximately 26%.
2h. I/M Credit. Since San Joaquin County is in an I/M area the I/M credit is set to 0.9.
2i. The composite emission factor is then:

$$7.8 + [34\ (26\% / 100)]\ (0.9) = 15.0$$

Step 3. Roadway Contribution
3a. Receptor Distance. A receptor site at the R/W line is chosen. The distance from the R/W to the edge of the traveled way is:
(100 - 48)/2 or 26 ft.
3b. Highway Width. The width is 4 lanes times 12 ft or 48 ft.
Since Lodi is in the Central Valley, Figure 6140.2A (sigma theta 5^{o}) is used to determine the dispersion factor. Using RD = 26 and the 48 ft curve the dispersion factors is 8.0.

$$\frac{(VPH)(EF)}{(DF)(1000)} \qquad \frac{(2000)(15.0)}{(8.0)(1000)} = 3.8 \text{ ppm}$$

Step 4. Results
4a. The maximum predicted 1-hour concentration is the sum of the roadway contributions and the background:

$$3.8 \text{ ppm} + 6 \text{ ppm} = 9.8 \text{ ppm}$$

4b. The maximum predicted 8-hour concentration is calculated as the max. 1-hour times a persistence factor of 0.7.

$$9.8 \text{ ppm } (0.7) = 6.9 \text{ ppm}$$

MICROSCALE CO SCREENING PROCEDURE

Figure 6160.1 Example 1.

Step 1. BACKGROUND CO
See Section 6120

Measured, Appendix 2A or Assumed Value:
3 ppm Rural 6 ppm Small Towns
10 ppm Small Cities

1 Hour Background

Background
BG 6

Step 2. EMISSION FACTOR
See Section 6130

[Hot-Stab + (Cold-Start-Factor X %-Cold-Starts / 100)] X IN = EF

Year: 1990
Temperature (See Appendix 1): 40 °F
Speed: 40 mph

Hot Stabilized Run. Emissions (Table 6130.1)		Cold Start Factor (Table 6130.2)		% Cold Starts (Fig. 6130.1)			Inspection & Maintenance Credit (0.9 or 1.0)		Emission Factor
7.8	+	34	X	26 %	÷	100	X 0.9	=	EF 15.0

Step 3. ROADWAY CONTRIBUTION
See Section 6140

$\frac{VPH \times EF}{DF \times 1000} = RC$

Project Location	Use Figure
Central Valley or don't know	6140.2A
Coastal or Coastal Valley	6140.2B
Mountain	6140.2C

3a. Single calculations or Near Lane Group

(Fig. 6140.1)

RD_1 26 ft; WA_1 48 ft. = DF_1 8.0

$\frac{VPH_1\ 2000 \times EF\ 15.0}{DF_1\ 8.0 \times 1000}$ =

Roadway Contribution
RC_1 3.8

3b. Far Lane Group

RD_2 ft; WA_2 ft = DF_2

$\frac{VPH_2 \times EF}{DF_2 \times 1000}$ =

Roadway Contribution
RC_2

Step 4. RESULTS
See Section 6150

4a. Max. 1-Hour
$RC_1 + RC_2 + BG = CO_1$

RC_1 3.8 + RC_2 + BG 6 =

1-Hour Max. CO
CO_1

4b. Max. 8-hour
CO_1 X Persistence Factor = CO_8

CO_1 9.8 X Persistence Factor 0.7 = (Usually 0.7)

8-Hour Max. CO
CO_8 6.9

Example 2

It is proposed to widen a section of Route 101 in Del Norte County just outside of Cresent City from 2 lanes to 4 lanes with a 40 ft median, 1995 peak hour volumes are 1600 in each direction at 50 mph. The closest receptor location is 50 ft from roadway.
Find the predicted 1995 Build CO concentration.

Step 1. Background CO.
There are no measured data nor any CARB stations in the vicinity of the proposed project; therefore an assumed value of 6 ppm is selected.

Step 2. Emission Factor.
2a. Year. 1995.
2b. Temperature. From Appendix 1, Del Norte County, the screening procedure temperature for Cresent City is 40^{o}.
2c. Speed. 50 mph.
2d. Peak Hour Traffic Volume. 1600 vph for near lanes & 1600 for far lanes.
2e. Stabilized Running Emission. From Table 6130.1 the SRE for 1995, 40^{o} at 50 mph is found to be 4.6.
2f. Cold Start Factor. From Table 6130.2 the CSF is 19.
2g. % Cold Starts. From Table 6130.3 it is determined that curve C (Outskirts of small town) best fits the land use near the proposed project. From Figure 6130.1 the percent cold starts for 3200 vph for curve C is approximately 17%.
2h. I/M Credit. Since Del Norte County is not in an I/M area the I/M credit is set to 1.
2i. The composite emission factor is then:

$$4.6 + [19\ (17 / 100)]\ (1.0) = 7.8$$

Step 3. Roadway Contribution
3a. Receptor Distance. Since the median is greater than 35 ft each direction is calculated separately.
Near lanes $RD_1 = 50$ ft.
Far lanes $RD_2 = 50 + 48 + 40 = 138$ ft.
3b. Highway Width. The width for both directions is 4 times 12 = 48 ft.
Since Cresent City is on the coast, Figure 6140.2B (sigma theta 10^{o}) is used to determine the dispersion factors.
For the near lanes with $RD_1 = 50$ & a width of 48 ft $DF_1 = 11.0$.
Far lanes, $RD_2 = 138$ & a width of 48, DF_2 is estimated at 19.5.

Near Lanes:

$$\frac{(VPH_1)(EF)}{(DF_1)(1000)} = RC_1 \qquad \frac{(1600)(7.8)}{(11.0)(1000)} = 1.1 \text{ ppm}$$

Far Lanes:

$$\frac{(VPH_2)(EF)}{(DF_2)(1000)} = RC_2 \qquad \frac{(1600)(7.8)}{(19.5)(1000)} = 0.6 \text{ ppm}$$

Step 4. Results
4a. The maximum predicted 1-hour concentration is the sum of the roadway contributions and the background:

1.1 ppm + 0.6 ppm + 6 ppm = 7.7 ppm

4b. Since the predicted 1-hour concentration is less than the 8-hour standard no 8-hour calculation is necessary.

MICROSCALE CO SCREENING PROCEDURE

Figure 6160.2 Example 2.

Step 1. BACKGROUND CO — See Section 6120
Measured, Appendix 2A or Assumed Value: 3 ppm Rural 6 ppm Small Towns 10 ppm Small Cities
1 Hour Background
Background: BG = 6

Step 2. EMISSION FACTOR — See Section 6130
[Hot-Stab + (Cold-Start-Factor X %-Cold-Starts / 100)] X IM = EF

Year	Temperature (See Appendix 1)	Speed
1995	40 °F	50 mph

Hot Stabilized Run. Emissions (Table 6130.1)		Cold Start Factor (Table 6130.2)		% Cold Starts (Fig. 6130.1)			Inspection & Maintenance Credit (0.9 or 1.0)		Emission Factor
4.6	+	19	X	17 %	÷	100	X 1.0	=	EF 7.8

Step 3. ROADWAY CONTRIBUTION — See Section 6140

$$\frac{VPH \times EF}{DF \times 1000} = RC$$

Project Location	Use Figure
Central Valley or don't know	6140.2A
Coastal or Coastal Valley	6140.2B
Mountain	6140.2C

3a. Single calculations or Near Lane Group

(Fig. 6140.1)

VPH_1 1600 X EF 7.8 =

RD_1 50 ft WM_1 48 ft = DF_1 11.0 X 1000

Roadway Contribution: RC_1 1.1

3b. Far Lane Group

VPH_2 1600 X EF 7.8 =

RD_2 138 ft WM_2 48 ft = DF_2 19.5 X 1000

Roadway Contribution: RC_2 0.6

Step 4. RESULTS — See Section 6150

4a. Max. 1-Hour $RC_1 + RC_2 + BG = CO_1$

RC_1 1.1 + RC_2 0.6 + BG 6 = (Persistence Factor)

1-Hour Max. CO: CO_1 7.70

4b. Max. 8-hour CO_1 X Persistence Factor = CO_8

CO_1 X (Usually 0.7) =

8-Hour Max. CO: CO_8

MICROSCALE CO SCREENING PROCEDURE

Worksheet

Step 1. BACKGROUND CO
See Section 6120

Measured, Appendix 2A or Assumed Value:
3 ppm Rural 6 ppm Small Towns
10 ppm Small Cities

1 Hour Background

Background: BG

Step 2. EMISSION FACTOR
See Section 6130

[Hot-Stab + (Cold-Start-Factor X %-Cold-Starts / 100)] X IM = EF

Year: _____

Temperature (See Appendix 1): _____ °F

Speed: _____ mph

Hot Stabilized Run. Emissions (Table 6130.1)		[Cold Start Factor (Table 6130.2)	X	% Cold Starts (Fig. 6130.1)	÷	100]	X	Inspection & Maintenence Credit (0.9 or 1.0)	=	Emission Factor
	+		X	%	÷	100	X		=	EF

Step 3. ROADWAY CONTRIBUTION
See Section 6140

$$\frac{VPH \times EF}{DF \times 1000} = RC$$

Project Location	Use Figure
Central Valley or don't know	6140.2A
Coastal or Coastal Valley	6140.2B
Mountain	6140.2C

3a. Single calculations or Near Lane Group

(Fig. 6140.1)

RD_1 ft	HW_1	=	DF_1	VPH_1	X	EF	=	Roadway Contribution
								RC_1

3b. Far Lane Group

RD_2 ft	HW_2 ft	=	DF_2	VPH_2	X	EF	=	Roadway Contribution
								RC_2

Step 4. RESULTS
See Section 6150

4a. Max. 1-Hour
$RC_1 + RC_2 + BG = CO_1$

RC_1	+	RC_2	+	BG	=	1-Hour Max. CO
						CO_1

Persistence Factor

4b. Max. 8-hour
CO_1 X Persistence Factor = CO_8

CO_1	X		=	8-Hour Max. CO
		(Usually 0.7)		CO_8

MICROSCALE CO SCREENING PROCEDURE

6200 Assumptions

The figures, tables and recommended values used in the Screening Procedure are based on the following:

6210 Background

The recommended background values are based on the 1-hour second annual maximum CO values from the CARB annual summaries (6200-1) for selected stations for 1983, '84, 85 & '86

Second Annual Maximum 1-Hour CO

Station	County	Population (1,000's)	Year 83	84	85	86
Burney	SHA	<5	-	2	2	- ppm
Bethel Island	CC	<5	2	2	2	2
Parlier	FRE	<5	-	3	4	4
El Rio	VEN	<5	3	3	3	4
Willits	MEN	<5	-	5	8	6
Shaver Lake	FRE	<5	2	-	-	-
Gilroy	SCL	20	6	7	6	6
San Juan Capistrano	ORA	20	4	4	-	-
Barstow	SBD	20	5	6	6	7
Laguna Beach	ORA	20	4	6	-	-
Woodland	YOL	30	7	9	8	12
Pittsburg	CC	35	7	8	8	9
Palm Springs	RIV	35	5	4	5	5
San Luis Obispo	SLO	35	12	9	10	9
Chico Manzanita	BUT	40	6	8	7	8
Fontana	SBD	40	9	5	5	6
El Torro	ORA	40	7	8	9	7
Redding	SHA	45	10	-	-	-
Redlands	SBD	45	4	2	-	-
Napa	NAP	50	9	10	9	9
Lancaster	LA	50	11	9	11	9
Visalia	TUL	50	9	13	9	11

MICROSCALE CO SCREENING PROCEDURE

Assumptions

6220 EMISSION FACTORS

The Stabilized Running Emissions shown in Table 6130.1 were generated using EMFAC7C (6200-2), 100% hot stabilized operating mode and the following vehicle mix:

Vehicle Mix.	
LDA	71.5 %
LDT	12.5 %
MDT	4.5 %
HDG	2.2 %
HDD	8.4 %
MC	0.9 %

The Cold Start Factors in Table 6130.2 were generated using same mix but with 100% cold starts and then subtracting the hot stabilized running emissions.

6221 PERCENT COLD STARTS

The curves shown in Figure 6220.1 for corrected percent cold starts were derived for a morning commute route transecting rural and residential communities.

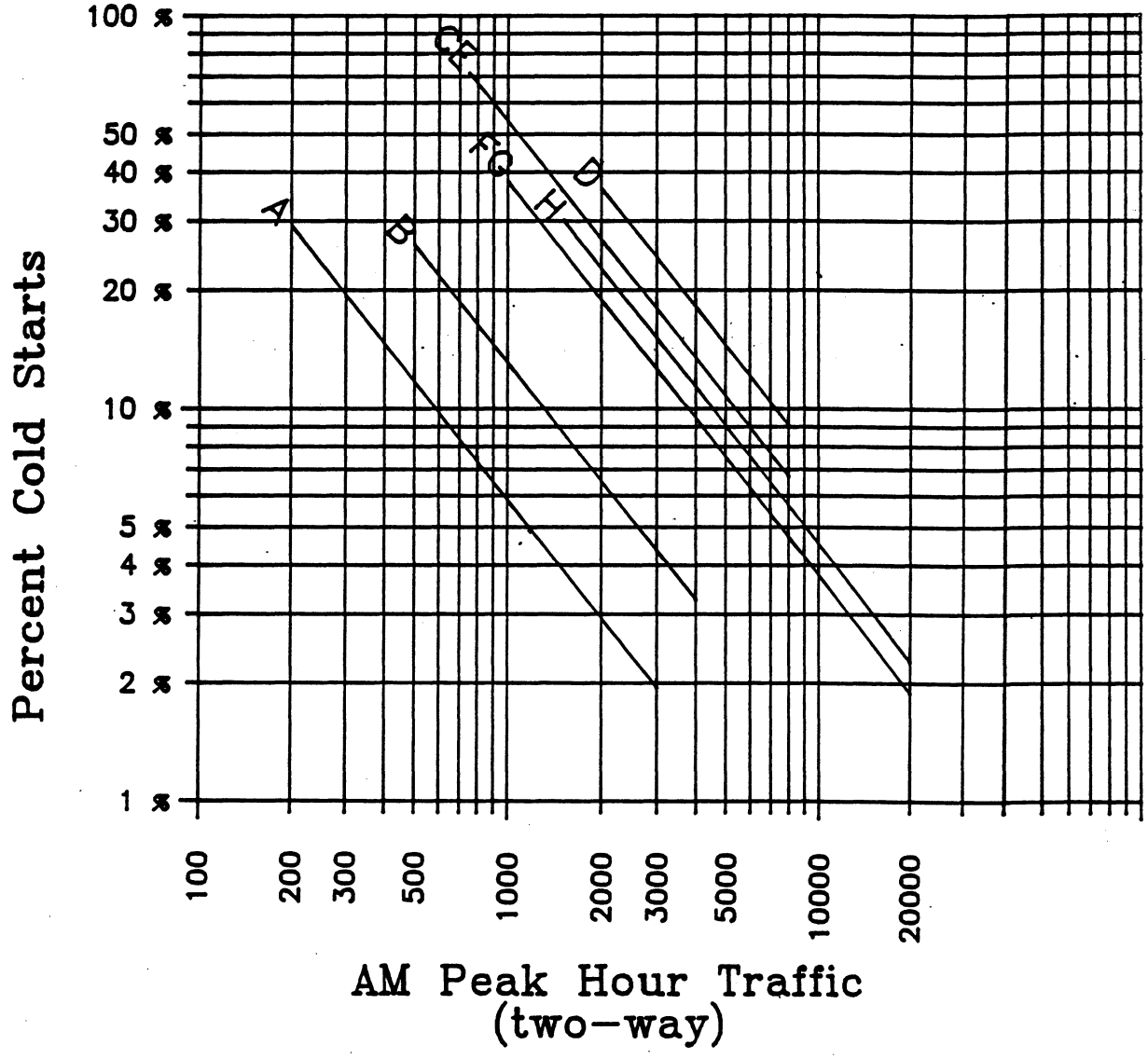
Figure 6220.1 was generated by applying equation 1 (from 6200-3) to the transient trip area shown in Figure 6220.2.

$$c^{f}t = \frac{f_t V}{v}\left[R - W\left[\frac{3}{2} - \frac{W}{R} + \frac{W^2}{4R^2}\right] - 3r_a\left[1 - \frac{W}{R} + \frac{W^2}{3R^2}\right] + 3r_a^2\left[\frac{1}{R} - \frac{W}{2R^2}\right] - \frac{r_a^3}{R^2}\right] \quad \text{eq(1)}$$

where:

$c^{f}t$ = Corrected transient fraction.
f_t = Fraction of attracted vehicles in transient mode.
v = Number of vehicles attracted to the highway in vehicles per hour per mile.
V = Highway Traffic Volume in vehicles per hour.
W = Corridor 1/2 width in miles.
R = 3.59 miles.
r_a = Highway access distance.

Figure 6220.1 Corrected Percent Cold Starts



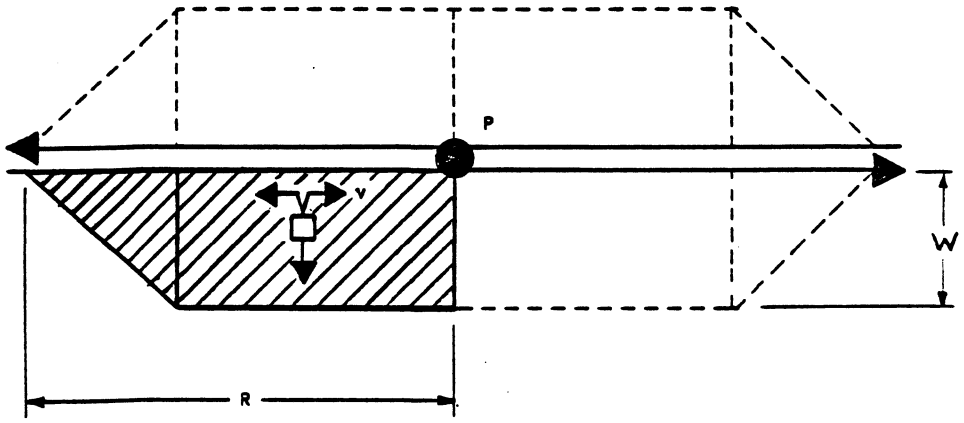
MICROSCALE CO SCREENING PROCEDURE

Assumptions

Curve:

A. Rural remote 2 lane highway, remote location, scattered development close to highway, few crossroads, direct access to highway, no alternate routes, 1 house every 10 acres.
B. Rural 2 lane highway, crossroads and parallel county roads every mile or 1/2 mile which offer some alternate routes, 3 to 5 acre parcels.
C. Outskirts of small town, 2 or 4 lane highway, small subdivisions mixed with sparsley developed areas, average density of 1 household per acre.
D. Suburban fringe 4 lane highway, predominantly residential but with large areas of undeveloped land, access to highway limited to major collectors in some spots.
E. Suburban 4 lane expresway, residential, some undeveloped areas.
F. Suburban 4/6 lane freeway, residential with some light commercial, highway access limited to interchanges.
G. Urban fringe 6/8 lane freeway, fully developed bedroom communities.
H. Urban 6/8 lane freeway, not CBD.

Figure 6220.2 Transient Trip Area



The cross-hatched portion is the area from which transient trips can originate (based on Figure 4 of Reference 6200-3) and for all four quadrants, yields the following equation:

$$v = \frac{640\ Q \left[W R - \frac{W^2}{2} \right] (HD)(PHT)(FH)(DS)}{2R} \qquad \text{eq(2)}$$

Where:

v = Number of trips attracted to the highway in vehicles per hour per mile
Q = 4 Quadrants.
W = Corridor 1/2 width.
R = 3.59 miles.
HD = Household Density in households per acre.
PHT = Peak Hour Trips per household (outbound).
FH = Fraction of trips attracted to Highway.
DS = Direction Split.

Values for v for use in equation 1 were calculated from equation 2 using the the assumptions in Table 6220.1.

Table 6220.1 Transient Trip Assumptions

		Curve A	B	C	D	E	F	G	H
1/2 Width	W	1.00	1.50	2.00	2.50	3.00	3.59	3.59	3.59
highway length	R	3.59	3.59	3.59	3.59	3.59	3.59	3.59	3.59
Household Density	HD	0.1	0.2	1.0	2.0	3.0	4.0	5.0	6.0
Peak Hr. Trips	PHT	0.45	0.45	0.45	0.50	0.50	0.50	0.50	0.50
% trips to highway	FH	100	100	80	80	60	60	50	50
Directional Split	DS	50/50	50/50	50/50	50/50	50/50	50/50	50/50	50/50
% Cold Start mode	f_t	100	100	100	90	90	80	80	80
highway access	r_a	0.00	0.00	0.00	0.25	0.50	0.75	0.75	0.75
vehicles/mile/quad	v	25	68	332	834	1006	1379	1436	1723

A PHT value of 0.50 for urban and suburban locations was derived by assuming 10 weekday trip ends per household for residential areas with 10% of the trip ends morning peak hour trips (6200-4):

MICROSCALE CO SCREENING PROCEDURE

Assumptions

10 trip ends = 5 outbound trips & 5 inbound trips.
5 outbound trips times 10% morning peak hour trips = 0.50 trips per household.

A slightly lower PHT value was assumed for rural locations where trips tend to less frequent but longer (6200-5).

The directional split assumption of 50/50 is unimportant when symmetry is assumed for all four quadrants of Figure 6220.2; the number of trips past point P (TTP) will always be 50% of the total highway trips generated when all four quadrants are used, regardless of the directional split (DS):

If:

$$DS_1 + DS_2 = 100\%$$

and the number of trips from each quadrant (TQ) is equal then the total trips past P (TTP) is:

$$TTP = DS_1(TQ) + DS_1(TQ) + DS_2(TQ) + DS_2(TQ)$$

and then by substitution:

$$TTP = 2TQ$$

Curves A-D were considered to be appropriate for use in the screening procedure for nonurban locations and were included in Figure 6130.1.■■

6230 DISPERSION FACTORS

The Dispersion Factors in Figures 6140.2A, B & C were generated using CALINE4 and the following assumptions:

Wind Speed	0.5 m/s.
Wind Angle	Worst Wind Angle Search.
Temperature	15 °C.
Stability Class	"G".
ZO	100 cm.
VS & VD	0 cm/s.
Vehicle Volume	1000 vph.
Emission Factor	100 g/mi.
Link Length	3000 ft up-wind.
Link Height	0 ft.
Link Type	At-Grade.
Link Width	
2 Lane	44 ft 2(12) + 10 + 10).
4 Lane	68 ft 4(12) + 10 + 10).
6 Lane	92 ft 6(12) + 10 + 10).
8 Lane	116 ft 8(12) + 10 + 10).
Receptor Locations	Various, starting from 10 ft inside the mixing zone (receptor 0 ft from edge of lane).
Sigma Theta	
Table 6140.2A	5°.
Table 6140.2B	10°.
Table 6140.2C	30°.

The Sigma Theta values used are the worst morning evening values for the various regions (6200-6).
The reciprocals of the resultant concentrations, times 100, were then plotted to yield the dispersion factors.■■

6240 TRAFFIC VOLUMES

The recommended peak hour traffic volumes for rural 2 lane highways are theoretical capacities derived from Chapter 8 of the 1985 Highway Capacity Manual (6200-7). The volumes for highways of more than 2 lanes are based on the capacities from the 1985 Caltrans Highway Capacity report (6200-8). All of The calculations use the following assumptions:

All volumes are for level of service E. No adjustments for substandard shoulders or lane width. All calculations assume 5% trucks. Directional split assumed 60/40.■■

MICROSCALE CO SCREENING PROCEDURE

Assumptions

References:

6200-1. California Air Quality Data, Gaseous and Particulate Pollutants, Annual Summary, Volumes XVI through XVIII, California Air Resources Board.

6200-2. Methodology to Calculate Emission Factors for On-Road Motor Vehicles, California Air Resources Board, Technical Support Division, Emission Inventory Branch, November 1986.

6200-3. P. E. Benson, Corrections to Transient Vehicle Fraction for Microscale Modeling, Presented at the 66th Annual Meeting of the Transportation Research Board, Washington, D. C., 1987.

6200-4. H. Chang and N. Lai, Thirteenth Progress Report on Trip Ends Generation Research Count, Caltrans, District 04, June 1981.

6200-5. Personal Travel in the U.S., Volume 1, 1983-1984 Nationwide Personal Transportation Study, FHWA, National Highway Traffic Safety Admin., Urban Mass Transportation Admin., August 1986.

6200-6. W. Nokes and P. Benson, Development of Worst Case Meteorology Criteria, Caltrans, FHWA/CA/TL-85/14, November 1985.

6200-7. Highway Capacity Manual, (Special Report 209), National Research Council, Transportation Research Board, 1985.

6200-8. F. D. Rooney, Highway Capacity, Caltrans, Div. of Transportation Operations, 1985.

GLOSSARY

GLOSSARY

Glossary

Å (Angstrom); equal to 10^{-1} nanometers or 10^{-10} meters.

Absorption. A process in which a substance (or energy) penetrates and is nearly uniformly distributed within a suitable gas, liquid, or solid substance.

Accuracy. A measure of how close a measurement is to the actual value.

Acetylene. H-C≡C-H; a light, relatively unreactive hydrocarbon found in the atmosphere whose major source is automobile exhaust. Because of its inertness to photochemical reactions, it is commonly used as an indicator of mobile source (auto) pollution.

Adiabatic lapse rate. The rate at which a small volume of air will cool as it rises in the atmosphere, assuming there is no exchange of heat between the environment and the volume of air. The normal dry adiabatic lapse rate if -5.4 F/1000 ft. (-1.0 C/100m).

Adiabatic process. A process in which heat is neither given to nor taken from a system.

Adsorption. A process in which a substance is collected on a suitable interface between a gas, liquid, or solid and a liquid or solid.

Advection. Transport of material (e.g., pollutants) by the wind. Aerometric. Referring to measurement in the atmosphere (e.g., of wind velocity, sunlight intensity, or pollutant concentration).

Aerosol. A suspension of fine solid or liquid particles in the air, such as smoke, haze, and fog; also, the particles that make up this suspension.

GLOSSARY

Age. (of an air mass). The amount of chemical reaction that has been experienced by an air mass as compared with the amount of reaction possible. An "aged" air mass has experienced most of its "chemical reaction potential."

Air parcel. Any air mass that is assumed to retain its identity; i.e., to be relatively free of mass interchanges with its surroundings.

Air quality. Ambient pollutant concentrations and their temporal and spatial distributions.

Air Quality Control Region (AQCR). An interstate or intrastate geographic area which, due to topography, meteorology, etc., needs a common strategy for controlling air pollution.

Air quality data base. A collection of information about ambient pollutant concentrations that existed within an area during a particular time period.

Air Quality Maintenance Area (AQMA). Areas which, due to their current air quality and/or projected growth rate, have been designated by the EPA as having the potential for exceeding the National Ambient Air Quality Standards within a ten-year period of their designation.

Air quality model. An mathematical relationship between pollutant emissions and pollutant concentrations.

Air quality monitor. A device for measuring pollutant concentrations.

Air quality standard. A legal requirement on air quality, usually expressed in terms of a maximum allowable pollutant concentration averaged over a specified interval.

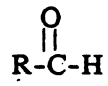
GLOSSARY

Airshed. A geographical region in which the air flow patterns are such that emissions sources within the region affect primarily the receptors within the region, and these receptors are affected primarily by those sources.

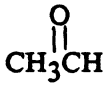
Air stagnation index. A measure of atmospheric diffusion and transport representing the degree of approach to stagnation (zero dispersal) conditions.

Albedo. Fraction of light reaching a surface that is reflected.

Aldehyde. A partially oxidized hydrocarbon with the structure



where R is a hydrogen atom or organic group, i.e., acetaldehyde,

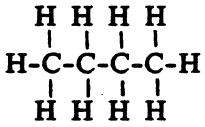


Aldehydes are formed by oxidation of hydrocarbons and are easily oxidized. Aldehyde photolysis produces radicals.

Algorithm. A calculation procedure used to solve a problem.

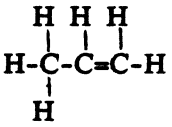
Alkane. A hydrocarbon containing only carbon-hydrogen and carbon-carbon single bonds, e.g., butane,

GLOSSARY



Alkanes of low molecular weight are colorless, flammable gases that react slowly in photochemical oxidant formation.

Alkene. A hydrocarbon containing one or more carbon-carbon double bonds, e.g., propylene,



Alkenes are also called olefins. Low molecular weight alkenes are colorless, flammable gases that react rapidly in photochemical oxidant formation.

Aloft. At a height (variably defined) above the surface.

Ambient air quality. The existing state of the atmospheric pollution in an outdoor area.

Ambient concentration. The concentration of a substance at some point as it would be without any local sources or sinks of that substance.

Ambient monitoring. Systematic measurements of the characteristics (e.g., pollutant concentration and wind velocity) of the air at a fixed location.

Anomalous concentration. A concentration that is much higher or much lower, relative to the usual variations, than the concentration a short distance or a short time away.

GLOSSARY

Anthropogenic. Resulting from man's activities.

Anticyclone. A large system of winds rotating about a high pressure center.

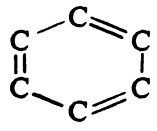
Appendix J. An empirical curve relating maximum oxidant concentrations to 6 a.m. - 9 a.m. hydrocarbon emissions. This curve was formerly recommended by the EPA for calculating hydrocarbon emissions reductions necessary to meet air quality standards.

AQCR. Air Quality Control Region; a region designated by the EPA that has significant air pollution or the potential for significant air pollution. The region includes all the counties that are affected by or have sources that contribute directly to the air quality of the region.

Area oxidant plume. A plume formed downwind of an area source of oxidant precursors.

Area source. A source of pollutant emissions composed of many small points spread over a large region and too numerous to treat individually.

Aromatic. Containing a benzene ring:



GLOSSARY

Aromatic hydrocarbons are more stable than olefins, which also have double bonds.

Arterial. A large, well-traveled street, usually with traffic signals and without limited access.

atm. Atmosphere; the nominal atmospheric pressure at sea level is 1 atm.

Atmospheric stability. The resistance to or enhancement of vertical air movement caused by the vertical temperature profile. See Temperature inversion.

Attainment area. An Air Quality Control Region which has attained the National Ambient Air Quality Control Standards.

Background concentration. The pollutant concentration which exists in the vicinity of the highway project from areawide and nearby point sources. Pollutant concentration in the absence of effects from local anthropogenic emissions.

Base year. The year associated with data used as a common reference point for comparison with data collected in other years.

Boundary conditions. The values of a variable at each point along the boundaries of a region being analyzed. Such values are necessary to determine the solution within the region.

Boundary layer. The lower 3280 feet (1000 m) of the atmosphere in which pollutant dispersion takes place.

Box model. A mathematical model that assumes that all emissions and reactions take place in a single well-mixed air parcel in which all conditions are homogeneous.

GLOSSARY

"3-C" Planning Process. See Urban Transportation Planning Process.

Calibration. To adjust mathematically the pollution concentration predicted by a model so as to match the results obtained from model validation field studies. Adjusting the output of a measuring device with a known sample: e.g., setting a scale at 100 pounds while a standard 100 pound weight is being weighed.

CAMP. Continuous Air Monitoring Program; a network of air monitoring stations in the major U.S. urban areas set up by the EPA to measure the variables associated with air pollution.

Catalytic converter. An emissions reduction device, commonly used on motor vehicles, intended to catalyze the chemical conversion of a pollutant to a less harmful compound.

Ceiling height. The lower limit of cloud formations in the atmosphere; same as mixing height.

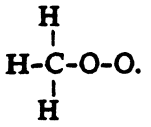
C.F.R. Code of Federal Regulations; the codification of the regulations published in the Federal Register by the executive departments and agencies of the federal government.

Chain reaction. A reaction that is initiated by one or more of its products. It is thus self-sustaining; e.g., A + B→C + A, where A is regenerated and can again react with B to form more C.

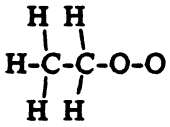
Chemical notation. A complete symbol, such as O_2 or NO_2, represents a molecule. A subscript indicates a repetition; e.g., O_2 is a molecule made from a combination of two oxygen atoms. A dot indicates the presence of an unpaired electron in a chemical species; hence, the species is a radical (e.g., OH.). A single line indicates

GLOSSARY

a single chemical bond, and a double line represents a double bond. R-represents a hydrocarbon chain. For example, RO_2. could be



or



,

among others.

Chemical reaction. A change in the chemical structure of a molecule.

Chemical symbols. Abbreviations for chemical substances:

CO = carbon monoxide

HNO_2 = nitrous acid

HO_2 = Hydroperoxy radical

H_2O_2 = hydrogen peroxide

NO = nitric oxide

NO_2 = nitrogen dioxide

NO_3 = nitrate

OH = hydroxyl radical

PAN = peroxyacetyl nitrate

PPN = peroxypropyl nitrate

RCO_3 = peroxyacyl radical

RO = alkoxyl radical

ROO = alkylperoxy radical

SO_2 = sulfur dioxide

SO_4 = sulfate

Chemical transformation. Same as "Chemical reaction."

Chemiluminescent. Of or relating to a chemical reaction producing light, e.g., the reaction of ethylene with ozone.

Chemiluminescent method. The method of measuring ozone by measuring the light emitted from the reaction between ozone and ethylene. The intensity of the light is proportional to the ozone concentration.

Clean Air Act. A series of Congressional acts and amendments regulating air pollution; when amended in 1967, it required that the Secretary of Health, Education, and Welfare developed and issued air quality criteria necessary to protect public health and welfare.

Clean Air Amendments. The 1970 Amendments to the Clean Air Act redefine the strategy of the Act and call for every state to submit an implementation plan to the EPA describing the control strategies to be used to attain compliance with National Ambient Air Quality Standards.

GLOSSARY

Coagulation. Physical agglomeration of particles into larger particles.

Cold Mode Operation. The initial stage of vehicle operation when the engine and coolant temperatures have not stabilized and usually the choke is in use. Cold mode operation is characterized by very high emission rates of CO and hydrocarbons relative to stabilized operation.

Cold start. Starting a motor vehicle with a cold engine.

Cold start emissions. Emissions emanating from an internal combustion engine during the first 505 seconds of operation.

Collector. A road connecting a residential area with an arterial or freeway.

Colorimetric. Of or relating to measurement based on color changes caused by chemical reaction.

Complex organic molecule. An organic molecule having many carbon atoms, side chains, and often inorganic components such as nitrate or sulfate.

Confidence interval. The interval in which a particular percentage of values is expected to fall based on previous experience, a limited sample of values, or mathematical analysis of the situation. For example, a 95 percent confidence interval of $\pm$0.07 ppm means that 95 percent of all the measurements are expected to fall within $\pm$0.07 ppm of the average (or actual) value.

Conformity. Requirement of Clean Air Act that any approved transportation project, plan or program must conform to the SIP.

Continuous control. A control strategy that is applied constantly, in contrast with intermittent control.

GLOSSARY

Control strategy. A combination of limiting measures, on an areawide or statewide basis, designed to achieve the aggregate reduction of emissions of the National Ambient Air Quality Standards.

Coriolis force. A force which deflects the movement of air, due to the turning motion of the earth on its axis. The conservation of angular momentum acting on a mass at the earth's surface that is moved north or south (i.e., closer to or further from the earth's axis of rotation). In the Northern Hemisphere, masses moving north or south tend to curve to the right.

Correlation coefficient. A measure of the extent to which two variable or two sets of data are related linearly.

Coulometric. Of or relating to measurement of the number of electrons or total charge transferred as a result of a chemical reaction.

Criteria pollutant. A pollutant for which the EPA has established an NAAQS; i.e., oxidant, NO_2, SO_2, CO, HC, or TSP.

Critical year. In air quality analysis, the year in which highest pollutant concentrations are expected to occur.

Diffusion. The gradual mixing of the molecules of two or more substances as a result of random thermal motion.

Diurnal. Related to a 24-hour period; e.g., diurnal variations in oxidant concentration.

Dispersion. The process by which atmospheric pollutants are transported and diluted due to wind and turbulent mixing.

Driving cycle. A profile of velocity versus time, specified for determining vehicular emissions rates.

Dustfall. The amount of particles settling out of the atmosphere.

Dynamic field calibration. Determination of the response of a measurement instrument located at a monitoring site to a known time-varying input signal.

EKMA (Empirical Kinetic Modeling Approach). An air quality model based on ozone isopleth diagrams.

Emissions factor. The rate of pollutant emissions under specified conditions. A number which describes the average emission of pollutants from a set of vehicles in various mixes of operating conditions.

Emissions inventory. A complete list of sources and rates of pollutant emissions within a specified area and time interval.

Emissions rate. The rate at which pollutants are emitted into the atmosphere by one source such as the exhaust system of a vehicle, or a combination of sources.

Emissions standard. A legal limit on a rate of emissions.

Empirical. Determined from or based on observation rather than physical law.

Entrainment. The drawing of material into an air mass as a consequence of the movement of that air mass.

Environmental Impact Statement (EIS). A document in which the impacts of major Federal actions which significantly affect the human environment are evaluated prior to construction; required by the National Environmental Policy Act of 1969.

EPA. U.S. Environmental Protection Agency.

Episode. A period of time when low wind speeds combine with limited mixing depths to create conditions favorable for high pollutant concentrations.

Episode alert. Public notification of a high level of pollution, usually accompanied by a warning to people with respiratory disease to stay indoors and by a request to motorists and industry to reduce emissions of pollutants.

Equivalent method. A method of sampling and analyzing the ambient air that is so designated by the EPA because of its equivalence to the federal reference method for the pollutant analyzed. Equivalence is demonstrated through a series of EPA-designated comparison tests.

Eulerian. Having a coordinate system fixed with respect to the earth's surface. Compare Lagrangian.

Exceedance (oxidant). An observed occurrence of oxidant concentration higher than the specified maximum one-hour average. An exceedance of the oxidant NAAQS more than once per year is a violation.

Exercise (of a model). Carrying out a simulation using full inputs and initial conditions.

Federal reference measurement principle. Refers to the principle of measurement required under Code of Federal Regulations, Title 40, Section 50.9 for automated ozone ambient analyzer or monitoring methods. For ozone, this principle is based on the observation of chemiluminescence due to the ozone-ethylene reaction.

GLOSSARY

Fed. Reg. Federal Register; a daily (weekday) publication of new public regulations and legal notices issued by federal agencies.

Federal Test Procedure (FTP). A detailed procedure prescribed by EPA for certifying the performance of motor vehicles with regard to compliance with federal emission regulations.

Fine scale. Small spacing, generally a mile or less, between data points determining the spatial resolution of a model.

Finite difference method. A method for solving differential equations by converting continuous equations into equations that are evaluated only at specific points in time and space. The finite difference method is numerical and is amenable to computer solution.

Flux. The rate per unit area at which material or energy moves. Often it is measured relative to the mean motion.

Frequency analysis. A study of the frequency of occurrence of various levels of a given variable in a data set.

Frequency distribution. A curve of the percentage frequency of occurrence of each value that a variable may take on.

Friction island effect. The reduction of surface wind speeds in an urban area caused by greater surface roughness due to buildings and other structures.

Frontal zone. The region of relatively sharp changes of temperature, humidity, and the like, between two large air masses. A frontal zone is often characterized by clouds and precipitation.

Gas chromatography. A method of analyzing the components of a mixture of gases based on the difference in adsorption of different gases on specially selected filter materials.

Gas phase reaction. A chemical reaction occurring between gaseous species.

Gaussian model. A pollutant dispersion model based on the Gaussian dispersion equation. A mathematical simulation of dispersion in which pollutant concentrations are normally distributed in the crosswind and vertical directions.

Geometric mean. The n^{th} root of the product of a series of n numbers.

Geostrophic layer. The portion of the troposphere, beginning at roughly 500 m above ground level, in which air flow is not affected by the roughness of the earth's surface.

Global maximum. The highest value observed or calculated if the value at every point in the space of interest were known.

GMT. Greenwich Mean Time; the time according to a 24-hour clock in Greenwich, England. GMT, which is eight hours later than Pacific Standard Time, is used as a worldwide standard for timing weather observations.

Gravitational settling. Removal of particles from the atmosphere through the action of gravity.

Grid model. An air quality model in which all relevant equations are solved at a number of discrete points that represent points on a grid covering the region of interest.

GLOSSARY

Half-life. The time required for a quantity to decrease to half its original amount (as by chemical reaction).

HC. Hydrocarbon.

Heat island effect. The effect of an urban area on air flow due to its greater heat emissions than surrounding rural areas.

Henry's Law. A physical law stating that the equilibrium partial pressure of a volatile substance above a solution is proportional to the percentage of molecules of that substance in the in the solution.

Heterogeneous reaction. A chemical reaction between reactants that are in different physical states; e.g., some reactions that the place on the surface of a dust particle involve both a gas and a solid.

hν. The energy contained in a photon of light; h is Planck's constant, and is the frequency of the light.

Hot soak emissions. Emissions emanating from an automobile immediately after engine is turned off while still warm.

HOV. High occupancy vehicle. A car, van or bus carrying more than one person.

Hydrocarbon-rich. Having a higher concentration of hydrocarbons that can react with the available reactants in a particular system; having too much hydrocarbon for the fastest production of ozone for a particular photochemically active atmosphere.

Hydroxyl. A radical containing a single oxygen and a single hydrogen atom (OH.) that is formed in reactions involving water or organic molecules. The hydroxyl radical is very reactive and is believed to play a major role in photo-chemical smog.

Indirect control. Control of air quality by altering activities that influence the rate and distribution of emissions (e.g., traffic patterns, land use). Indirect control contrasts with direct control at the source of the emissions (e.g., devices on automobiles or smokestacks).

Indirect source. Any structure or installation which attracts activity that results in emissions of pollutants.

Initial conditions. The values of a variable at each point of a region at a specified starting time that are necessary to determine a solution at subsequent times.

Insolation. Rays of the sun that reach the surface of the earth; the delivery rate of solar energy per unit surface area.

Inspection and Maintenance (I/M). An emissions testing and inspection program implemented by states in nonattainment areas to ensure that in-use vehicles are properly maintained to meet emissions standards.

Interference. The portion of a measurement due to the influence of a substance or effect that is not meant to be included in the measurement.

Intermittent control. A control strategy that is applied only during those meteorological conditions that lead to smog episodes.

Inversion. A condition in the atmosphere where temperature increases with altitude. A thermal gradient created by warm air situated above cooler air. An inversion suppresses turbulent mixing and thus limits the upward dispersion of polluted air.

Inversion base. The lowest altitude of the thermal gradient that forms an inversion.

GLOSSARY

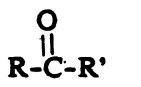
Isobar. A line on a map connecting points of equal barometric pressure.

Isopleth. A line connecting points of equal value, e.g., a contour line connecting points of equal elevation on a topographic map, or an isotherm connecting points of equal temperature on a weather map.

Isoprene. A diolefin whose chemical symbol is C_5H_8.

Joint distribution frequency. The distribution of the frequency of occurrence of two variables having values greater than some set of value combinations.

Ketone. A partially oxidized hydrocarbon with the structure:



where R and R' are hydrocarbon groups (not hydrogen).
Compare with Aldehyde.

Kinetic mechanism. A set of chemical reactions and rate constants intended to represent some chemical process. Because of incomplete knowledge, kinetic mechanism contain uncertainties regarding the values of rate constants and the products of particular reactions.

Lagrangian. Having a coordinate system that moves with respect to the earth's surface. Compare Eulerian.

Lag time. The time interval for an instrument between a step change in input concentration and the first observable corresponding change in response.

Lake breeze. A light wind blowing from a lake to surrounding land areas during the day due to temperature differences between land and water. Compare Land breeze, Sea breeze.

Land breeze. A light wind blowing from land to a large body of water at night due to temperature differences between land and water. Compare Lake breeze, Sea breeze.

LARPP. Los Angeles Reactive Pollutant Program; an intensive study of atmospheric pollutant concentrations carried out in the fall of 1973 in Los Angeles.

Layer aloft. A layer of air that can be differentiated from the air above and below it, as by an inversion,

Level of service. A measure of the level of traffic congestion on a roadway. There are six levels of service, A through F, with A representing the best operating conditions and F the worst.

Line source. A long, narrow source of emissions such as a roadway or railroad.

Link. A portion of a road in a highway network. Usually defined by nodes at each end-point.

LIRAQ. Livermore Regional Air Quality Model; a grid-based physicochemical model developed by Lawrence Livermore Laboratory to predict pollutant concentrations in the San Francisco Bay region.

Local meteorology. The weather conditions, temperature, wind velocity, mixing height, cloud cover, and so forth, that exist in a particular urban or rural area.

GLOSSARY

Lognormal distribution. A statistical distribution in which the logarithm of the random variable follows a normal distribution.

Long range transport. Atmospheric transport of pollutants over long distances (e.g., 100-1000 km) with relatively little dispersion.

Macroscale. Large scale, involving distance of 100 to several thousand kilometers.

mb. Millibar; a unit of pressure equal to 10^3 dyne/cm^2. Atmospheric pressure equals 1.013 x 10^3mb.

Mean. The arithmetic average; i.e., the sum of the values divided by the number of the values.

Measurement drift. The tendency of the output of a measuring instrument to increase or decrease over time though the input is constant. For example, a thermomenter may read 75.0 at noon, 75.1 at 1:00 p.m., and 75.2 at 2:00 p.m. even though the actual temperature does not change. See also Zero Drift and Span Drift.

Measurement noise. Random fluctuations in the electrical signal from a measurement device.

Measurement principle. The basic chemical or physical phenomenon that is the basis for a measurement method.

Measurement specificity. The degree to which a measurement reflects the value for only the substance or effect of interest and does not include interference from other substances or effects.

Median. The data point in a set of data points that has a value such that half the data points have smaller values and half larger values.

Mesoscale. Literally "middle scale" between microscale and macroscale, involving distances of 1 to 100 kilometers and times of 1 to 24 hours.

Meteorological variables. Wind speed and direction, mixing depth, temperature, pressure, degree of turbulence, sunlight intensity, humidity, and precipitation; also, the variation of these parameters.

Methane. The simplest hydrocarbon (CH_4); the major component of natural gas.

Methyl. A radical containing a carbon atom and three hydrogens (CH_3).

Metropolitan Planning Organization (MPO). The agency in a metropolitan area that is officially designated by the local jurisdictions as the agency responsible, together with the State, for carrying out the provisions of the Federal legislation for urban area transportation planning.

Microscale. Small scale, involving distances up of less than 1 km. For highway projects, microscale usually refers to the area within 300m of the roadway and 1-5 kilometers up-wind.

Mixed layer. Layer of air near the ground where turbulent mixing of pollutants occurs. It is limited by an inversion base, if one is present.

Mixing depth. The depth of the mixed layer.

Mixing height. The upper limit of ground-based turbulence in the atmosphere. (See ceiling).

Mobile source. A moving vehicle that emits pollutants. Such sources include automobiles, trucks, trains, ships, and farm equipment.

GLOSSARY

Modal emissions factors. Vehicular emissions factors for individual modes of operation, e.g., accelerate, cruise, decelerate, idle.

Modal Split. The distribution of total persion trips by mode of travel.

Monitoring network. An array of measurement devices designed to characterize regional air quality and, in some cases, meteorology.

Monitoring site. The location of a measurement device in a monitoring network.

NAAQS. National Ambient Air Quality Standard; established by the EPA to protect human health (primary standards) and to protect property and aesthetics (secondary standards).

Natural sink. Natural process that removes pollutants from the atmosphere.

Natural source. A source of pollutant emissions unrelated to man's activities, e.g., a volcano.

Negative interference. Phonomenon that consistently causes a measurement to be lower than the true value.

Network. A system of links and nodes describing a highway system.

NMHC. Nonmethane hydrocarbons, typical determined by measuring total hydrocarbons and methane and subtracting. NMHC is commonly reported because methane reacts slowly in photochemical oxidant formation.

Nocturnal inversion. A surface-based temperature inversion formed at night by radiational cooling of the earth's surface and, hence, the air near the surface.

Nocturnal jet. A high-velocity wind observed to occur at night within inversion layers.

Node. A designated point on a street or highway that delinates the end-point.

Nonattainment area. A region which has not or is not expected to attain the NAAQS.

Nonmethane hydrocarbon. A hydrocarbon other than methane. See NMHC.

Non-ozone-specific method. A method that measures the concentration of a group of oxidants (the exact group depends on the method), rather than just the concentration of ozone.

Normal distribution. The Gaussian or "bell curve" distribution.

NO_x-poor. Having less NO_x than would be required for the fastest production of ozone for a particular concentration of hydrocarbons; same as "hydrocarbon-rich."

Nucleation. Formation of a droplet by collection of water vapor on a particle.

Olefin. A hydrocarbon containing a carbon-carbon double bond. See Alkene.

Oxidation. Partial or complete loss of an electron from an atom in a chemical reaction. For example, in the reaction.

$$2CO + O_2 \longrightarrow 2CO_2$$

the carbon atoms are oxidized because some electrons initially at those atoms pulled further from the carbon atoms by the oxygen atoms. Oxygen atoms attract electrons more strongly then almost all other atoms, hence, a reaction with oxygen is usually

GLOSSARY

an oxidation. Compare Reduction.

Ozone (O_3). A strong photochemical oxidant whose molecules consist of three bound oxygen atoms, O-O-O.

PAN. Peroxyacetyl nitrate, $CH_3C(O)OONO_2$, an oxidant normally found in photochemical smog and believed to cause eye irritation.

Paraffin. A hydrocarbon containing only hydrogen and carbon and having no double or triple bonds. See Alkane.

Parcel trajectory. The path taken by a volume of air as it is advected by the wind.

Particle-in-cell technique. A method for solving fluid flow and turbulent diffusion problems on a digital computer that represents the distribution of fluid or pollutants as a collection of Lagrangian mass points that move through a network of Eulerian grid cells.

Particulates. Microscopic particles suspended in air. See Aerosol.

Pasquill stability class (or Pasquill-Gifford Stability Classification). A standard classification scheme for atmosphere stability. An indicator of atmospheric conditions or vertical movement of air close to the surface. Stability class is a function of time of day, insolation, amount of cloud cover, and surface wind speed.

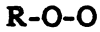
Peroxide. A molecule containing an oxygen-oxygen single bond, e.g., hydrogen peroxide, H-O-O-H.

Peroxy. A molecule containing two oxygen atoms (-O-O). A hyderoperoxy radical has the formula HO_2.

Peroxyacyl. A radical whose chemical structure is

where R is an organic group.

Peroxyalkyl. A radical whose chemical structure is



where R is an organic group.

Photochemical aerosol. Liquid and solid particles (usually less than 10 m in diameter) that are formed in the atmosphere through processes that are affected by the presence and intensity of light.

Photochemical reactions. Chemical transformation whose character, rates, or both are affected by the presence and intensity of light.

Photochemical smog. The atmospheric condition that results when hydrocarbons and nitrogen oxides emitted into the atmosphere react in the presence of sunlight to form other pollutants, such as oxidants, PAN, and aerosols.

Photodissociation. See Photolysis.

Photolysis. The decomposition of a chemical compound by light.

Physicochemical model. A mathematical model that explicitly accounts for both physical and chemical processes in its formulation.

Pibal. A pilot balloon, which is released and optically tracked to determine winds.

GLOSSARY

Planetary boundary layer. The lower part of the atmosphere (from the ground surface to less than one mile above) in which wind patterns are affected by drag against the earth's surface.

Plume. The spreading pollutants emitted by a fixed source, such as a smokestack.

Point source. A single origin of emissions located at a fixed point.

Point stationary source. A pollutant source that is fixed to the ground and that releases pollutants through a relatively small area (e.g., a smokestack).

ppb. Parts per billion (10^9) by volume.

pphm. Parts per hundred million (10^8) by volume.

ppm. A volume measure of air pollutant concentrations. To convert to a weight measure (ug/m^3) of carbon monoxide multiply ppm by

$$\frac{\text{molec. wt. x } 10^6}{24{,}500}$$

For example, 50 ppm of carbon monoxide is equivalent to

$$50\ \frac{(28)(10^6)}{24{,}500} = 5.71 \text{ x } 104 \quad g/m^3$$

or 57.1 miligrams per cubic meter since 1 milligram = 103 micrograms.

ppmC. Parts per million carbon; ratio of the volume of hydrocarbons to 1 million parts of air that would result if all carbon atoms were in the form of methane.

GLOSSARY

ppt. Parts per trillion (10^{12}) by volume.

Precipitation scavenging. Removal of a pollutant from the atmosphere by precipitation, by either nucleation around the pollutant in the formation of precipitation or scavenging of the pollutant by precipitation as it falls.

Precision. A measure of the reproducibility of measurement of the same quantity made at different times. A measurement may be precise but not accurate if some fault, such as zero error, is present.

Precursor. A chemical compound that leads to the formation of a pollutant, e.g., hydrocarbons and nitrogen oxides are precursors of photochemical oxidant.

Primary. Injected into the atmosphere rather than formed in the atmosphere.

Primary pollutant. Chemical contaminants which are released directly to the atmosphere by a source.

Primary standard. A National Ambient Air Quality Standard set to protect human health.

Priority. Requirement of the Clean Air Act that Federal agencies give priority to implementing transportation control measures in nonattainment areas.

Pristine. Undegraded by man's activities.

Quality assurance program. The program implemented as part of a measurement program to (1) identify and quantify sources of variability, (2) delineate operating procedures, (3) estab-lish quality control checks and performance standards, (4) eliminate determinate errors and minimize indeterminate errors, and (5) operate and maintain a primary standards laboratory.

Quality assurance program. The program applied to routine systems in order to evaluate and document the ability of a function, activity, or person to produce results that are valid within predetermined limits.

Radiation flux. The amount of light energy per unit area per unit of time.

Radical. A chemical species having an unpaired electron. Radicals are very reactive.

Radical transfer. Transfer of an unpaired electron from one molecule to another.

Radiosonde. A light electronic device that senses temperature, humidity, and pressure and transmits this information on a radio signal. Radiosondes are designed to be carried aloft (into the atmosphere) beneath a buoyant balloon.

Radiosonde soundings. Free flights of radiosonde-equipped balloons during which information is transmitted to ground-level radio equipment as the balloons rise in the atmosphere. This information includes temperature, humidity, and pressure at various altitudes.

Rainout. The removal of a pollutant from the air in a cloud during the process of precipitation. Compare with Washout.

Random error. An error that follows a statistical distribution and that cannot be predicted or corrected.

Rate constant. A constant of proportionality that relates the rate at which the concentration of a species changes with time to the concentration of the reactant species at any particular time. For example, for the reaction A + B products, the rate constant k is given by $(dc_A/dt)/c_Ac_B$, where c_A is the concentration of A.

Rawinsonde. A radiosonde balloon that is tracked by radar to estimate wind velocity.

Reactive hydrocarbon (RHC). A hydrocarbon that readily combines with radicals and thereby contributes to the production of ozone.

Receptor. A designated point location where pollutant levels are examined.

Reduction. Partial or complete gain of an electron by an atom in a chemical reaction. For example, in the reaction

$$2CO + O_2 \rightarrow 2CO_2 \quad ,$$

the oxygen atoms in the O_2 molecule are reduced because they attract electrons from the carbon atoms. Compare oxidation.

Reference method. A method required by EPA regulations to be used for measuring the concentration of a pollutant to ascertain whether an area is in violation or in compliance with the air quality standard for that pollutant.

Regression analysis. The construction of a relationship between a set of predictor variables and a predicted variable. The procedure, which involves the use of past measurements, is based on minimization of the sum of the squared errors in prediction.

Reliability. The extent to which a model, experiment, or test will yield the correct results for a variety of trials.

GLOSSARY

Removal process. A process that removes a pollutant from the atmosphere.

RH. Relative humidity.

RHC. Reactive hydrocarbon. See the definition of the full term.

ROG. Reactive Organic compounds.

Rollback. A simple model that assumes that if emissions from each source affecting a given receptor are decreased by the same percentage, ambient air quality concentrations decrease proportionately.

Rollback relationship. An oxidant prediction relationship that consists of a plot of expected oxidant concentrations as a function of hydrocarbon concentrations or emissions. It is used to estimate the reduction in emissions necessary to meet air quality standards.

Scavenging. Removal of a pollutant from the atmosphere, particularly by precipitation or chemical reaction.

Screening. A relatively simple analysis technique to determine if a given source is likely to pose a threat to air quality.

Secondary or Secondary pollutant. Produced in the atmosphere rather than directly emitted as a result of chemical reactions, such as hydrolysis, oxidation, and photochemistry.

Secondary standard. A National Ambient Air Quality Standard set to protect human welfare and aesthetics. Secondary standards are generally more stringent than primary standards.

Sensitivity analysis. A test of a model using different input and parameters to discover what effects changes in their values have on model predictions.

Simulation model. A mathematical description of real physical and/or chemical process. The responses of the model to input variations are analogous to those of the real processes.

Sink. A process that removes pollutants from the atmosphere.

Smog chamber. An experimental apparatus used to study the chemical reactions that take place in a polluted atmosphere. Such a chamber may have controllable inlets for introducing pollutants and outlets for removing samples. It can also be artificially illuminated to simulate sunlight.

Solar radiation. Energy emitted by the sun that reaches the earth as ultraviolet, visible, and infrared light.

Sounding. Measurement of meteorological properties, such as temperature of wind velocity, during a vertical transit of the atmosphere.

Span drift. The percentage change in the response of a measuring device to a pollutant concentration that registers high in the range of the instrument over a 24-hour period of continuous, unadjusted operation.

Span error. An error in the response of a measuring device to a pollutant concentration that registers high in the range of the measurement device.

Spatial resolution. A measure of the precision with which two points separated in space are distinguished from one another. In air pollution models, it is the characteristic distance over which major dependent variables, such as wind and emissions, are averaged.

GLOSSARY

Spatial scale. The distance over which significant changes of phenomena are being studied.

Spent air mass. An air mass containing nearly completely reacted pollutants.

Stability. A property of the atmosphere which determines the amount of vertical mixing.

Stable layer. A layer of air in which very little mixing takes place.

Stable layer aloft. A layer of air at least 100 feet thick, located 500 to 5000 feet above the ground, in which little or no mixing takes place.

Standard deviation. The square root of the variance. The standard deviation is a measure of the spread in a set of measurements of a single parameter.

Standard geometric deviation. A measure of the variability in a set of data; it is defined as

$$\exp\left[\sum_{1}^{N}\frac{(\ln x_i - \ln M_g)^2}{N}\right]^{1/2},$$

where $x_1, x_2, \ldots, x_N$ are the data with geometric mean M_g.

State Implementation Plan (SIP). The strategy to be used by a state to control air pollution so that the National Ambient Air Quality Standards will be met. EPA regulations require that each state devise such a plan.

Stationary source. A source of pollutants that is immobile. Such sources include industrial complexes, power plants, and individual heating units. Aircraft are sometimes also included in this category because they are a significant pollutant source only near airports.

Statistical model. A statistical relationship between a set of predictor variables and a predicted variable.

Steady-state assumption. The assumption that a system or variable remains unchanged with the passage of time because of the equality of input to and outflow from the system.

Stratosphere. A layer of the atmosphere immediately above the troposphere; it extends to a height of roughly 50 kilometers, and it is characterized by little variation in temperature, low air pressure, and the absence of clouds.

Stratospheric intrusion. The transport of ozone from the stratosphere into the troposphere.

Subsidence inversion. A type of temperature inversion associated with high-pressure systems in which a thermal gradient is established by the heating due to compression of an air parcel as it decends.

Sulfur oxide (SO_X). Any of several oxides of sulfur, such as sulfur dioxide (SO_2).

Surface flux. The rate per unit area at which some quantity passes through or is emitted from a surface.

Surface layer. The layer of air near the ground, generally 1 to 100 meters deep, where surface features (e.g., trees, buildings) affect atmospheric turbulence and diffusion.

GLOSSARY

Surface removal rate. The rate at which pollutants are removed through reactions with, adsorption on, or absorption by surfaces.

Surface roughness. The characteristic height of obstructions in the path of the wind near the surface, such as the height of trees and buildings.

Surface sink. A surface that removes pollutants from the air by reaction or absorption.

Synoptic. Same as macroscale.

Systematic error. A nonrandom error that is caused by some inherent characteristic of a device or by flaws in analysis.

Temperature field. The distribution of temperatures over some area or within a volume.

Temperature gradient. Change of the ambient temperature as a function of distance (either vertical or horizontal).

Temporal resolution. A measure of the precision with which two points separated in time are distinguished from one another. In air pollution models, it is the characteristic time over which major dependent variables, such as winds and emissions, are averaged.

Texture. The surface roughness of a city.

THC. Total hydrocarbon (i.e., reactive plus nonreactive).

TOG. Total Organic compounds.

Tracer. A substance used to follow the path of a physical, chemical, or biological process.

Traffic Assignment. The process of determining probable travel paths over the highway network between analysis zones.

Trip Distribution. A general term describing the distribution of trips between each zone and all other zones.

Trip Generation. To define an area's trip-making characteristics based on factors such as land-use, socioeconomic structure, demographics etc.

Trajectory model. A mathematical model designed to follow a single parcel of air along a trajectory determined by the wind.

Transport. Movement of pollutants or other material in the atmosphere from one location to another.

Transportation Control Measures (TCM). Any measure in a State Implementation Plan directed toward reducing emissions of air pollutants from transportation sources.

Tropopause. The (approximate) interface between the troposphere and the stratosphere at which the vertical temperature gradient changes sign (positive in the stratosphere and negative in the troposphere) and through which exchange of air between the two spheres is inhibited.

Troposphere. The lower layer of the atmosphere, 10 to 15 kilometers deep, where most of the processes commonly considered "weather" occur.

TSP. Total suspended particulate matter.

GLOSSARY

Turbulence. Unsteady and irregular motions of air in the atmosphere.

Turbulent wake. The area of turbulence caused by a moving vehicle.

Ultraviolet light. Light of a wavelength in the range of 40 to 4000 Angstroms (10^{-10} meters). These wave lengths are shorter (corresponding to higher frequences) than those of visible light.

Unreactive hydrocarbon. A hydrocarbon that reacts much slower than the organic compounds that influence the production of smog. Unreactive hydrocarbons thus have little effect on oxidant production.

Urban air parcel. An air mass that has passed over an urban area and that contains anthropogenic pollutants.

Urban plume. A very large plume whose source is an entire city or metropolis. It can be transported to the countryside downwind.

Urban transportation planning process. (3-C planning process)--The continuing, comprehensive, and cooperative transportation planning process established by Federal legislation for urban areas.

UV. Ultraviolet light (see the definition of the full term.)

Validation. The testing of the accuracy of mathematical models used to predict pollution concentrations by comparing predicted concentrations to measured concentrations under equivalent conditions.

Validity. The extent to which a model or relationship actually predicts the real-world behavior of a system.

Variance. A measure of variability in a data set. The variance is given by

$$\frac{\sum_{1}^{n} (x_i - \bar{x})^2}{n - 1},$$

where x_1, x_2, ..., x_n are the data points and x is their mean value.

Vehicle miles of travel (VMT). The sum of distances traveled by all motor vehicles in a specified region.

Velocity field. The distribution of flow velocities over some area or within a volume.

Ventilation. The transport of air through a given region. The rate of ventilation is equal to the mixing depth times the transport wind speed.

Venting. Movement of pollutants in the vertical direction--generally caused by convection or wind convergence.

Verification study. An experiment designed to provide data that can be used to verify the predictions or computations of a mathematical or graphical model.

Vertical sounding. Same as Sounding.

VMT. Vehicle miles traveled.

GLOSSARY

Volumetric. Pertaining to measurement of or within a volume.

Washout. The removal of pollutants from the air beneath the clouds by precipitation. Compare with Rainout.

Wind field. The same as Velocity field.

Wind rose. A circular diagram showing the frequency of wind directions experienced at a given location over some period of time.

Wind shear. The spatial variation of wind velocity. It is frequently used to mean the variation of wind velocity with height above the ground.

Zenith angle. The measurement of the inclination of the sun from the horizon (0°) towards its highest point (90°) and back to the horizon.

Zero air or zero gas. A gas that contains none of the substance that is being measured and that is used to calibrate a measurement device at the null condition.

Zero drift. The change in reading of a measuring instrument with zero input over 12- or 24-hour periods of unadjusted operation.

Zero error. The error in the reading of a measuring instrument with zero input.

Appendix 1 TEMPERATURE DATA

JANUARY MEAN MINIMUM TEMPERATURES

County	Station	Latitude & Longitude	Elev.	Jan Mean Min. Temp Year '84	'85	'86	Screen Proc. Temp.
Alameda	BERKELEY	37 52 122 15 W	345	44.1	39.8	47.5	45
	LIVERMORE	37 40 121 46 W	480	36.0	34.8	42.7	40
	NEWARK	37 31 122 02 W	10	43.7	41.9	48.6	45
	OAKLAND MUSEUM	37 48 122 16 W	30	45.2	40.8	48.3	45
	OAKLAND WSO AP	37 44 122 12 W	6	45.0	42.1		45
	TRACY PUMPING PLANT	37 48 121 35 W	61	38.9	34.1	43.4	40
Alpine	TWIN LAKES	38 42 120 02 W	8000	20.6	17.5	26.0	25
	WOODSFORDS	38 47 119 49 W	5670	21.0	19.5	28.8	25
Amador	ELECTRA POWER HOUSE	38 20 120 40 W	715	34.2	29.8	39.9	35
	SALT SPRINGS PWR HOUSE	38 30 120 13 W	3700	38.9	33.7	40.3	40
	TIGER CREEK P H	38 27 120 29 W	2355	33.4	32.4	38.8	35
Butte	CHICO UNIVERSITY FARM	39 42 121 49 W	185	35.5	31.0	40.5	35
	DE SABLA	39 52 121 37 W	2720	31.5	29.3	39.3	35
	OROVILLE	39 31 121 33 W	171	36.9	31.4	37.5	35
	PARADISE	39 45 121 37 W	1750	39.3	35.4	43.8	40
Calaveras	CALAVERAS BIG TREES	38 17 120 19 W	4695	30.6	26.5	33.8	30
	CAMP PARDEE	38 15 120 51 W	658	39.7	35.3	45.2	40
Colusa	COLUSA 2 SSW	39 12 122 01 W	50	39.6	34.5	43.1	40
	EAST PARK RESERVOIR	39 22 122 31 W	1205	34.4	26.8	34.5	30
	WILLIAMS	39 09 122 09 W	85	37.3	33.5	41.5	40
Contra Costa	ANTIOCH PUMPING PL 3	37 59 121 44 W	60	37.5	33.4	43.5	40
	MARTINEZ WATER PLANT	38 01 122 07 W	40	34.8	34.7	44.0	40
	MOUNT DIABLO JUNCTION	37 52 121 56 W	2170	41.0	38.8	43.3	45
	RICHMOND	37 56 122 21 W	55	42.7	38.8	46.3	45
Del Norte	CRESCENT CITY 1 N	41 46 124 12 W	40	40.2	37.2	45.1	40
	KLAMATH	41 31 124 02 W	25	39.1	35.5	43.9	40
El Dorado	ECHO SUMMIT-SIERRA SKI R	38 47 120 02 W	7350	23.3	21.2	27.7	25
	GEORGETOWN RANGER STA	38 55 120 47 W	3001		32.6		40
	PLACERVILLE	38 44 120 48 W	1890	34.1	24.6	36.9	30
	PLACERVILLE IFG	38 44 120 44 W	2755	41.4	35.1	44.0	40
	TAHOE VALLEY FAA AP	38 54 120 00 W	6254	20.2	15.7	25.2	20
Fresno	AUBERRY 1 NW	37 05 119 30 W	2140	33.5	33.5	44.5	40
	BALCH POWER HOUSE	36 55 119 05 W	1720	38.5	35.1	44.3	40
	COALINGA	36 09 120 21 W	670	37.2	34.7	43.6	40
	FIVE POINTS 5 SSW	36 22 120 09 W	285	38.6	36.9	40.4	40
	FRESNO WSO AP	36 46 119 43 W	328	40.3	37.0	45.8	40
	FRIANT GOVERNMENT CAMP	36 59 119 43 W	410	39.0	32.5	43.2	40
	HUNTINGTON LAKE	37 14 119 13 W	7020	28.7	23.3	32.7	30
Glenn	ORLAND	39 45 122 12 W	254	38.0	34.5	39.0	40
	STONY GORGE RESERVOIR	39 35 122 32 W	800	33.4		37.5	40
	WILLOWS 6 W	39 31 122 18 W	233	38.1	33.5	42.1	40

JANUARY MEAN MINIMUM TEMPERATURES

County	Station	Latitude & Longitude	Elev.	Jan Mean Min. Temp Year '84	'85	'86	Screen Proc. Temp.
Humboldt	EUREKA WSO CI	40 48 124 10 W	60	41.8	40.5	47.1	45
	GRIZZLY CREEK ST PK	40 29 123 54 W	410	36.4	33.6	40.8	40
	HOOPA TRINITY RIVER	41 03 123 40 W	333		33.5		40
	ORICK PRAIRIE CREEK PK	41 22 124 01 W	160	36.7	34.1	42.1	40
	ORLEANS	41 18 123 32 W	410	35.1	31.5	41.6	35
	RICHARDSON GROVE ST PK	40 02 123 47 W	500	37.1	35.5	42.1	40
	SCOTIA	40 29 124 06 W	139	39.7	38.5	45.4	45
	SHELTER COVE AVIATION	40 01 124 04 W	415	48.0	45.5		50
	WILLOW CREEK 1 NW	40 57 123 38 W	461		30.7		35
Imperial	BRAWLEY 2 SW	32 57 115 33 W	-100	41.5	39.6	42.9	45
	EL CENTRO 2 SSW	32 46 115 34 W	-30	42.4	38.8	46.5	45
	GOLD ROCK RANCH	32 53 114 52 W	485	49.2	45.5	53.0	50
	IMPERIAL	32 51 115 34 W	-64	44.9	42.7	46.8	50
Inyo	BISHOP WSO AP	37 22 118 22 W	4108	24.7	22.2	24.3	25
	DEATH VALLEY	36 28 116 52 W	-194	41.4	37.5	40.7	45
	DEEP SPRINGS COLLEGE	37 22 117 59 W	5225	20.5	18.0		25
	HAIWEE	36 08 117 57 W	3825	32.5	28.4	33.5	35
	INDEPENDENCE	36 48 118 12 W	3950	33.3	29.9	36.7	35
	WILDROSE RANGER STN	36 16 117 11 W	4100	33.7			40
Kern	BAKERSFIELD WSO AP	35 25 119 03 W	495	39.6	35.8	43.7	40
	BUTTONWILLOW	35 24 119 28 W	269	38.0		40.8	45
	GLENNVILLE	35 43 118 42 W	3140	29.9	28.1	34.8	35
	INYOKERN	35 39 117 49 W	2440	33.9	28.9	34.8	35
	KERN RIVER P H 1	35 28 118 47 W	970	43.5	39.5		45
	KERN RIVER P H 3	35 47 118 26 W	2703	34.6	32.8	40.1	40
	MARICOPA	35 05 119 23 W	675	37.5	34.3	42.8	40
	MOJAVE	35 03 118 10 W	2735	34.2	32.0	39.1	35
	RANDBURG	35 22 117 39 W	3570	39.3	33.9	40.9	40
	TEHACHAPI	35 08 118 27 W	4017	34.3	31.1	37.9	35
	TEJON RANCHO	35 02 118 45 W	1425	35.9	31.8	42.2	35
	WASCO	35 36 119 20 W	345		35.4	42.1	40
Kings	CORCORAN IRRIG DIST	36 06 119 34 W	200	38.6	34.5	43.1	40
	HANFORD 2 S	36 18 119 39 W	240	37.3		42.0	40
Lake	CLEARLAKE 4 SE	38 54 122 36 W	1349	31.5	28.1		35
	LAKEPORT	39 02 122 55 W	1315	34.0	30.3		35
Lassen	DOYLE 4 SSE	39 58 120 05 W	4390	22.5	17.0	29.8	20
	SUSANVILLE AIRPORT	40 22 120 34 W	4146	19.5	16.6	28.4	20
	TERMO	40 52 120 27 W	5300	17.5	6.2	24.9	10
Los Angeles	AVALON PLEASURE PIER	33 21 118 19 W	25			53.1	60
	BURBANK VALLEY PMP PLT	34 11 118 21 W	655	43.4	37.8	47.5	45
	CANOGA PARK PIERCE COL	34 11 118 34 W	790	41.6	39.5		45
	CULVER CITY	34 01 118 24 W	55		46.7		50
	DRY CANYON RESERVOIR	34 29 118 32 W	1455	36.6		38.3	40
	FAIRMONT	34 42 118 26 W	3060	37.2	33.7	41.4	40
	LANCASTER FSS/FAA	34 44 118 13 W	2340	30.0	29.0	33.3	35
	LONG BEACH WSO AP	33 49 118 09 W	34	46.0	44.7	49.5	50
	LOS ANGLES CIVIC CTR	34 03 118 14 W	257	50.1	48.1	56.3	55
	LOS ANGLES WSO AP	33 56 118 23 W	100	48.6	47.4	53.1	50
	MONTEBELLO	34 02 118 06 W	240	48.0	45.3	54.1	50
	MT WILSON 2	34 14 118 04 W	5709	40.5	34.8	44.7	40

JANUARY MEAN MINIMUM TEMPERATURES

County	Station	Latitude & Longitude	Elev.	Jan Mean Min. Temp Year '84	'85	'86	Screen Proc. Temp.
Los Angles (continued)	PALMDALE	34 35 118 06 W	2596	30.4		35.5	35
	PASADENA	34 09 118 09 W	864	47.3	41.9	48.8	45
	PEARLBLOSSOM	34 30 117 53 W	3050	39.3		39.3	45
	POMONA CAL POLY	34 04 117 49 W	740	42.1	39.8	46.5	45
	SAN GABRIEL FIRE DEPT	34 06 118 06 W	450	43.0	40.7	48.3	45
	SANDBERG WSMO	34 45 118 44 W	4517	39.4		42.7	45
	SANTA MONICA PIER	34 00 118 30 W	14	52.5	47.3	53.2	50
	TORRANCE	33 48 118 20 W	110	47.6	45.4	50.9	50
	TUJUNGA	34 16 118 17 W	1820	46.1	40.3	47.3	45
	U C L A	34 04 118 27 W	430	52.5	49.0	55.7	55
	VALYERMO FIRE STN 79	34 27 117 52 W	3600	28.9	26.6		30
Madera	MADERA	36 57 120 02 W	270	38.0	31.7	42.2	35
	NORTH FORK RANGER STA	37 14 119 30 W	2630		29.9		35
Marin	KENTFIELD	37 57 122 33 W	128	40.6	36.9	44.6	40
	SAN RAFAEL-CIVIC CENTER	38 00 122 31 W	120		36.9		40
Mariposa	SO ENT YOSEMITE N P	37 30 119 38 W	5120	27.8	25.5	32.7	30
	YOSEMITE PARK HEADQTRS	37 45 119 35 W	3966	30.2	27.1	33.5	30
Mendocino	COVELO	39 47 123 15 W	1430	28.2		37.6	35
	FORT BRAGG 1 E	39 27 123 48 W	165	41.4	37.8	44.3	45
	POINT ARENA	38 54 123 42 W	100	39.8	34.2	42.5	40
	POSEY 3 E	39 22 123 08 W	1015	35.6		35.6	40
	POTTER VALLEY P H	39 22 123 08 W	1015	35.8		40.2	40
	UKIAH	39 09 123 12 W	623	37.4	35.0	41.4	40
	WILLITS 1 NE	39 25 123 20 W	1350	34.1	30.8	38.5	35
Merced	LOS BANOS	37 03 120 52 W	120	36.1	34.1	43.4	40
	LOS BANOS DET RESV	37 01 120 56 W	407	38.5	35.4	43.7	40
	MERCED MUNICIPAL AP	37 17 120 31 W	153	36.8	35.9	42.9	40
	SAN LUSI DAM	37 03 121 04 W	277	37.9	36.0	44.0	40
Modoc	ADIN RANGER STATION	41 12 120 57 W	4195		15.8		20
	ALTURAS RANGER STATION	41 30 120 33 W	4400	18.2	13.2	28.0	20
	CEDARVILLE	41 32 120 10 W	4670	13.4	11.1	28.8	15
	FORT BIDWELL	41 51 120 08 W	4500	14.6	13.7	27.4	20
	JESS VALLEY	41 16 120 18 W	5300	18.6	12.1	26.0	15
Mono	BODIE	38 13 119 01 W	8370	5.0	1.1	12.5	5
	BRIDGEPORT	38 15 119 14 W	6470	13.3	5.7	21.6	10
	MONO LAKE	38 00 119 09 W	6450	19.3	13.5	25.4	20
Monterey	KING CITY	36 12 121 08 W	320	33.5	31.5	42.6	35
	MONTEREY	36 36 121 54 W	385	44.4	42.0	47.8	45
	PRIEST VALLEY	36 11 120 42 W	2300	29.1		36.3	35
	SALINAS 3 E	36 40 121 36 W	85	43.3	37.4	46.7	40
	SALINAS FAA AP	36 40 121 36 W	69	40.5	37.8	45.4	45
Napa	ANGWIN PAC UNION COL	38 34 122 26 W	1815	38.8	34.9	40.8	40
	CALISTOGA	38 35 122 35 W	364	37.8	32.3	41.2	35
	MARKLEY COVE	38 30 122 07 W	480	35.5	32.3	39.5	35
	NAPA STATE HOSPITAL	38 17 122 16 W	60	39.2	34.3	45.1	40

JANUARY MEAN MINIMUM TEMPERATURES

County	Station	Latitude & Longitude	Elev.	Jan Mean Min. Temp Year '84	'85	'86	Screen Proc. Temp.
Nevada	BOCA	39 23 120 06 W	5575	17.3	5.4	20.1	10
	BOWMAN DAM	39 27 120 39 W	5365	29.1	28.6	31.8	35
	DEER CREEK FOREBAY	39 18 120 50 W	4455	35.4	32.5	38.3	40
	DONNER MEMORIAL ST PK	39 19 120 14 W	5937	16.1	11.4	22.5	15
	GRASS VALLEY 2	39 13 121 04 W	2400	29.8	27.4	36.6	30
	LAKE SPAULDING	39 19 120 38 W	5156	26.4	23.9	29.1	30
	NEVADA CITY	39 15 121 02 W	2600	30.9	28.7	39.5	35
	SAGEHEN CREEK	39 26 120 14 W	6337	14.2	9.0	23.3	15
	TRUCKEE RANGER STATION	39 20 120 11 W	5995	16.6	12.8	23.9	20
Orange	LAGUNA BEACH	33 33 117 47 W	35	44.9	40.3	45.6	45
	NEWPORT BEACH HARBOR	33 36 117 53 W	10	50.6	47.1	51.0	50
	SANTA ANA FIRE STATION	33 45 117 52 W	135	48.7	46.5	50.5	50
	TUSTIN IRVINE RANCH	33 44 117 47 W	118	43.8	41.4	44.8	45
Placer	AUBURN	38 54 121 05 W	1292	36.5	33.4	43.7	40
	AUBURN DAM PROJECT	38 53 121 04 W	1272	32.0			35
	BLUE CANYON WSMO	39 17 120 42 W	5280	37.9	34.6	38.6	40
	COLFAX	39 06 120 57 W	2410	35.1	31.5	40.4	35
	TAHOE CITY	39 10 120 08 W	6230	21.5	19.6	26.4	25
Plumas	CANYON DAM	40 10 121 05 W	4560	22.9	20.3	29.2	25
	CHESTER	40 18 121 14 W	4525	19.1	19.8	25.9	25
	PORTOLA	39 48 120 28 W	4850		20.1	28.3	25
Riverside	BEAUMONT 1 E	33 56 116 58 W	2600	42.3	39.1	45.7	45
	BLYTHE	33 37 114 36 W	268	40.8	40.0	41.7	45
	BLYTHE FAA AIRPORT	33 37 114 43 W	390	43.9	43.0	45.6	50
	CORONA	33 53 117 33 W	610	40.6	41.7	46.0	45
	EAGLE MOUNTAIN	33 48 115 27 W	973	47.5	43.8	49.4	50
	ELSINORE	33 40 117 20 W	1285	39.9	37.7	43.3	45
	HAYFIELD PUMPING PLANT	33 42 115 38 W	1370	43.1	37.4	41.6	40
	IDYLLWILD FIRE DEPT	33 45 116 43 W	5397	30.7	28.3	34.2	35
	MECCA FIRE STATION	33 34 116 04 W	180	40.9	38.2	43.2	45
	PALM DESERT	33 44 116 23 W	195	41.6	38.4		45
	PALM SPRINGS	33 50 116 30 W	425	46.1	42.3	48.8	45
	RIVERSIDE CIT EXP STN	33 58 117 21 W	986	44.5	43.1	46.0	50
	RIVERSIDE FIRE STA 3	33 57 117 23 W	840	40.9	39.9	44.8	45
	SAN JACINTO RANGER STN	33 47 116 58 W	1560	37.1	34.5	38.6	40
	SUN CITY	33 43 117 12 W	1420	37.7	35.4	38.6	40
	THERMAL FAA AP	33 38 116 10 W	-112	42.8	39.0	43.6	45
Sacramento	FOLSOM DAM	38 42 121 10 W	350	39.9	35.9	43.2	40
	SACRAMENTO FAA AP	38 31 121 30 W	18	40.8	36.3	44.9	40
	SACRAMENTO WSO CI	38 35 121 30 W	84	41.4	36.8	46.3	40
San Benito	HOLLISTER 2	36 51 121 24 W	280	37.4	33.3	42.5	40
	PINNACLES NAT MONUMENT	36 29 121 11 W	1307	32.1	28.9	37.4	35
San Bernadino	BAKER	35 16 116 04 W	940	35.1	34.7	35.9	40
	BARSTOW FIRE STN	34 54 117 01 W	2320	33.6	30.2	32.9	35
	BIG BEAR LAKE	34 15 116 53 W	6790	22.6		25.7	30
	DAGGETT FAA AIRPORT	34 52 116 47 W	1922		34.8	38.3	40
	EL MIRAGE FIELD	34 36 117 36 W	2910	26.8	27.0	30.9	30
	FONTANA KAISER	34 05 117 31 W	1100	42.5			50
	IRON MOUNTAIN	34 08 115 08 W	922	46.5	44.0	48.3	50
	LAKE ARROWHEAD	34 15 117 11 W	5205	31.5	27.7	33.5	35

JANUARY MEAN MINIMUM TEMPERATURES

County	Station	Latitude & Longitude	Elev.	Jan Mean Min. Temp Year '84	'85	'86	Screen Proc. Temp.
San Bernadino (continued)	MITCHELL CAVERNS	34 56 115 32 W	4350	40.4	35.7	43.8	40
	MOUNTAIN PASS	35 28 115 32 W	4730	30.9	27.1	33.6	30
	NEEDLES FAA AIRPORT	34 46 114 37 W	914	43.9	42.1	46.1	45
	PARKER RESERVOIR	34 17 114 10 W	738	44.5	42.1	47.8	45
	REDLANDS	34 03 117 11 W	1318	40.6	40.5	46.3	45
	SAN BERNARDINO CO HOSP	34 08 117 16 W	1125	43.8	41.7	45.6	45
	TRONA	35 46 117 23 W	1695	36.8	34.2	40.5	40
	TWENTYNINE PALMS	34 08 116 02 W	1975	38.0	34.9	38.9	40
	VICTORVILLE PUMP PLANT	34 32 117 18 W	2858	30.3	29.0	35.2	35
San Diego	ALPINE	32 50 116 46 W	1735	43.7	39.7	48.6	45
	BORREGO DESERT PARK	33 15 116 24 W	805	45.4	41.1	47.2	45
	CAMPO	32 38 116 28 W	2630	35.8		39.7	40
	CHULA VISTA	32 36 117 06 W	9	46.7	43.9	48.9	50
	CUYAMACA	32 59 116 35 W	4640	34.0	30.8	34.6	35
	EL CAJON	32 49 116 58 W	405	39.8	40.2	45.5	45
	EL CAPITAN DAM	32 53 116 49 W	600	42.5	37.0	42.7	40
	ESCONDIDO 2	33 07 117 05 W	600	42.5	41.1	46.6	45
	HENSHAW DAM	33 14 116 46 W	2700	30.4	31.2	34.4	35
	JULIAN WYNOLA	33 06 116 39 W	3650	38.1	36.0	40.8	40
	LA MESA	32 46 117 01 W	530		44.9	50.5	50
	OAK GROVE RANGER STN.	33 23 116 48 W	2750	35.9	35.0		40
	OCEANSIDE MARINA	33 13 117 24 W	10	46.9	44.3	49.5	50
	PALOMAR MT OBSERVATORY	33 21 116 52 W	5550	35.2	31.8	40.7	35
	RAMONA FIRE DEPT	33 03 116 52 W	1450		39.2	44.5	45
	SAN DIEGO WSO AP	32 44 117 10 W	13	52.8	49.3	51.6	55
	SAN PASQUAL ANIMAL PK	33 05 117 00 W	420	40.4		43.1	45
	VISTA 2 NNE	33 14 117 14 W	510	45.9	43.7	50.1	50
San Francisco	S F RICHMOND SUNSET	37 46 122 30 W	32			47.1	50
	SAN FRAN MISSION DOLORES	37 46 122 26 W	75	44.9	43.6	51.5	50
San Joaquin	LODI	38 07 121 17 W	40	38.2	34.7	42.8	40
	STOCKTON FIRE STA 4	38 00 121 19 W	12	32.8	32.7	41.7	40
	STOCKTON WSO AP	37 54 121 15 W	22	36.6	35.0	44.5	40
	TRACY CARBONA	37 42 121 25 W	140			42.5	50
San Luis Obispo	MORRO BAY FIRE DEPT	35 22 120 51 W	115	42.2	38.9	43.2	45
	PASO ROBLES	35 38 120 41 W	700	35.1	31.3	39.1	35
	PASO ROBLES FAA AP	35 40 120 38 W	800	34.5	31.8	39.4	35
	PISMO BEACH	35 08 120 38 W	80		38.5	45.7	45
	SAN LUIS OBISPO POLY	35 18 120 40 W	315	42.3	39.3	44.1	45
San Mateo	HALF MOON BAY	37 28 122 27 W	36	44.2	42.1	47.5	45
	PACIFICA	37 36 122 29 W	375	46.3	42.5	49.0	50
	REDWOOD CITY	37 29 122 14 W	31	39.4	37.3	44.9	40
	SAN FRANCISCO WSO AP	37 37 122 23 W	8	44.4	39.7	47.8	45
	SAN GREGORIO 2 SE	37 18 122 22 W	275	40.7	37.6	44.6	45
	WOODSIDE FIRE STN 1	37 26 122 15 W	380	36.5	33.3	39.2	40
Santa Barbara	CACHUMA LAKE	34 35 119 59	781	39.9	37.4	44.0	40
	LOMPAC	34 39 120 27 W	95	41.5	39.9	45.8	45
	NEW CUYAMA FIRE STA	34 57 119 41 W	2160	29.7	27.5	36.5	35
	SANTA BARBARA	34 25 119 41 W	5	47.1		48.0	50
	SANTA BARBARA FAA AP	34 26 119 50 W	9	41.6	39.0	43.1	45
	SANTA MARIA WSO AP	34 54 120 27 W	254	40.3	36.4	42.8	40
	TWITCHELL DAM	34 59 120 19 W	582	43.7	36.6	42.1	40

JANUARY MEAN MINIMUM TEMPERATURES

County	Station	Latitude & Longitude	Elev.	Jan Mean Min. Temp Year '84	'85	'86	Screen Proc. Temp.
Santa Clara	GILROY	37 00 121 34 W	194	37.6	34.0	41.7	40
	LOS GATOS	37 14 121 58 W	365	37.5	35.5	43.9	40
	MOUNT HAMILTON	37 20 121 39 W	4206	42.8	38.0	43.3	45
	PALO ALTO	37 27 122 08 W	25	38.6	37.0	44.3	40
	SAN JOSE	37 21 121 54 W	67	41.8		47.0	45
Santa Cruz	BEN LOMAND 4	37 05 122 05 W	450	37.0	33.8	41.0	40
	SANTA CRUZ	36 59 122 01 W	130	38.9	37.2	44.8	40
	WATSONVILLE WATERWORKS	36 56 121 46 W	95	39.5	36.5	45.2	40
Shasta	BURNEY	40 53 121 40 W	3140	15.7	14.5	23.0	20
	HAT CREEK P H 1	40 56 121 33 W	3015	22.4	21.5	30.6	25
	MANZANITA LAKE	40 32 121 34 W	5750	22.6	20.8	27.5	25
	REDDING FIRE STN 4	40 33 122 23 W	470	35.8	31.1	40.3	35
	SHASTA DAM	40 43 122 25 W	1075	41.9	37.3	43.5	40
	WHISKEYTOWN RES	40 37 122 32 W	1295	38.2	33.6	40.2	40
Sierra	DOWNIEVILLE	39 34 120 50 W	2915	29.5	27.9	33.9	35
	SIERRA CITY	39 34 120 38 W	4230	30.0	32.0	32.8	35
	SIERRAVILLE R S	39 35 120 22 W	4975		12.2		15
Siskiyou	CALLAHAN	41 19 122 48 W	3185	24.6	23.6	32.9	30
	CECILVILLE 1 SE	41 08 123 08 W	2960	28.9		34.1	35
	DUNSMUIR TRTMT PLANT	41 12 122 16 W	2170	29.7	29.7	34.1	35
	FORT JONES RANGER STN	41 36 122 51 W	2725		20.7		25
	LAVA BEDS NAT MONUMENT	41 44 121 31 W	4770	24.6	20.2	29.3	25
	MC CLOUD	41 15 122 08 W	3280	24.0	23.9	29.2	30
	MOUNT SHASTA WSO CI	41 19 122 19 W	3539	27.0			30
	TULELAKE	41 58 121 28 W	4035	18.0	16.5	29.7	20
	WEED FIRE DEPT	41 26 122 23 W	3590	22.5	19.9	29.2	25
	YREKA	41 43 122 38 W	2625	23.9			30
Solano	LAKE SOLANO	38 30 122 00 W	140	37.1	32.1	42.1	35
	VACAVILLE	38 22 121 57 W	105	36.8	33.2	41.5	40
	FAIRFIELD FIRE STN 2	38 16 122 02 W	40	35.7	29.6	37.3	35
Sonoma	CLOVERDALE 3 SSE	38 46 122 59 W	320	39.0	34.4	41.9	40
	FORT ROSS	38 31 123 15 W	112	42.6	37.7	39.2	45
	GRATON	38 26 122 52 W	200	36.4	32.2	41.1	35
	HEALDSBURG	38 37 122 52 W	100	41.2	36.0	44.2	40
	PETALUMA FIRE STN 3	38 14 122 38 W	27	38.0	34.4	43.2	40
	SANTA ROSA	38 27 122 42 W	167	40.4	34.0	42.0	40
	SONOMA	38 18 122 28 W	97	37.3	31.1	41.3	35
	WARM SPRINGS DAM	38 43 123 00 W	224	37.8	32.8		40
Stanislaus	MODESTO	37 39 121 00 W	91	38.8	36.7	44.5	40
	NEWMAN	37 18 121 02 W	90	36.6	34.5	41.6	40
Tehama	MINERAL	40 21 121 36 W	4875	23.9	21.8	28.8	25
	RED BLUFF WSO AP	40 09 122 15 W	342	37.9	35.1	43.0	40
Trinity	FOREST GLEN	40 23 123 20 W	2340	28.1	27.9		35
	TRINITY RIVER HATCH	40 43 122 48 W	1860	31.6	29.9	36.0	35
	WEAVERVILLE RANGER STN	40 44 122 56 W	2050		26.2		30

JANUARY MEAN MINIMUM TEMPERATURES

County	Station	Latitude & Longitude	Elev.	Jan Mean Min. Temp Year '84	'85	'86	Screen Proc. Temp.
Tulare	ASH MOUNTAIN	36 29 118 50 W	1708	38.0	34.6	43.5	40
	GRANT GROVE	36 44 118 58 W	6600	30.5	25.2	34.5	30
	LEMON COVE	36 23 119 02 W	513	40.0	35.6	42.3	40
	LINDSAY	36 12 119 03 W	420	37.5	34.7	40.1	40
	LODGEPOLE	36 36 118 44 W	6735	18.1	12.5	23.3	20
	PORTERVILLE	36 04 119 01 W	393	39.2	37.2	43.3	40
	THREE RVRS EDISON PH 1	36 28 118 52 W	1140	36.7	33.4		40
	VISALIA	36 20 119 18 W	325	39.9	35.6	43.7	40
Tuolumne	CHERRY VALLEY DAM	37 58 119 55 W	4765	31.9	28.5	35.4	35
	HETCH HETCHY	37 57 119 47 W	3870	30.9	28.0	34.3	35
	NEW MELONES DAM	37 57 120 32 W	775	36.0	32.0	40.5	35
	SONORA R S	37 59 120 23 W	1749		36.0		40
Ventura	OJAI	34 27 119 14 W	750	37.3	34.4	40.9	40
	OXNARD	34 12 119 11 W	49	47.9	45.1	51.7	50
	SANTA PAULA	34 19 119 09 W	237	42.0	38.9	46.6	45
Yolo	BROOKS FARMHAM RANCH	38 46 122 09 W	294	36.4	33.0		40
	DAVIS 2 WSW EXP FARM	38 32 121 46 W	60	36.8	33.5	42.8	40
	WINTERS	38 32 121 58 W	135	37.8	33.6	42.5	40
	WOODLAND 1 WNW	38 41 121 48 W	69	38.0	34.3	43.6	40
Yuba	STRAWBERRY VALLEY	39 34 121 06 W	3808	30.8	27.3	34.6	30

Appendix 2A ANNUAL MAXIMUM CO DATA

ANNUAL MAXIMUM
CO DATA

ANNUAL MAXIMUM CO DATA

Basin	Co	Location	Year	Annual Max. CO (ppm) 1-Hour 1st	1-Hour 2nd	8-Hour 1st	8-Hour 2nd	Ratio of 2nd Annual Max. by Year	3 Yr. High
North Coast	TRN	Weaverville-Hosp 53-00912	87 *	4	4	3.0	2.9	0.73	0.73
	MEN	Willits-Firehouse 23-00753	87						0.52
			86 *	6	6	3.1	3.1	0.52	
			85 *	8	8	5.5	4.1	0.51	
			84 *	6	5	4.1	3.6	0.72	
			83						
			82						
			81						
San Francisco Bay	ALA	Fremont-Chapel Wy 60-00336	87	10	10	5.0	4.6	0.46	0.64
			86	10	10	5.6	5.4	0.54	
			85	10	9	6.1	5.8	0.64	
			84	9	9	5.1	4.9	0.54	
			83	11	10	5.1	5.1	0.51	
			82	9	8	4.5	4.4	0.55	
			81	10	9	4.8	4.6	0.51	
	ALA	Livermore Old Fst S 60-00340	87	10	8	3.6	3.5	0.44	0.61
			86	10	10	4.9	4.5	0.45	
			85	8	8	5.3	4.9	0.61	
			84	12	10	4.3	4.1	0.41	
			83	10	9	4.4	3.9	0.43	
			82	8	8	4.8	4.0	0.50	
			81 *	8	7	3.8	3.3	0.47	
	ALA	Oakland-Alice 60-00339	87	9	8	4.9	4.9	0.61	0.64
			86	12	11	7.5	6.5	0.59	
			85	9	9	5.8	5.8	0.64	
			84	11	10	8.0	7.3	0.73	
			83 *	11	9	7.3	5.4	0.60	
			82	10	10	7.5	7.1	0.71	
			81	12	8	6.0	5.4	0.68	
	CC	Bethel Island Rd 07-00442	87	3	3	2.3	2.0	0.67	0.67
			86 *	2	2	1.3	1.3	0.65	
			85 *	8	2	1.3	1.1	0.55	
			84 *	3	2	1.3	1.1	0.55	
			83 *	2	2	1.3	1.1	0.55	
			82 *	2	2	1.3	1.1	0.55	
			81 *	3	3	1.5	1.4	0.47	
	CC	Concord-2975 Treat 07-00440	87	12	11	5.5	5.0	0.45	0.61
			86	10	9	5.6	5.5	0.61	
			85	11	9	5.3	5.0	0.56	
			84	12	12	5.9	5.3	0.44	
			83	13	9	5.6	5.5	0.61	
			82	18	14	6.4	5.8	0.41	
			81	14	11	5.1	5.0	0.45	
	CC	Pittsburg 07-00430	87	8	8	5.5	4.3	0.54	0.59
			86	9	9	5.6	5.3	0.59	
			85	9	8	3.8	3.6	0.45	
			84	8	8	4.9	4.8	0.60	
			83	9	7	5.1	3.6	0.51	
			82	8	7	4.9	4.4	0.63	
			81	8	8	4.0	3.8	0.48	

* Incomplete Data

ANNUAL MAXIMUM
CO DATA

Basin	Co	Location	Year	Annual Max. CO (ppm) 1-Hour 1st	1-Hour 2nd	8-Hour 1st	8-Hour 2nd	Ratio of 2nd Annual Max. by Year	3 Yr. High
San Francisco Bay (cont.)	CC	Richmond-13th St 07-00433	87	8	8	4.8	3.7	0.46	0.63
			86	8	8	5.9	5.0	0.63	
			85	8	7	4.3	3.8	0.54	
			84	8	8	4.8	4.5	0.56	
			83	9	8	4.3	4.0	0.50	
			82	7	7	3.9	3.6	0.51	
			81	8	8	3.8	3.5	0.44	
	MRN	San Rafael 21-00451	87	12	11	4.5	4.5	0.41	0.58
			86	10	10	5.9	5.8	0.58	
			85	10	9	4.6	4.5	0.50	
			84	14	13	5.8	5.3	0.41	
			83	11	11	5.5	4.5	0.41	
			82	14	14	5.6	5.3	0.38	
			81	12	11	4.5	4.5	0.41	
	NAP	Napa-Jefferson St 28-00783	87	12	9	5.6	4.9	0.54	0.70
			86	11	9	6.8	5.6	0.62	
			85	10	9	6.6	6.3	0.70	
			84	11	10	7.1	7.0	0.70	
			83	10	9	6.1	6.0	0.67	
			82	10	10	6.6	6.1	0.61	
			81	9	8	6.5	5.5	0.69	
	SF	San Francisco-Ellis 90-00303	87	17	16	10.0	8.5	0.53	0.69
			86	20	15	12.6	10.4	0.69	
			85	21	19	15.0	12.3	0.65	
			84	15	14	10.8	7.9	0.56	
			83	14	13	8.0	7.9	0.61	
			82	18	17	14.5	9.4	0.55	
			81	14	12	7.3	6.6	0.55	
	SF	San Francisco 10 AR 90-00306	87	9	9	6.5	6.3	0.70	0.76
			86	9	9	7.1	6.8	0.76	
			85 *	8	7	4.9	4.3	0.61	
			84						
			83						
			82						
			81						
	SF	San Francisco 23rd 90-00304	87						0.78
			86 *	7	7	4.8	4.5	0.64	
			85	10	9	7.1	7.0	0.78	
			84	11	10	7.7	6.1	0.61	
			83	7	7	5.1	5.1	0.73	
			82	12	11	9.1	6.1	0.55	
			81	8	7	5.3	4.8	0.69	
	SM	Redwood City 41-00541	87	13	10	5.5	5.0	0.50	0.57
			86	12	12	6.4	6.3	0.53	
			85	14	11	6.4	6.3	0.57	
			84	13	13	5.6	5.5	0.42	
			83	15	14	9.6	8.8	0.63	
			82	14	13	6.0	5.6	0.43	
			81	12	11	6.7	6.0	0.55	
	SCL	Gilroy-9th St 43-00389	87	5	4	2.9	2.9	0.73	0.77
			86	7	6	3.8	3.6	0.60	
			85	6	6	5.3	4.6	0.77	
			84	7	7	3.4	3.3	0.47	
			83	6	6	5.0	5.0	0.83	
			82	8	5	3.6	3.5	0.70	
			81	6	6	4.3	4.1	0.68	

* Incomplete Data

ANNUAL MAXIMUM
CO DATA

Basin	Co	Location	Year	Annual Max. CO (ppm) 1-Hour 1st	1-Hour 2nd	8-Hour 1st	8-Hour 2nd	Ratio of 2nd Annual Max. by Year	3 Yr. High
San Francisco Bay (cont.)	SCL	San Jose-4th St 43-00382	87	12	12	7.4	7.1	0.59	0.72
			86	16	15	11.0	10.6	0.71	
			85	20	20	15.6	14.3	0.72	
			84	18	18	11.4	10.0	0.56	
			83	16	16	9.9	9.8	0.61	
			82	16	16	12.4	10.6	0.66	
			81	17	15	11.3	10.8	0.72	
	SCL	San Jose-4th St 43-00382	87	13	13	7.4	7.3	0.56	0.71
			86	16	16	11.3	11.0	0.69	
			85	21	20	16.1	14.1	0.71	
			84	20	20	12.1	10.8	0.54	
			83	17	17	10.6	10.0	0.59	
			82	16	16	12.3	11.3	0.71	
			81	16	13	11.0	10.8	0.83	
	SOL	Vallejo-Tuolumne 48-00879	87	13	13	9.4	8.3	0.64	0.78
			86	13	13	10.8	10.1	0.78	
			85	12	11	8.6	8.5	0.77	
			84	15	13	9.8	9.8	0.75	
			83	13	13	9.9	8.0	0.62	
			82	13	13	10.9	10.3	0.79	
			81	14	11	8.6	8.4	0.76	
	SON	Santa-Rosa-837 Fift 49-00893	87	7	7	4.3	4.1	0.59	0.64
			86	9	9	5.3	5.0	0.56	
			85	9	9	5.9	5.8	0.64	
			84	10	9	4.9	4.5	0.50	
			83	8	7	4.6	4.3	0.61	
			82	9	9	5.8	5.1	0.57	
			81 *	8	7	4.5	3.9	0.56	
North Central Coast	MON	Salinas II 27-00544	87	5	5	2.3	2.3	0.46	0.58
			86 *	4	4	2.3	2.3	0.58	
			85 *	6	5	3.3	2.8	0.56	
			84 *	5	4	3.0	2.3	0.58	
			83	3	3	2.1	2.1	0.70	
			82	6	4	2.6	2.5	0.63	
			81	4	4	2.9	2.8	0.70	
	SCR	Davenport 44-00851	87 *	1	1	1.0	1.0	1.00	ERR
South Central Coast	SLO	San Luis Obispo-Mar 40-00835	87	10	9	3.9	3.6	0.40	0.53
			86	10	9	4.9	4.8	0.53	
			85	11	10	4.7	4.6	0.46	
			84	11	9	4.7	3.4	0.38	
			83	13	12	4.8	4.6	0.38	
			82 *	12	11	4.7	4.7	0.43	
			81	10	9	6.6	3.9	0.43	
	SB	Goleta 42-00363	87	7	6	2.9	2.7	0.45	0.45
			86	6	6	3.0	2.7	0.45	
			85	7	7	2.5	2.4	0.34	
			84	7	6	2.8	2.5	0.42	
			83	7	6	3.1	3.0	0.50	
			82 *	6	5	2.8	2.5	0.50	
			81						

* Incomplete Data

ANNUAL MAXIMUM
CO DATA

Basin	Co	Location	Year	Annual Max. CO (ppm) 1-Hour 1st	1-Hour 2nd	8-Hour 1st	8-Hour 2nd	Ratio of 2nd Annual Max. by Year	Ratio of 2nd Annual Max. 3 Yr. High
South Central Coast (cont.)	SB	Lompoc-128 South H 42-00381	87	7	5	2.3	2.2	0.44	0.44
			86	6	6	3.3	2.5	0.42	
			85						
			84						
			83						
			82						
			81						
	SB	Santa Barbara-Canon 42-00378	87	14	14	7.5	7.4	0.53	0.66
			86	18	17	8.6	8.4	0.49	
			85	17	16	10.5	10.5	0.66	
			84 *	16	16	9.6	8.1	0.51	
			83 *	14	12	8.6	7.9	0.66	
			82						
			81						
	SB	Vandenberg AFB-Hera 42-00383	87						0.50
			86 *	2	2	1.0	1.0	0.50	
			85						
			84						
			83						
			82						
			81						
	SB	Vandenberg AFB-Watt 42-00382	87	1	1	1.0	1.0	1.00	1.00
			86	1	1	1.0	1.0	1.00	
			85						
			84						
			83						
			82						
			81						
	VEN	El Rio-Rio Mesa Sch 56-00419	87 *	6	6	3.4	2.8	0.47	0.73
			86	5	4	3.0	2.9	0.73	
			85	3	3	2.0	1.6	0.53	
			84	3	3	2.7	2.1	0.70	
			83 *	4	3	2.6	2.3	0.77	
			82						
			81						
	VEN	Simi Valley 56-00413	87	12	11	5.7	5.0	0.45	0.54
			86	15	13	7.0	5.6	0.43	
			85 *	12	11	6.0	5.9	0.54	
			84	12	11	4.4	4.4	0.40	
			83 *	15	13	6.0	5.7	0.44	
			82	13	13	6.0	6.0	0.46	
			81						
South Coast	LA	Azusa 70-00060	87	9	8	6.0	4.9	0.61	0.76
			86	10	7	5.5	5.3	0.76	
			85	9	8	4.9	4.9	0.61	
			84	7	6	4.6	4.4	0.73	
			83	10	10	6.6	6.1	0.61	
			82	9	8	6.9	5.5	0.69	
			81	11	11	9.5	8.3	0.75	
	LA	Burbank 70-00069	87	15	15	12.5	11.9	0.79	0.79
			86	19	18	16.4	12.5	0.69	
			85	21	20	16.1	12.4	0.62	
			84	19	18	12.0	11.9	0.66	
			83	24	20	16.6	16.3	0.82	
			82	21	20	16.4	16.4	0.82	
			81	25	24	21.1	19.3	0.80	

* Incomplete Data

ANNUAL MAXIMUM
CO DATA

Basin	Co	Location	Year	Annual Max. CO (ppm) 1-Hour 1st	1-Hour 2nd	8-Hour 1st	8-Hour 2nd	Ratio of 2nd Annual Max. by Year	Ratio of 2nd Annual Max. 3 Yr. High
South Coast (cont.)	LA	Hawthorne 70-00094	87	22	21	14.1	13.4	0.64	0.82
			86	21	22	15.0	14.5	0.66	
			85 *	26	22	21.3	18.1	0.82	
			84						
			83						
			82						
			81						
	LA	Glendora-Laurel 70-00591	87						
			86						
			85						
			84 *	6	6	4.0	3.4	0.57	
			83	6	6	4.5	3.6	0.60	
			82	7	7	4.4	3.5	0.50	
			81 *	8	7	6.1	5.0	0.71	
	LA	Lennox 70-00076	87						0.78
			86						
			85	29	27	24.0	21.1	0.78	
			84	24	24	19.7	18.9	0.79	
			83	31	28	18.4	17.8	0.64	
			82	26	23	17.7	16.7	0.73	
			81	27	27	19.1	18.4	0.68	
	LA	Los Angles-No Main 70-00087	87	15	14	10.9	8.8	0.63	0.74
			86	13	13	11.6	9.6	0.74	
			85	14	13	9.9	9.1	0.70	
			84	15	14	9.1	9.1	0.65	
			83	17	16	13.1	12.4	0.78	
			82	15	14	11.9	11.6	0.83	
			81	18	18	14.9	12.5	0.69	
	LA	Lynwood 70-00084	87	26	25	19.6	16.9	0.68	0.86
			86	27	26	19.7	18.1	0.70	
			85	33	32	27.7	27.4	0.86	
			84	29	26	18.9	17.6	0.68	
			83	24	23	20.9	18.9	0.82	
			82	27	24	21.3	19.6	0.82	
			81	31	30	25.3	20.5	0.68	
	LA	North Long Beach 70-00072	87	13	13	9.4	9.0	0.69	0.79
			86	13	13	10.3	10.3	0.79	
			85	19	19	15.7	14.7	0.77	
			84	14	13	10.3	9.4	0.72	
			83	14	13	12.1	11.4	0.88	
			82	14	13	11.6	9.9	0.76	
			81	13	13	11.3	10.4	0.80	
	LA	Pasadena-Wilson 70-00088	87	15	15	11.3	9.9	0.66	0.69
			86	14	13	10.1	9.0	0.69	
			85	17	16	11.3	11.0	0.69	
			84	13	12	8.0	7.9	0.66	
			83	19	18	12.3	12.0	0.67	
			82 *	20	19	12.9	12.9	0.68	
			81						
	LA	Pico Rivera 70-00085	87	12	12	10.0	9.3	0.78	0.78
			86	14	13	10.7	8.9	0.68	
			85	19	15	13.1	10.7	0.71	
			84	13	13	8.7	8.4	0.65	
			83	14	13	10.9	10.7	0.82	
			82	13	13	11.9	10.1	0.78	
			81	15	14	11.9	10.8	0.77	

* Incomplete Data

ANNUAL MAXIMUM

CO DATA

Basin	Co	Location	Year	Annual Max. CO (ppm) 1-Hour 1st	1-Hour 2nd	8-Hour 1st	8-Hour 2nd	Ratio of 2nd Annual Max. by Year	Ratio of 2nd Annual Max. 3 Yr. High
South Coast (cont.)	LA	Pomona 70-00075	87	14	14	10.0	8.4	0.60	0.65
			86	11	11	8.7	7.1	0.65	
			85	12	11	7.4	7.1	0.65	
			84	13	13	7.3	6.7	0.52	
			83	15	13	8.0	7.7	0.59	
			82	12	11	9.1	8.0	0.73	
			81	12	12	9.6	9.5	0.79	
	LA	Reseda 70-00074	87	15	14	12.1	9.3	0.66	0.79
			86	19	16	15.7	12.6	0.79	
			85	16	16	14.1	12.3	0.77	
			84	15	15	11.0	10.9	0.73	
			83	20	19	16.0	15.9	0.84	
			82	26	24	19.4	16.7	0.70	
			81	27	26	21.6	19.9	0.77	
	LA	West LA-Robertson 70-00086	87						0.71
			86						
			85 *	15	15	10.7	10.7	0.71	
			84	17	16	11.6	10.9	0.68	
			83	22	20	12.9	12.6	0.63	
			82	21	19	14.6	13.5	0.71	
			81	19	18	14.8	12.9	0.72	
	LA	West Los Angles-VA 70-00091	87	13	12	7.5	6.5	0.54	0.64
			86	11	11	8.6	7.0	0.64	
			85	15	12	6.9	6.1	0.51	
			84 *	10	10	7.0	6.6	0.66	
			83						
			82						
			81						
	LA	Whittier 70-00080	87	13	13	9.7	9.0	0.69	0.69
			86	15	14	8.7	7.9	0.56	
			85	18	17	14.6	10.7	0.63	
			84	14	14	9.4	8.7	0.62	
			83	16	16	13.6	11.1	0.69	
			82	15	15	12.7	10.9	0.73	
			81	17	16	13.7	13.6	0.85	
	ORA	Anaheim 30-00176	87	16	16	8.7	8.1	0.51	0.65
			86	16	15	9.7	8.9	0.59	
			85	19	18	17.0	11.7	0.65	
			84	18	16	14.4	10.1	0.63	
			83	17	15	10.9	10.7	0.71	
			82	13	13	9.6	9.4	0.72	
			81	19	19	13.4	11.9	0.63	
	ORA	Costa Mesa-Placenti 30-00192	87	12	12	8.4	8.3	0.69	0.71
			86	15	14	10.4	10.0	0.71	
			85	19	15	13.3	10.7	0.71	
			84	13	12	9.6	8.4	0.70	
			83	14	14	10.6	8.7	0.62	
			82	21	15	10.4	10.0	0.67	
			81	15	15	11.7	10.6	0.71	
	ORA	El Toro 30-00186	87	8	8	6.3	5.7	0.71	0.71
			86	7	7	4.9	4.3	0.61	
			85	10	9	7.7	5.8	0.64	
			84	8	8	6.1	4.3	0.54	
			83	7	7	5.7	4.3	0.61	
			82	8	7	5.3	4.6	0.66	
			81 *	9	9	7.0	5.0	0.56	

* Incomplete Data

ANNUAL MAXIMUM CO DATA

Basin	Co	Location	Year	Annual Max. CO (ppm) 1-Hour 1st	1-Hour 2nd	8-Hour 1st	8-Hour 2nd	Ratio of 2nd Annual Max. by Year	Ratio of 2nd Annual Max. 3 Yr. High
South Coast (cont.)	ORA	La Habra 30-00177	87	21	20	10.6	9.7	0.49	0.60
			86	20	19	10.3	8.9	0.47	
			85	22	21	14.0	12.7	0.60	
			84	21	20	9.6	9.1	0.46	
			83	22	21	11.7	11.3	0.54	
			82	19	18	11.9	11.5	0.64	
			81	22	21	13.0	12.1	0.58	
	ORA	Laguna Beach 30-00193	87						
			86						
			85						
			84 *	7	6	3.9	3.8	0.63	
			83 *	5	4	3.5	3.3	0.83	
			82						
			81						
	ORA	San Juan Capistrano 30-00188	87						
			86						
			85						
			84 *	5	4	3.4	3.0	0.75	
			83 *	5	4	3.0	2.9	0.73	
			82						
			81						
	RIV	Riverside-Magnolia 33-00146	87	13	12	7.6	7.4	0.62	0.62
			86	18	15	8.3	8.1	0.54	
			85	14	14	9.1	8.0	0.57	
			84	16	14	8.9	6.6	0.47	
			83	15	15	7.9	7.5	0.50	
			82 *	13	13	8.6	7.8	0.60	
			81	13	12	9.6	8.7	0.73	
	RIV	Riverside-Rubidoux 33-00144	87	9	8	6.1	5.9	0.74	0.80
			86	9	8	6.0	5.8	0.73	
			85	8	7	5.7	5.6	0.80	
			84	8	8	6.3	6.0	0.75	
			83	8	7	6.3	5.6	0.80	
			82	8	7	6.4	5.5	0.79	
			81	10	9	7.5	7.4	0.82	
	SBD	Fontana-Arrow Hwy 36-00197	87	6	6	4.0	3.8	0.63	0.85
			86	6	6	5.9	5.1	0.85	
			85	5	5	4.0	3.9	0.78	
			84	6	5	4.4	4.1	0.82	
			83	10	9	5.1	4.9	0.54	
			82 *	8	7	4.4	4.4	0.63	
			81 *	7	6	5.1	4.6	0.77	
	SBD	Redlands-Univ of Gr 36-00192	87						
			86						
			85						
			84 *	2	2	0.9	0.3	0.15	
			83	4	4	3.0	2.9	0.73	
			82	5	4	3.0	2.7	0.68	
			81	6	6	4.9	4.3	0.72	
	SBD	San Bernardino-E 3R 36-00194	87						0.49
			86						
			85 *	9	9	5.3	4.4	0.49	
			84	9	9	5.1	5.0	0.56	
			83	9	8	5.4	5.4	0.68	
			82	10	10	6.9	6.6	0.66	
			81 *	10	10	6.0	5.9	0.59	

* Incomplete Data

ANNUAL MAXIMUM
CO DATA

Basin	Co	Location	Year	Annual Max. CO (ppm) 1-Hour 1st	1-Hour 2nd	8-Hour 1st	8-Hour 2nd	Ratio of 2nd Annual Max. by Year	3 Yr. High
South Coast (cont.)	SBD	San Bernardino-Four 36-00203	87	11	10	6.7	6.4	0.64	0.70
			86 *	9	9	6.7	6.3	0.70	
			85						
			84						
			83						
			82						
			81						
	SBD	Upland ARB 36-00175	87	7	7	5.1	4.9	0.70	0.71
			86	8	8	6.6	5.7	0.71	
			85	10	8	6.3	5.0	0.63	
			84 *	8	8	5.6	4.5	0.56	
			83 *	17	16	8.7	8.7	0.54	
			82 *	9	8	5.4	5.1	0.64	
			81 *	14	10	6.9	6.7	0.67	
San Diego	SD	Chula Vista 80-00114	87	7	6	3.4	3.3	0.55	0.59
			86	7	7	5.1	4.1	0.59	
			85	7	6	3.9	3.5	0.58	
			84	7	6	4.6	4.6	0.77	
			83	13	10	4.4	4.1	0.41	
			82	9	8	4.1	3.9	0.49	
			81	8	7	4.5	4.3	0.61	
	SD	El Cajon-Redwood Av 80-00131	87	10	10	6.6	6.0	0.60	0.68
			86	11	10	8.3	6.1	0.61	
			85 *	12	10	7.0	6.8	0.68	
			84	10	10	6.9	6.3	0.63	
			83	10	10	6.6	6.3	0.63	
			82	11	11	7.1	5.8	0.53	
			81 *	10	10	6.4	5.9	0.59	
	SD	Escondido-Valley Pk 80-00115	87	14	13	9.3	7.8	0.60	0.64
			86	15	14	9.4	8.9	0.64	
			85	16	15	9.8	8.9	0.59	
			84	16	15	7.6	7.3	0.49	
			83 *	14	14	8.9	8.8	0.63	
			82 *	15	13	10.3	8.3	0.64	
			81 *	15	12	11.3	8.0	0.67	
	SD	Oceanside-1701 Miss 80-00134	87	6	6	4.3	4.0	0.67	0.68
			86	6	6	4.4	4.1	0.68	
			85	8	7	4.4	3.8	0.54	
			84	7	7	4.4	3.4	0.49	
			83 *	7	6	3.9	3.8	0.63	
			82						
			81						
	SD	San Diego-Island Av 80-00120	87	12	11	9.4	7.5	0.68	0.68
			86	16	15	9.0	8.8	0.59	
			85	15	15	9.4	8.8	0.59	
			84	12	12	7.6	6.9	0.58	
			83	16	15	8.0	7.6	0.51	
			82	15	14	8.8	8.6	0.61	
			81	12	12	8.8	8.6	0.72	
	SD	San Diego-Overland 80-00123	87 *	7	7	4.0	3.6	0.51	0.85
			86 *	7	6	4.8	4.1	0.68	
			85	4	4	3.6	3.4	0.85	
			84 *	6	5	4.0	3.1	0.62	
			83	13	12	6.4	3.8	0.32	
			82	6	5	2.9	2.6	0.52	
			81	7	6	4.4	4.3	0.72	

* Incomplete Data

ANNUAL MAXIMUM
CO DATA

Basin	Co	Location	Year	Annual Max. CO (ppm) 1-Hour 1st	1-Hour 2nd	8-Hour 1st	8-Hour 2nd	Ratio of 2nd Annual Max. by Year	3 Yr. High
San Diego (cont.)	SD	San Diego-1133 Unio 80-00130	87	14	13	9.3	7.9	0.61	0.63
			86	14	13	10.4	8.2	0.63	
			85	17	16	13.0	10.0	0.63	
			84	11	11	8.5	7.6	0.69	
			83 *	16	15	12.1	8.0	0.53	
			82	14	14	10.1	7.6	0.54	
			81 *	12	12	8.9	8.5	0.71	
	SD	San Diego-880 Front 80-00135	87 *	14	13	9.0	8.4	0.65	ERR
Northeast Plateau	SIS	Yreka 47-00861	87 *	12	11	10.4	8.9	0.81	0.81
Sacramento Valley	SHA	Burney-1.5N-Black R 45-00563	87						0.55
			86						
			85 *	2	2	1.1	1.1	0.55	
			84 *	3	2	1.1	1.0	0.50	
			83						
			82						
			81						
	SHA	Anderson-Center St 45-00558	87 *	4	4	2.5	2.3	0.58	0.58
			86 *	5	5	2.8	2.5	0.50	
			85						
			84						
			83						
			82						
			81						
	SHA	Redding-1615 Contin 45-00564	87 *	3	3	2.3	2.0	0.67	0.67
	BUT	Chico-Manzanita 04-00628	87	7	6	3.7	3.3	0.55	0.63
			86	9	8	4.3	3.9	0.49	
			85	9	7	4.5	4.4	0.63	
			84 *	8	8	4.6	4.4	0.55	
			83 *	7	6	4.1	3.5	0.58	
			82 *	8	7	4.9	3.9	0.56	
			81 *	6	6	3.1	3.1	0.52	
	BUT	Chico-Salem St 04-00633	87 *	12	12	8.6	7.9	0.66	0.66
			86	20	20	10.4	10.1	0.51	
			85	15	15	9.8	9.6	0.64	
			84	14	14	10.9	7.4	0.53	
			83	12	11	6.5	6.1	0.55	
			82	17	16	12.4	10.5	0.66	
			81 *	15	14	8.4	6.9	0.49	

* Incomplete Data

ANNUAL MAXIMUM
CO DATA

Basin	Co	Location	Year	Annual Max. CO (ppm) 1-Hour 1st	1-Hour 2nd	8-Hour 1st	8-Hour 2nd	Ratio of 2nd Annual Max. by Year	3 Yr. High
Sacramento Valley (cont.)	SAC	Citrus Hts-Sunrise 34-00293	87	8	8	5.0	5.0	0.63	0.72
			86	11	10	6.1	6.0	0.60	
			85	9	9	7.4	6.5	0.72	
			84	9	8	5.1	5.1	0.64	
			83	9	8	5.4	5.3	0.66	
			82	10	9	8.4	6.1	0.68	
			81	10	10	5.1	5.1	0.51	
	SAC	North Highlands-Bla 34-00294	87 *	9	8	7.3	6.9	0.86	0.86
			86	10	8	6.3	4.5	0.56	
			85	10	9	6.3	6.3	0.70	
			84 *	8	8	5.4	4.1	0.51	
			83	8	8	5.1	4.9	0.61	
			82	9	8	4.9	4.6	0.58	
			81	9	8	3.9	3.9	0.49	
	SAC	Sacramento-Del Paso 34-00295	87	12	12	9.0	8.4	0.70	0.76
			86	13	12	9.5	8.8	0.73	
			85	12	12	9.3	9.1	0.76	
			84	13	12	9.1	7.9	0.66	
			83	12	11	10.9	9.3	0.85	
			82 *	14	14	13.3	10.3	0.74	
			81 *	12	11	10.3	6.8	0.62	
	SAC	Sacramento-El Cmno 34-00289	87	15	14	10.0	9.6	0.69	0.69
			86 *	20	18	13.9	12.5	0.69	
			85			13.3	12.3		
			84	18	16	12.4	10.9	0.68	
			83	19	18	14.1	10.9	0.61	
			82 *	17	17	15.1	11.6	0.68	
			81	17	15	13.5	12.3	0.82	
	YOL	Woodland-Main St 57-00569	87	14	13	8.4	4.5	0.35	0.45
			86	13	12	6.0	4.6	0.38	
			85 *	12	8	4.9	3.6	0.45	
			84	9	9	4.1	3.4	0.38	
			83	10	7	3.8	3.0	0.43	
			82	9	9	6.4	4.7	0.52	
			81	13	9	4.3	4.3	0.48	
San Joaquin Valley	FRE	Fresno-Cal State #2 10-00241	87	9	9	5.6	5.4	0.60	0.63
			86	15	13	7.4	5.8	0.45	
			85	10	10	7.5	6.3	0.63	
			84 *	14	11	8.0	6.3	0.57	
			83	10	9	6.0	5.4	0.60	
			82	16	15	11.5	9.8	0.65	
			81	11	11	8.5	7.4	0.67	
	FRE	Fresno-Olive 10-00234	87	15	14	10.9	10.7	0.76	0.78
			86	21	20	16.3	15.6	0.78	
			85	18	17	10.7	10.6	0.62	
			84 *	21	20	15.1	11.0	0.55	
			83 *	17	16	13.1	11.9	0.74	
			82 *	18	17	14.3	9.9	0.58	
			81	16	15	13.6	12.0	0.80	
	FRE	Fresno-Sierra Skypa 10-00245	87 *	6	5	3.3	3.0	0.60	0.60
			86 *	9	7	5.3	3.3	0.47	
			85						
			84						
			83						
			82						
			81						

* Incomplete Data

ANNUAL MAXIMUM
CO DATA

Basin	Co	Location	Year	Annual Max. CO (ppm) 1-Hour 1st	1-Hour 2nd	8-Hour 1st	8-Hour 2nd	Ratio of 2nd Annual Max. by Year	3 Yr. High
San Joaquin Valley (cont.)	FRE	Fresno-4232Herndon-10-00243	87						0.66
			86 *	7	7	6.4	4.6	0.66	
			85	8	7	4.9	4.3	0.61	
			84 *	24	13	7.6	5.4	0.42	
			83 *	6	6	3.6	3.4	0.57	
			82						
			81						
	FRE	Fresno-4706 E Drumm 10-00244	87 *	7	7	5.0	4.9	0.70	0.70
			86 *	9	9	5.8	5.7	0.63	
			85	12	11	5.7	5.1	0.46	
			84 *	8	8	6.1	6.0	0.75	
			83						
			82						
			81						
	FRE	Parlier 10-00230	87 *	5	3	2.5	2.3	0.77	0.77
			86 *	4	4	2.6	2.3	0.58	
			85 *	4	4	2.0	1.9	0.48	
			84 *	3	3	2.4	2.3	0.77	
			83						
			82						
			81						
	KER	Bkrsfld-Chester St 15-00203	87	10	9	6.9	6.5	0.72	0.72
			86	14	12	8.8	7.9	0.66	
			85	10	10	6.0	6.0	0.60	
			84	11	10	6.9	6.9	0.69	
			83 *	14	14	8.9	8.7	0.62	
			82 *	14	14	11.3	8.0	0.57	
			81 *	14	14	10.1	7.9	0.56	
	KER	McKittrick-Hwy 58&H 15-00240	87 *	2	2	1.3	1.2	0.60	0.60
	KER	Oildale-3311Manor 15-00243	87	6	5	4.2	3.3	0.66	0.66
			86 *	5	5	4.1	3.1	0.62	
			85						
			84						
			83						
			82						
			81						
	SJ	Stockton-Hazelton S 39-00252	87	15	13	7.6	6.3	0.48	0.67
			86	17	17	9.3	6.5	0.38	
			85	12	9	6.3	6.0	0.67	
			84 *	9	9	5.3	4.7	0.52	
			83 *	17	16	9.7	8.5	0.53	
			82	16	13	8.6	7.4	0.57	
			81	14	14	7.5	6.1	0.44	
	SJ	Stockton-4310 Clare 39-00266	87 *	16	16	12.9	8.5	0.53	0.59
			86 *	19	19	12.1	11.0	0.58	
			85 *	13	12	8.4	7.1	0.59	
			84	16	13	7.8	7.5	0.58	
			83 *	16	16	12.1	9.6	0.60	
			82 *	18	16	11.5	11.0	0.69	
			81						

* Incomplete Data

ANNUAL MAXIMUM
CO DATA

Basin	Co	Location	Year	Annual Max. CO (ppm) 1-Hour 1st	1-Hour 2nd	8-Hour 1st	8-Hour 2nd	Ratio of 2nd Annual Max. by Year	3 Yr. High
San Joaquin Valley (cont.)	STA	Crows Landing-Davis 50-00571	87 *	2	2	1.4	1.3	0.65	0.65
	STA	Modesto-814 14th St 50-00568	87	12	12	8.8	8.6	0.72	0.72
			86	18	17	11.3	11.1	0.65	
			85	15	15	11.0	9.1	0.61	
			84 *	15	14	8.4	7.3	0.52	
			83 *	14	13	8.6	8.6	0.66	
			82 *	11	10	6.9	6.8	0.68	
			81 *	15	13	11.8	7.8	0.60	
	TUL	Visalia-Church St 54-00568	87	13	11	5.8	5.5	0.50	0.59
			86 *	12	11	6.9	6.2	0.56	
			85	9	9	5.5	5.3	0.59	
			84 *	13	13	5.4	5.0	0.38	
			83	9	9	5.3	4.3	0.48	
			82	10	10	5.1	5.1	0.51	
			81	10	10	5.5	5.3	0.53	
Great Basin Valleys	MNO	Mammoth Lakes-GateW 26-00785	87	9	9	6.4	5.3	0.59	0.59
			86	11	10	6.0	5.3	0.53	
			85	16	13	7.4	6.3	0.48	
			84 *	13	12	7.3	6.0	0.50	
			83						
			82						
			81						
Southeast Desert	LA	Lancaster 70-00082	87	12	7	3.9	3.7	0.53	0.53
			86	9	9	4.6	4.0	0.44	
			85	12	11	5.7	5.4	0.49	
			84	10	9	4.9	4.9	0.54	
			83	13	11	6.3	5.7	0.52	
			82	10	9	5.0	4.9	0.54	
			81	9	9	7.4	4.9	0.54	
	RIV	Palm Springs-Fire S 70-00137	87	5	5	2.9	2.1	0.42	0.48
			86	5	5	3.6	2.4	0.48	
			85	5	5	2.6	2.4	0.48	
			84	4	4	2.1	1.9	0.48	
			83	7	5	2.8	2.5	0.50	
			82	5	5	2.6	2.4	0.48	
			81	6	6	3.8	3.5	0.58	
	SBD	Barstow 36-00155	87 *	6	6	4.3	3.1	0.52	0.52
			86 *	8	7	3.4	3.3	0.47	
			85 *	6	6	3.5	3.0	0.50	
			84 *	6	6	2.9	2.7	0.45	
			83	8	5	2.9	2.9	0.58	
			82 *	5	5	3.3	2.7	0.54	
			81	6	4	2.1	1.9	0.48	
	SBD	Hesperia-17288 Oliv 36-00201	87 *	5	5	4.0	3.0	0.60	0.60
			86 *	4	4	2.6	1.9	0.48	
			85						
			84						
			83						
			82						
			81						

* Incomplete Data

ANNUAL MAXIMUM CO DATA

Basin	Co	Location	Year	Annual Max. CO (ppm) 1-Hour 1st	1-Hour 2nd	8-Hour 1st	8-Hour 2nd	Ratio of 2nd Annual Max. by Year	3 Yr. High
Mountain Counties	PLU	Quincy-So. Redburg 32-00817	87 *	3	3	2.3	2.2	0.73	0.80
			86 *	6	5	4.2	4.0	0.80	
			85						
			84						
			83						
			82						
			81						
Lake Tahoe	ED	Lk Tahoe-3377 Tahoe 09-00684	87	11	9	3.9	3.9	0.43	0.50
			86	12	11	5.0	4.7	0.43	
			85	17	12	6.1	6.0	0.50	
			84 *	16	14	8.1	7.8	0.56	
			83 *	20	19	11.3	10.8	0.57	
			82 *	20	17	12.4	12.1	0.71	
			81						
	ED	Lake Tahoe-Bijou 09-00680	87	8	7	4.0	3.4	0.49	0.63
			86	7	7	4.0	3.8	0.54	
			85	11	8	5.0	5.0	0.63	
			84	9	8	4.4	3.6	0.45	
			83	11	10	6.0	5.1	0.51	
			82	10	10	5.8	5.5	0.55	
			81 *	9	8	5.1	3.9	0.49	
	ED	So Lake Tahoe-State 09-00683	87	19	19	13.0	12.5	0.66	0.71
			86	20	17	12.5	12.0	0.71	
			85	23	23	16.3	15.8	0.69	
			84	23	22	14.8	14.3	0.65	
			83	30	25	17.4	16.4	0.66	
			82	22	21	16.4	13.8	0.66	
			81	25	23	15.4	15.3	0.67	
	PLA	Tahoe City-No Lk Ta 31-00814	87						
			86						
			85						
			84 *	13	12	7.3	6.5	0.54	
			83						
			82 *	15	13	8.5	8.4	0.65	
			81 *	11	10	7.9	6.5	0.65	

* Incomplete Data

The CO data listed here are the 1st and 2nd annual maximum CO for both the 1-hour and 8-hour time periods. The data has been summarized from California Air Quality Data, Gaseous and Particulate Pollutants, Annual Summary, Volumes XIII through XIX.

Information on individual station locations is in Appendix 2B.

The ratios shown in the next to last column were calculated by dividing the 8-hour 2nd annual maximum by the 1-hour 2nd annual maximum. The ratios in the last column are the highest ratio of the last three years (see AQ-TAN 5200, Persistence Factor).

Years which have an asterisk behind them indicate incomplete data and users may need to examine the data to insure that it is valid (see also, Criteria for Representativeness in Annual Summary).

ANNUAL MAXIMUM
CO DATA

Appendix 2B CO MONITORING STATION LOCATIONS

CARB ANNUAL SUMMARY

CO MONITORING STATION LOCATIONS

Basin	Number	Name & Address	Location
North Coast	23-00753	WILLITS 74 East Commercial St. Willits CA 95400	W 123 20 59 N 39 24 46
		Willits Police & Fire Dept. Bldg. Intersection of Humbolt St., 1 block from Main St. Center City	
San Francisco Bay Area	60-00336	FREMONT 40733 Chapel Way Fremont CA 94538	W 121 57 38 N 37 32 08 BAAQMD
		Between Grimmer & Fremont, 1 block from Washington. Suburban - Commercial	
	60-00340	LIVERMORE 2614 Old First St. Livermore CA 94550	W 121 45 58 N 37 41 06 BAAQMD
		Near Rte 84 & Livermore Ave. Center City - Commercial	
	60-00339	OAKLAND 822 Alice St. Oakland CA 94607	W 122 16 00 N 37 47 58 BAAQMD
		Oakland Fire Station Engine Co. #12. Between Alice & Jackson, and 8th & 9th. 3 or 4 blocks from Rte 17. Center City - Commercial.	
	07-00442	BETHEL ISLAND 5551 Bethel Island Rd.	W 121 38 29 N 38 00 38 ARB
		Rural Agricultural population 2000	
	07-00440	CONCORD 2975 Treat Blvd. Concord CA	W 122 01 29 N 37 56 19 BAAQMD
		Treat Blvd near Oak Grove Rd. Suburban - Residential	
	07-00430	PITTSBURG 583 West Tenth St. Pittsburg CA	W 121 53 31 N 38 01 45 BAAQMD
		Near Reecon St. 1/2 mile South of PG&E power steam plant Suburban Industrial Commercial	
	07-00433	RICHMOND 1144 13th St. Richmond CA	W 122 21 21 N 37 57 00 BAAQMD
		Near Costa Ave & Sanford Ave. Suburban Industrial	

CARB ANNUAL SUMMARY
CO MONITORING STATION LOCATIONS

Basin	Number	Name & Address	Location
San Francisco Bay Area (continued)	21-00451	SAN RAFAEL 534 Fourth St. San Rafael CA 94901	W 122 31 08 N 37 58 20 BAAQMD
		Between Irwin St & Grend Ave. 1 1/2 blocks to Rte 101, 3 blocks from San Rafael High School Center City Commercial	
	28-00783	NAPA 2552 Jefferson St. Napa CA 94558	W 122 17 41 N 38 18 40 BAAQMD
		Between Central Ave & Lincoln Ave near Napa High School. Center City Commercial	
	90-00303	SAN FRANCISCO (ELLIS ST) 939 Ellis St. San Francisco CA	W 122 25 14 N 37 47 01 BAAQMD
		In BAAQMD office Bldg. Between Franklin & Van Ness Center City Commercial	
	90-00306	SAN FRANCISCO (ARKANSAS) 10 Arkansas St. San Francisco CA	W 122 23 52 N 37 45 58 BAAQMD
		Between Rte 101 & 280 near 16th St. Center City Industrial	
	41-00541	REDWOOD CITY 897 Barron Ave Redwood City CA 94063	W 122 12 11 N 37 28 57 BAAQMD
		Just off Bay Rd, across street from Ampex Corp. Suburban Commercial	
	43-00389	GILROY 9th and Princevalle Gilroy CA 95050	W 121 34 28 N 37 00 00 BAAQMD
		Next to pump house in NE corner of Gilroy Childrens Center. Suburban Residential	
	43-00382	SAN JOSE 4TH ST 120 North 4th St. Suite B San Jose CA 95112	W 121 53 15 W 121 53 15 N 37 20 24 BAAQMD
		Between John & James St. 2 blocks to San Jose State Center City Commercial	
	48-00879	VALLEJO 304 Tuolumne St. Vallejo CA 94590	W 122 14 06 N 38 06 15 BAAQMD
		Near County Branch Office & DMV, just off of Solano St. Center City Commercial	

CARB ANNUAL SUMMARY

CO MONITORING STATION LOCATIONS

Basin	Number	Name & Address	Location
San Francisco Bay Area (continued)	49-00893	SANTA ROSA 837 Fifth St. Santa Rose CA 95404	W 122 42 28 N 38 26 43 BAAQMD
		Fremont Park, near King St and 5th. Center City Commercial	
North Central Coast	27-00544	SALINAS II 1270 Natividad Rd. Salinas CA 93906	W 121 37 57 N 36 41 50 MBUAPCD
		In Health Dept. Building, between Pachero St. and East Central Dr. Suburban Residential	
South Central Coast	40-00835	SAN LUIS OBISPO 1160 Marsh Suite Q San Luis Obispo CA 93401	W 120 39 15 N 35 17 02 CARB
		Center City Commercial	
	42-00363	GOLETA 380 North Fairview Goleta CA 93017	W 119 49 30 N 34 27 00 SBAPCD
		Located in open 7 acre field behind Cathevan Church Between Berkley & Shirrell St. Suburban Commercial	
	42-00378	SANTA BARBARA 25 West Canon Perdido st. Santa Barbara CA 93101	W 119 41 59 N 34 25 13 CARB
		Between State St & Chapala St near Rte 101. Center City Commercial	
	56-00419	EL RIO 545 Central Ave. Oxnard CA 93030	W 119 08 36 N 34 15 15 VCAPCD
		Rio Mesa High School, between Vineyard (232) & Rose 5 miles N of downtown Oxnard. Rural Agricultural	
	56-00434	SIMI VALLEY 5400 Cochran St. Simi Valley CA 93063	W 118 41 05 N 34 16 39 VCAPCD
		Simi Valley High School. Between Stearns & Stow. Near San Fernando Frwy. This is old site 56-00413, which was moved 1000' Suburban Residential	
	56-00420	VENTURA End of Figueroa near beach Ventura CA 93003	W 119 17 56 N 34 16 27 VCAPCD
		In seaside transfer station 50 yds from beach, near Rte 101 Suburban	

CARB ANNUAL SUMMARY
CO MONITORING STATION LOCATIONS

Basin	Number	Name & Address	Location
South Coast	70-00060	AZUSA 803 North Loren Ave Azusa CA	W 117 55 22 N 34 08 09 SCAQMD
		North of Foothill Blvd., 1/2 mile NE of intersection Irwindale & Foothill Blvds. Suburban Industrial	
	70-00069	BURBANK 228 West Palm Ave. Burbank CA	W 118 18 58 N 34 10 34 SCAQMD
		Near intersection Victory Blvd & Olive St. 1/3 mile to I-5. Center City Industrial	
	70-00094	HAWTHORNE 5234 West 120th St. Hawthorn CA 90250	W 118 22 08 N 33 55 50 SCAQMD
		On Anza Elementary School grounds. South of SE corner 120th St & La Cienega Blvd. approx. 5 blocks to Imperial Hwy. Near Rte 405 & LAX. Center City Commercial	
	70-00591	GLENDORA 840 Laural Glendora CA	W 117 51 04 N 34 08 38 SCAQMD
		Special CARB study, terminated 3/84. Previous site of EPA monitoring on plowed soil. Vacant field in residential area. Suburban Residential	
	70-00076	LENNOX 11408 La Cienega Blvd Los Angeles CA 90045	W 118 22 07 N 33 55 49 SCAQMD
		1/2 mile South of LAX, 300 ft. West San Diego Fwy. Between Imperial Hwy & 115th. Commercial North, Residential South	
	70-00087	LOS ANGLES 1630 North Main St. Los Angeles CA	W 118 13 21 N 34 04 02 SCAQMD
		Located in LA County Water & Power Maint. yard. Near North Main & Wilhardt Sts. Commercial Industrial	
	70-00087	LYNWOOD 11220 Long Beach Blvd Lynwood CA 90262	W 118 13 21 N 34 04 02 CARB
		Between San Born & Beachwood, near Imperial Hwy and Long Beach Freeway. 1/2 block to Post Office. Center City Residential	

CARB ANNUAL SUMMARY

CO MONITORING STATION LOCATIONS

Basin	Number	Name & Address	Location
South Coast (continued)	70-00072	NORTH LONG BEACH 3648 North Long Beach Blvd Long Beach CA 90812	W 118 11 19 N 33 49 25 SCAQMD
		Near intersection of Long Beach Blvd & 37th St 1/2 mile North of San Diego Fwy. 1 mile East Long Beach Fwy. Suburban Commercial	
	70-00088	PASADENA 7525 South Wilson Ave. Pasadena CA 91125	W 118 07 37 N 34 08 01 SCAQMD
		Trailer on SW end of Cal-Tech athletic field Center City Residential Recreation area	
	70-00085	PICO RIVERA 3713-B San Gabriel River Parkway Pico Rivera CA 90661	W 118 03 30 N 34 00 54 SCAQMD
		Near 605 Fwy, 75 ft from San Gabriel River Suburban Commercial	
	70-00075	POMONA 924 North Garey Ave Pomona CA 91767	W 117 45 03 N 34 04 01 SCAQMD
		Near intersection of McKinley Ave & Gary Ave One mile South of San Bernardino Fwy Center City Commercial	
	70-00074	RESEDA 18330 Gault Reseda CA 91335	W 118 32 00 N 34 11 58 SCAQMD
		SE of intersection Reseda Blvd & Sherman Wy 1 1/2 miles North of Ventura Fwy Center City Commercial	
	70-00091	WEST LA (VA HOSP.) 11301 Wilshire Blvd Los Angles CA 90073	W 118 27 19 N 34 03 03 SCAQMD
		Trailer on VA hospital grounds. 1/2 mile to 405. Center City	
	70-00080	WHITTIER 14427 Leffingwell Road Whittier CA 90604	W 118 01 29 N 33 55 25 SCAQMD
		Near Leffingwell Rd, Telegraph & Colima Suburban Residential	
	30-00176	ANAHEIM 1010 South Harbor Blvd Anaheim CA 92805	W 117 54 48 N 33 49 15 SCAQMD
		Near Vermont Ave. 5/8 mile to Disneyland, 1/4 mile to Santa Ana Fwy. Suburban Residential	

CARB ANNUAL SUMMARY
CO MONITORING STATION LOCATIONS

Basin	Number	Name & Address	Location
South Coast (continued)	30-00192	COSTA MESA 2310 Placentia Ave Costa Mesa	W 117 55 47 N 33 39 22 SCAQMD
		Intersection Joann St., 200 ft from Fire House, near Fairview State Hosp. & Costa Mesa Golf Club Suburban Residential	
	00-00186	EL TORO 23022 El Toro Rd. El Toro CA	W 117 41 25 N 33 37 39 SCAQMD
		Near intersection Jeronimo Rd. 1 1/2 miles to San Diego Fwy. Suburban Commercial Agricultural	
	30-00177	LA HABRA 621 West Lambert Rd. La Habra CA	W 117 57 03 N 33 55 34 SCAQMD
		On Lambert between Idaho St. & Walnut. Suburban Residential Commercial	
	30-00193	LAGUNA BEACH 1505 Arroyo Drive Laguna Beach CA	W 117 46 20 N 33 32 13 SCAQMD
		In Laguna /canyon, 1 mile from coast, 3/4 mile NE of civic center, near Hwy 133 & Canyon Acres Dr. Caltrans' van. Suburban	
	30-00188	SAN JUAN CAPISTRANO 32400 Paseo Adelanto San Juan Capistrano CA	W 117 39 50 N 33 29 38 SCAQMD
		2 1/2 miles from ocean, 1/2 mile from San Diego Fwy Suburban Commercial	
	33-00144	RIVERSIDE (RUBIDOUX) 5888 Mission Blvd Riverside CA 92509	W 117 24 52 N 34 00 01 SCAQMD
		On Mission between La Roe & Riverview Dr. Residential Commercial	
	33-00146	RIVERSIDE (MAGNOLIA) 7002 Magnolia Ave Riverside CA	W 117 24 00 N 33 56 44 CARB
		Intersection of Magnolia & Arlington Aves Center City Residential Commercial	
	36-00197	FONTANA 14360 Arrow Blvd Fontana CA 92335	W 117 30 18 N 34 05 58 SCAQMD
		Intersection of Arrow & Cherry. Suburban Industrial	

CARB ANNUAL SUMMARY

CO MONITORING STATION LOCATIONS

Basin	Number	Name & Address	Location
South Coast (continued)	36-00192	REDLANDS 825 Grove Ave. Redlands CA 92373	W 117 09 00 N 34 04 00 SCAQMD
		Grass lot East edge of Univ. of Redlands Campus, near intersection of Grove & Calton Ave. Suburban Residential	
	36-00194	SAN BERNARDINO 695 East Third St. San Bernardino CA 92408	W 117 16 34 N 34 06 26 SCAQMD
		On Third St between Waterman Rd & Lena Rd, 3/4 North of County jail. Center City Commercial	
	36-00175	UPLAND 1350 San Bernardino Rd Space #62	W 117 37 42 N 34 06 13 SCAQMD
		Intersection San Bernardino Rd & Grove Ave, 2 blks to San Antonio Community Hospital. Center City Residential Commercial	
San Diego	80-00114	CHULA VISTA 80 East J St	W --- -- -- N -- -- -- SDAQMD
		Near Hilltop & J, in Fire House substation lot adjacent to Hilltop Elem. & Jr High School Suburban Residential	
	80-00131	EL CAJON 1155 Redwood Ave El Cajon CA	W 116 56 30 N 32 47 29 SDAQMD
		NE corner Lexington School. Relocated site 80-00104 Suburban Residential	
	80-00115	ESCONDIDO 600 East Valley Parkway	W 117 04 01 N 33 07 29 SDAQMD
		Near Ash, Washington & Orland Sts, 1/2 mile to I-5 Residential Commercial	
	80-00134	OCEANSIDE 1701 Mission Ave.	W 117 22 01 N 33 12 10 SDAQMD
		County Administration Center, next to Oceanside Police HQ.	
	80-00120	SAN DIEGO (ISLAND AVE) 1111 Island Ave	W 117 09 13 N 32 43 38 SDAQMD
		Intersection Island & 12th, I-5 7 blocks East. Center City Commercial Light Industry	

CARB ANNUAL SUMMARY
CO MONITORING STATION LOCATIONS

Basin	Number	Name & Address	Location
San Diego (continued)	80-00123	SAN DIEGO (OVERLAND) 5555 Overland Ave	W 117 08 00 N 32 49 43 SDAQMD
		NE corner San Diego County Operations Center. 1/4 mile to 395 Suburban Commercial	
	80-00130	SAN DIEGO (UNION) 1133 Union St.	W 117 09 55 N 32 43 02 SDAQMD
		Microscale curbside CO site in County Courthouse Center City Commercial	
Northeast Plateau	45-00563	BURNEY 1 1/2 Miles North of Burney	W 121 39 08 N 40 54 19 SCAPCD
		0.8 miles North on Black Ranch Rd off Highway 299 In sewage pump station in open field .6 miles west of county road. Rural	
Sacramento Valley	04-00628	CHICO (MANZANITA) 468 Manzanita Ave Suite 9 Chico CA	W 121 50 50 N 39 45 23 CARB
		Near intersection Manzanita Ave & Cohasset Rd. 1/4 mile to Freeway, 1/4 mile to shopping Center Suburban Commercial	
	04-00633	CHICO (SALEM) 101 Salem St. Suite 4 Chico CA	W 121 50 37 N 39 43 49 CARB
		Near West 1st St. Center City	
	34-00293	CITRUS HEIGHTS 7400 Sunrise Blvd Citrus Heights CA 95610	W 121 15 00 N 38 40 00 CARB
		On school grounds, between Oak Ave & Michigan Dr. Suburban Residential	
	34-00294	NORTH HIGHLANDS 7823 Blackfoot Wy Building 5390 North Highlands CA 95660	W 121 22 48 N 38 42 45 SCAPCD
		McClellan AFB golf course maintenance yard Suburban Residential	
	34-00295	SACRAMENTO (DEL PASO MANOR) 2701 Avalon Dr. Sacramento CA 95821	W 121 22 00 N 38 36 50 SCAPCD
		Off Avalon between Mariloma & Maryal, trailer in open field, near little league diamond Suburban Residential	

CARB ANNUAL SUMMARY

CO MONITORING STATION LOCATIONS

Basin	Number	Name & Address	Location
Sacramento Valley (continued)	34-00289	SACRAMENTO (EL CAMINO/WATT) 3535 El Camino Sacramento CA 95825	W 121 22 50 N 38 36 40 SCAPCD
		350 ft East of Watt on South side El Camino Weinstocks' parking lot. Center City Commercial	
	45-00560	REDDING 1855 Placer St. Redding CA 96001	W --- -- -- N -- -- -- SCAPCD
		Intersection Placer & Court Center City Commercial	
	57-00569	WOODLAND 117 West Main St Suite 15 Woodland CA 95695	W 121 47 18 N 38 40 22
		Near California & Main. Center City Commercial Residential	
San Joaquin Valley	10-00241	FRESNO (CAL STATE #2) Maple & Shaw Fresno CA 91125	W 119 44 25 N 36 48 49 FCAPCD
		Suburban	
	10-00234	FRESNO (OLIVE) 3250 East Olive Fresno CA	W 119 45 00 N 36 43 30 FCAPCD
		Olive Ave & Fisher, 1 block from North First. Next door to Acme Electric Co. Suburban Commercial	
	10-00239	FRESNO (L ST) 1246 "L" St Fresno CA	W 119 47 25 N 36 44 17 FCAPCD
		Center City Commercial	
	10-00236	SHAVER LAKE	W 119 18 45 N 37 06 45 FCAPCD
		Division 11 Fresno County Road Dept. Rural	
	10-00244	FRESNO (DRUMMOND) 4706 East Drummond Fresno CA	W 119 44 30 N 36 41 45 FCAPCD
		Midvalley Fire Station #7, near Jensen & Maple St. Suburban Commercial	

CARB ANNUAL SUMMARY
CO MONITORING STATION LOCATIONS

Basin	Number	Name & Address	Location
San Joaquin Valley (continued)	10-00230	PARLIER 9240 South Riverbend Parlier CA	W 119 30 28 N 36 36 00 FCAPCD
		U.C. Davis Kearney Agricultural Field Station South Riverbend & Mannins Rural Agricultural	
	15-00203	BAKERSFIELD (CHESTER) 225 Chester Ave Room 309 Bakersfield CA	W 119 01 06 N 35 21 33 CARB
		Intersection of Chester & 2nd St. 1/4 mile from downtown, 1 mile to Rte 99 Center City Commercial	
	39-00252	STOCKTON (HAZELTON) 1601 East Hazelton Ave Stockton CA 95205	W 121 16 07 N 37 57 04 CARB
		On Hazelton Ave near Wilson Way, adjacent to county health center Center City Commercial	
	39-00266	STOCKTON (CLAREMONT) 4910 Claremont Stockton CA 95207	W 121 18 29 N 37 59 43 CARB
		Storage room of St. Andrews Church, East of Penneys' shopping center. Center City Commercial	
	50-00568	MODESTO 814 14th St Modesto CA	W 120 59 37 N 37 38 30 CARB
		In Bates Building near Henry Museum, On 14th between H & I Sts, 8 blocks to Rte 99 Center City Commercial	
	54-00568	VISALIA (CHURCH ST) 309 North Church St Visalia CA	W 119 17 25 N 36 19 56 CARB
		In new building behind old county jail. Center City Commercial	
Great Basin Valley	26-00785	MAMMOTH LAKES (GATEWAY) Mammoth Lakes CA 93546	W 118 58 00 N 37 38 00 GBUAPCD
		Gateway Home Center, Hwy 203 & old Mammoth Rd, near Meridian Blvd. Center City Commercial	
	26-00778	MAMMOTH LAKES (SIERRA) P.O.Box 1320 Sierra Park Road Mammoth Lakes CA 93546	W 118 58 24 N 37 38 52 GBUAPCD
		Roof of Mammoth High near Sierra Park & Meridian Rural Residential	

CARB ANNUAL SUMMARY

CO MONITORING STATION LOCATIONS

Basin	Number	Name & Address	Location
Southeast Desert	70-00082	LANCASTER 45547 North Beech St Lancaster CA 93534	W 118 08 21 N 34 42 44 SCAQMD
		Antelope Valley Fairgrounds 3/4 mile SE, Civic center 1 mile SW Suburban Residential	
	33-00137	PALM SPRINGS 590 East Racquet Club Rd Palm Springs CA 92262	W 116 32 25 N 33 51 09 SCAQMD
		Fire station, Racquet Club between Starr & Miralesta Suburban Residential	
	36-00155	BARSTOW 301 East Mountain View Barstow CA 92311	W 117 01 24 N 34 53 38 SBCAPCD
		On hill overlooking Main St. Center City Commercial	
Lake Tahoe	09-00684	S LAKE TAHOE (TAHOE BLVD) 3377 Tahoe Blvd South Lake Tahoe CA	W 119 58 00 N 38 56 45 CARB
		Center City Commercial	
	09-00680	S LAKE TAHOE (BIJOU) 3501 Spruce Ave South Lake Tahoe CA	W 119 57 30 N 38 56 30 CARB
		Bijou Elementary School grounds Suburban Residential	
	09-00683	S LAKE TAHOE (STATELINE) 4045 Highway 50 South Lake Tahoe CA	W 119 56 30 N 38 56 29 CARB
		Sugar house, 1 block NW to casinos Center City Commercial	

Mailing List

In order to keep the users of these notes up to date as additions, changes or modifications occur, please provide us with the information below and return to:

- -

California Department of Transportation
Office of Transportation Laboratory
Research & Enviro-Chemical Services Branch
5900 Folsom Blvd
P.O.Box 19128
Sacramento, CA 95819

Caltrans Air Quality Technical Analysis Notes Mailing list.

NAME: . . . . . .

TITLE: . . . . . .

ORGANIZATION: . . . . . .

ADDRESS: . . . . . .

CITY: . . . . . STATE: . . . . . ZIP CODE . . . . . .

PHONE: (. . . .) . . . . . .

HOW MANY SETS OF NOTES FOR THIS LOCATION? . . . . . .

Mailing List

Questions? Comments? Suggested changes? Additions?

AIR QUALITY

Paul Benson
Office of Research, Corrosion
Enviro-Chemical and Graphics

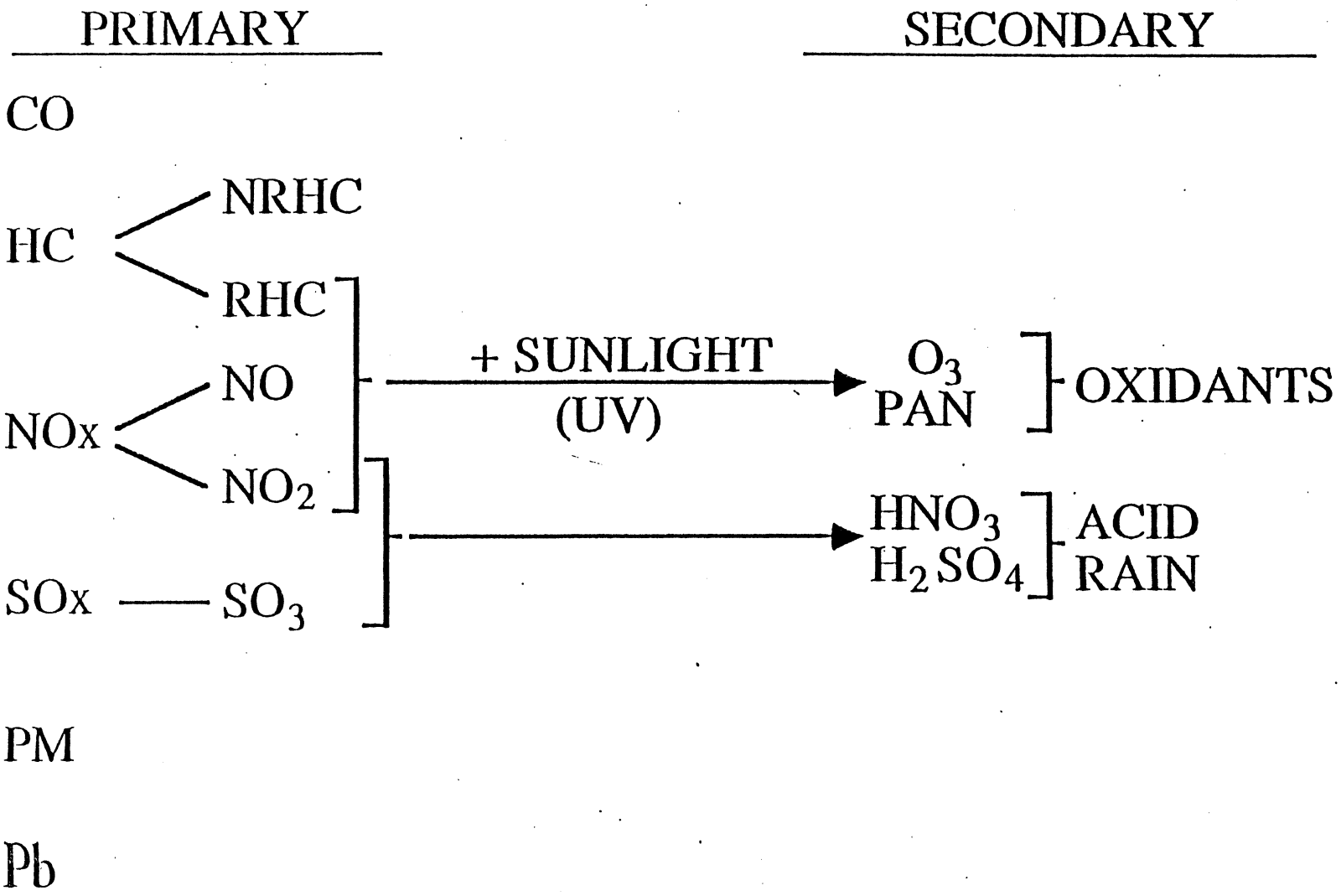
October 1990

MAN-MADE EMISSIONS

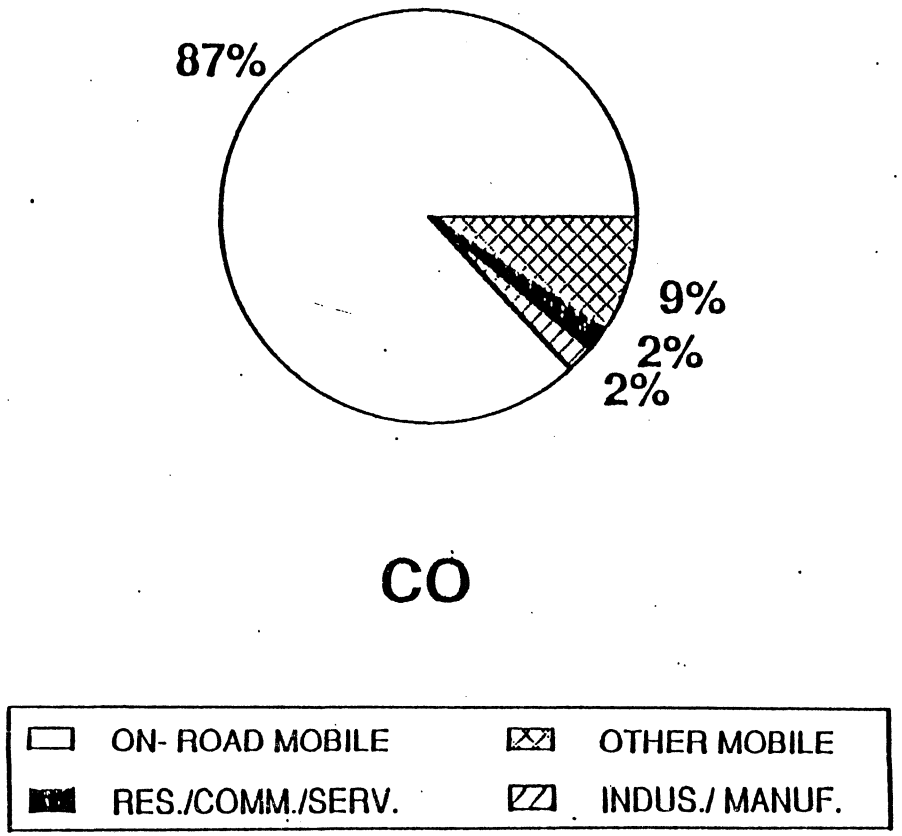
3 BROAD CATEGORIES:

- STATIONARY SOURCES
- AREA SOURCES
- MOBILE SOURCES

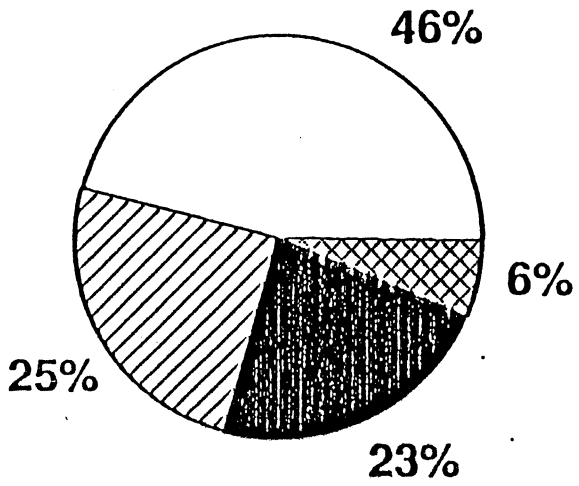
MOBILE SOURCE POLLUTANTS



1985 EMISSIONS INVENTORY (SOUTH COAST)



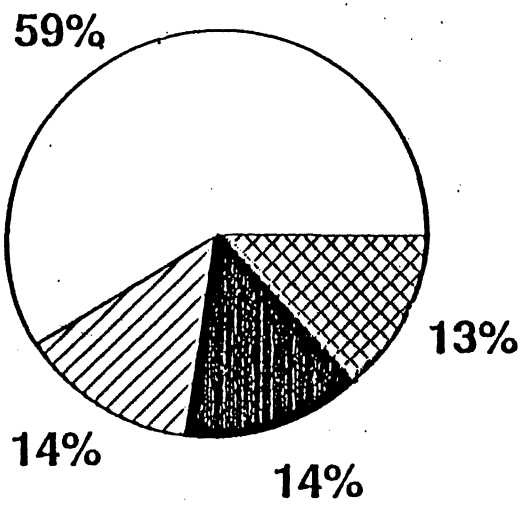
1985 EMISSIONS INVENTORY (SOUTH COAST)



ROG

ON- ROAD MOBILE	OTHER MOBILE
RES./COMM./SERV.	INDUS./ MANUF.

1985 EMISSIONS INVENTORY (SOUTH COAST)

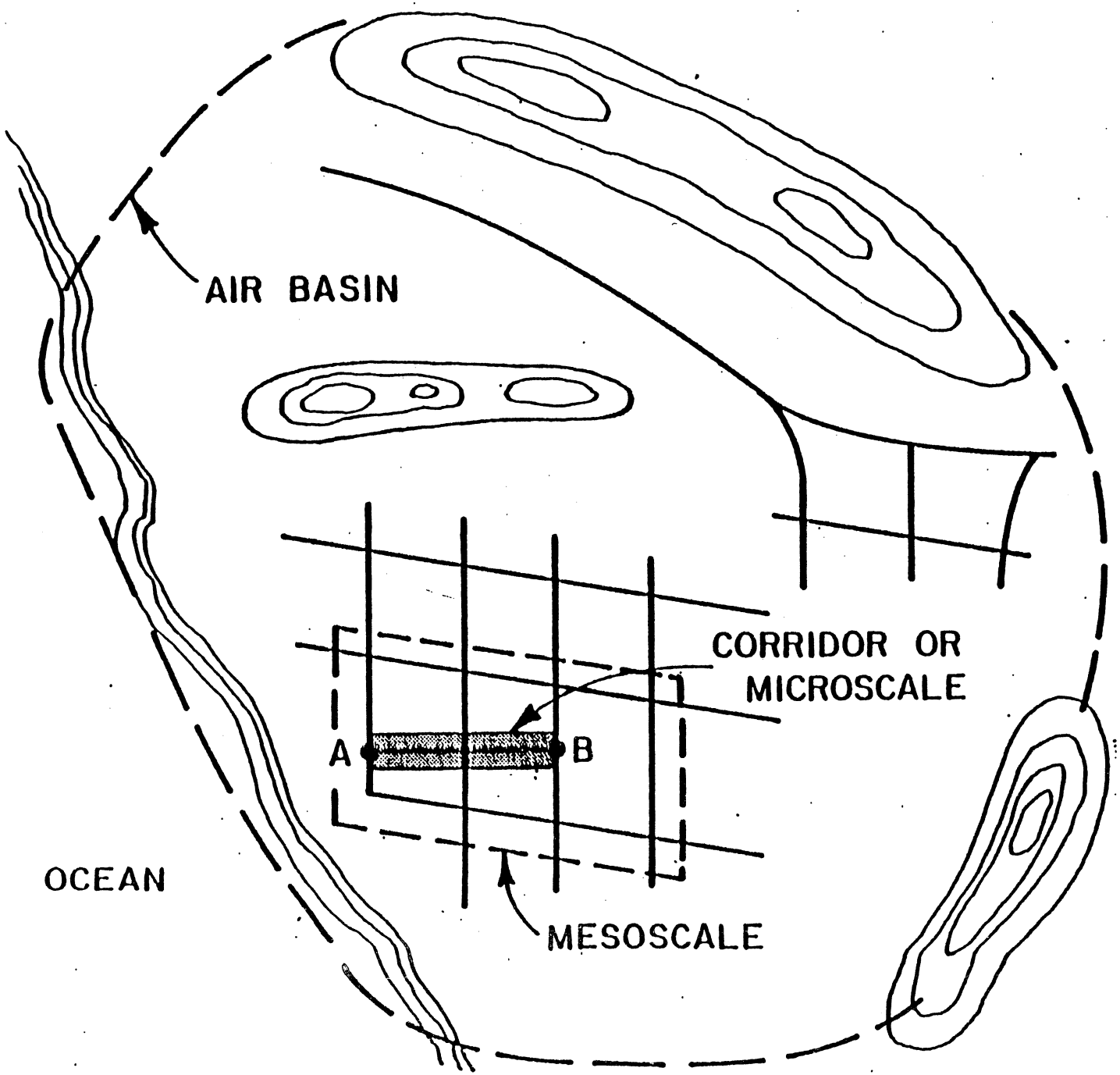


NOx

☐	ON- ROAD MOBILE	⊠	OTHER MOBILE
▮	RES./COMM./SERV.	▨	INDUS./ MANUF.

CO STANDARDS (PPM)

	NAT'L	CALIF.
1-HR	35	20
8-HR	9	9.0


AIR BASIN
CORRIDOR OR
MICROSCALE
A
B
OCEAN
MESOSCALE

MICROSCALE ANALYSIS

- CO (ppm) - 1-HR & 8-HR
- "WORST" CASE

- GEOMETRY
- EMISSIONS
- METEOROLOGY
- BACKGROUND

3 LEVELS OF ANALYSIS

- SCREENING
- WORST CASE 1-HOUR + PERSISTENCE FACTOR
- MULTI-HOUR

COMPUTER PROGRAMS

- EMFAC
- OBSMAX
- CALINE

MITIGATION

- RELIEVE CONGESTION
  - — CHANNELIZATION
  - — REVERSIBLE LANES
  - — SIGNAL COORDINATION
  - — RAMP METERING
- DECREASE VMT
  - — HOV LANES
  - — PARK & RIDE LOTS
  - — TRANSITWAYS
  - — RIDESHARE PROGRAMS

California Department of Transportation

ENERGY CONSIDERATIONS FOR TRANSPORTATION PROJECTS

October 1989

BACKGROUND

Historical

In 1973, the United States experienced its first energy crisis. Before that time, very few people considered petroleum a finite resource. Consequently, there was little concern for the rate at which this resource was being consumed. Energy, and gasoline in particular, was inexpensive and people assumed that new oil fields would continue to be discovered. Therefore, conservation was not practiced. Immediately after the petroleum shortfall in 1973, energy received a lot of publicity and many research studies were funded to examine energy use in all sectors of the economy. However, as time passed, the emphasis on energy conservation decreased.

Another energy shortfall developed in 1979. That crisis was quickly resolved, but it contributed to dramatic increases in the prices of petroleum products which, in turn, has affected almost every facet of the economy.

Although at their peak, these shortfalls were only about 8 to 12% of the United States' regular consumption rate; this caused the price of petroleum to increase many fold. These experiences have shown that petroleum is a very inelastic commodity - small changes in supply can have dramatic changes in the price and availability.

Most experts agree that the energy shortages of the 1970's were precipitated largely by the United State's heavy dependence on Middle Eastern oil imports. Figure 1 shows

that we are much less dependent on Middle Eastern oil now, which is largely responsible for the stabilization (and slight decline) of oil prices in the mid 1980's.

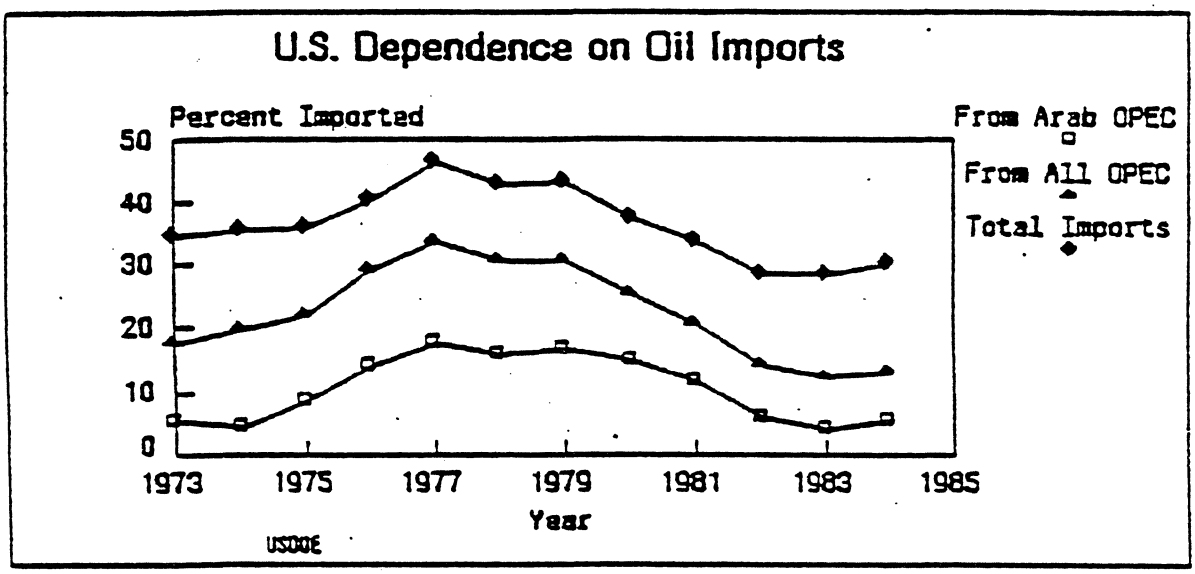


Figure 1

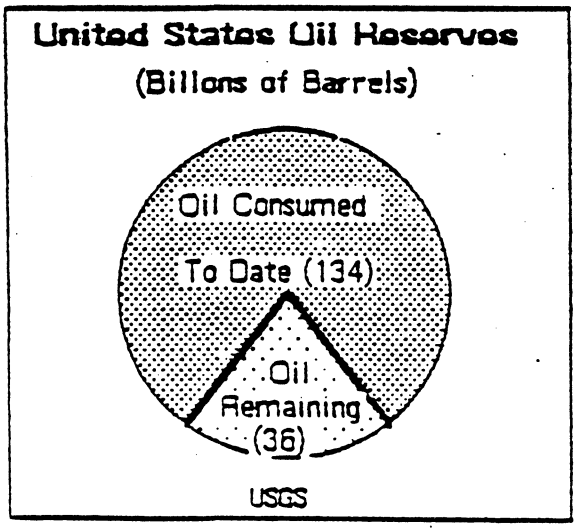


Figure 2

This trend is not expected to continue indefinitely.. Figure 2 shows that of the 170 billion barrels of oil we once had in the United State, we only have 34 billion (20%) remaining. Although it is believed that there are still some substantial untapped oil fields offshore, recent unsuccessful exploratory drilling has caused the U.S. Geological Survey to reduce its estimates of undiscovered offshore oil by 55%.

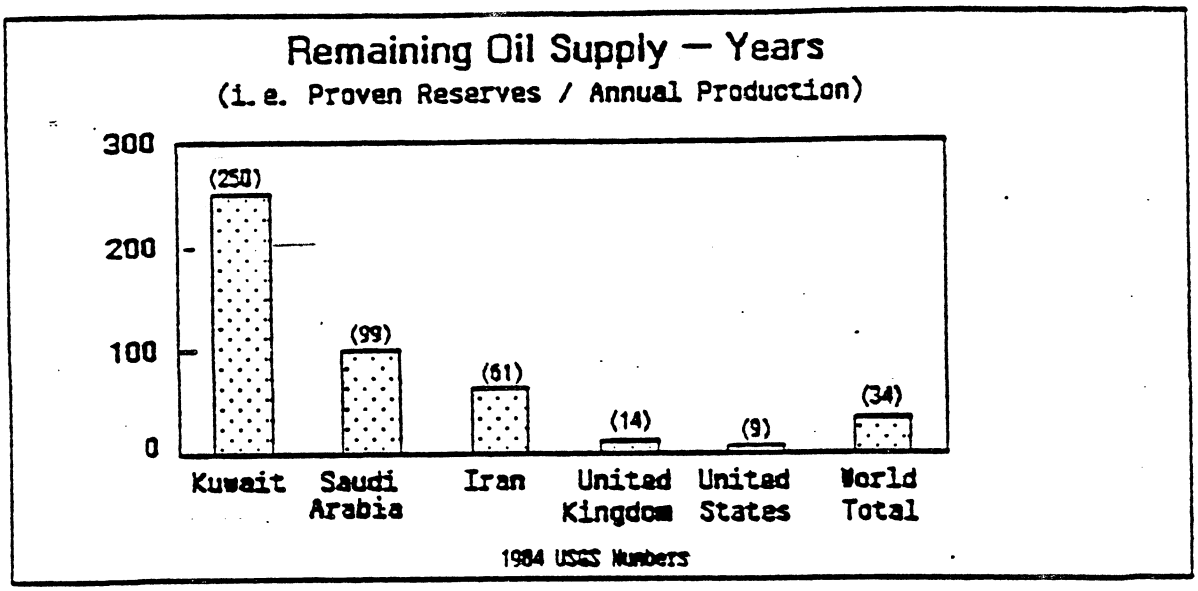


Figure 3

Figure 3 shows that although the world in total has enough proven reserves to last for 34 years; we here in the United States only have enough oil to last 9 more years at the current consumption rates. This indicates that by the 1990's virtually all the worlds remaining oil will be centered in the Middle East and the United States will be heavily dependent on imported oil once again.

The vast majority of energy expended for a transportation project is petroleum based. Since our domestic supplies of petroleum are expected to be exhausted by the turn of the century, each transportation project must be carefully analyzed to determine its energy impact. Concurrently, transportation energy conservation strategies should be pursued and alternative sources of transportation energy investigated as a means of reducing our dependence on petroleum energy.

Figure 4 shows California energy by origin and use by sector. Figure 5 shows the energy used for transportation in California.

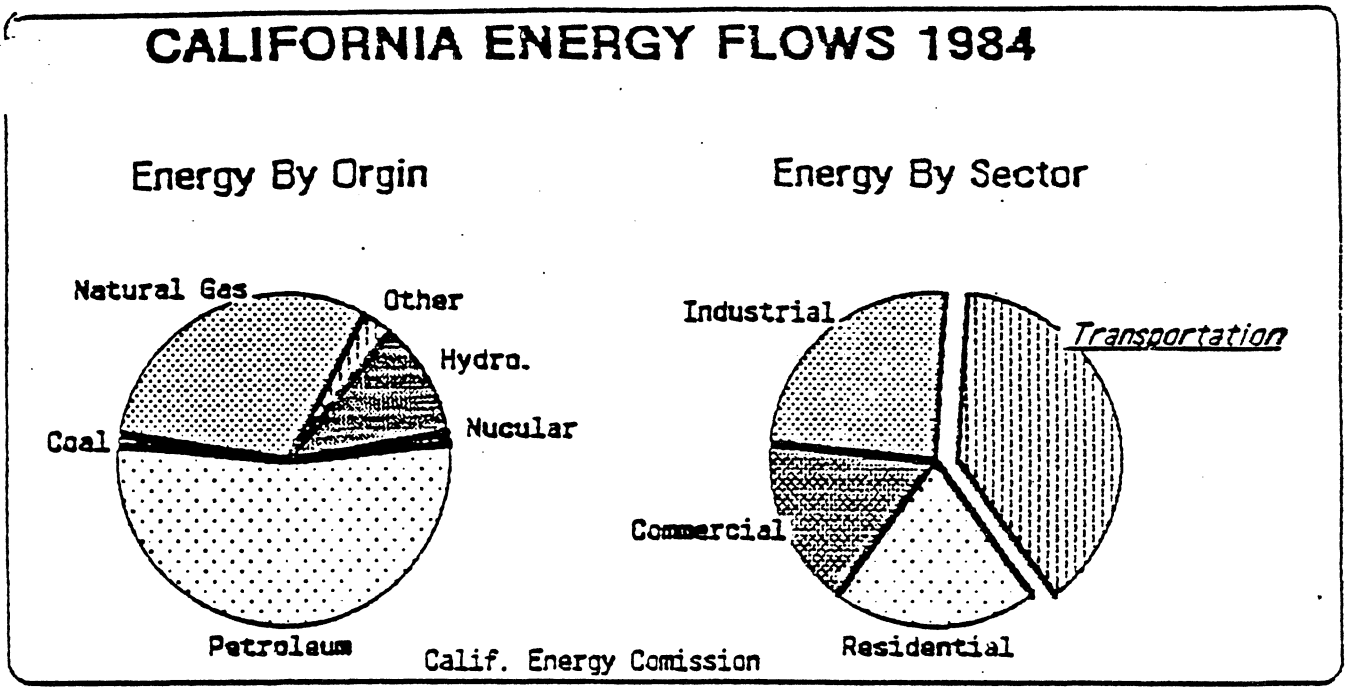


Figure 4

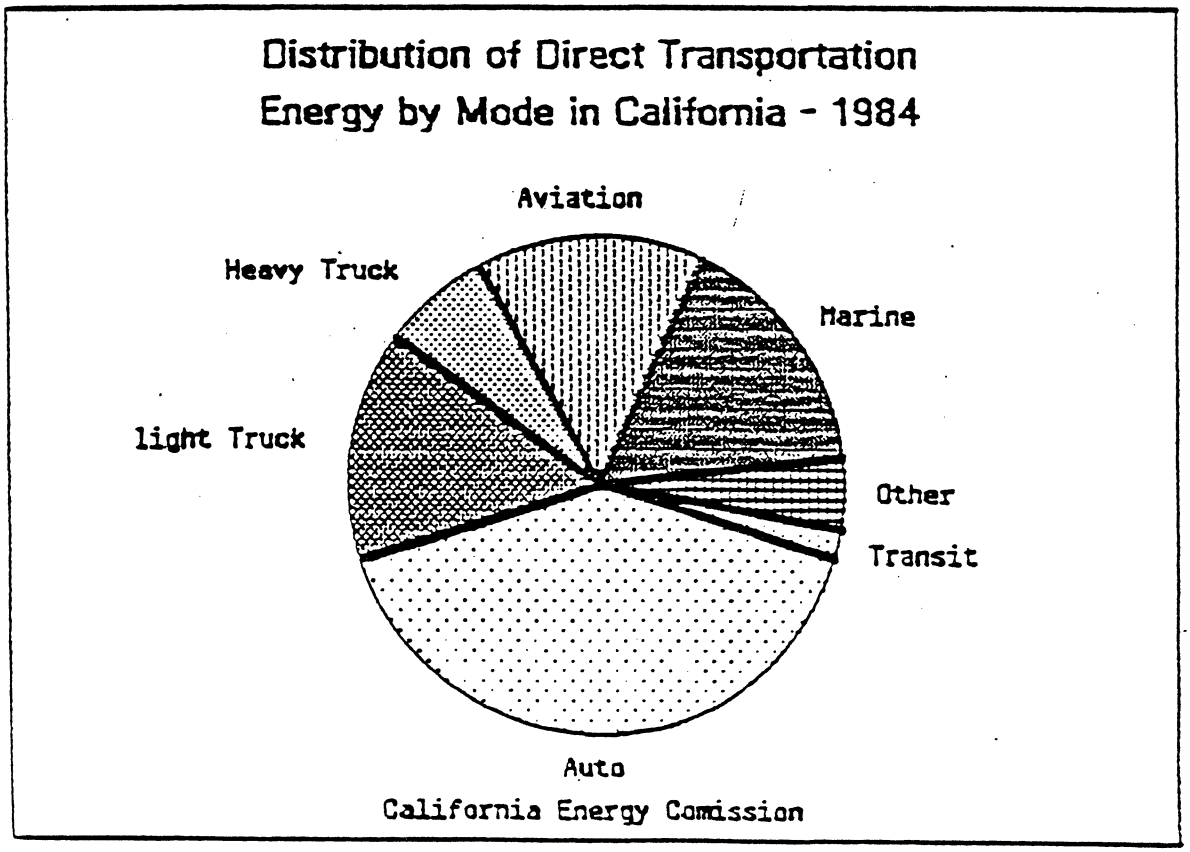


Figure 5

Laws Relating to Energy

Various federal and state laws, regulations and policies require energy studies for input into environmental documents. Those laws and regulations require that energy be conserved. Figure 6 shows the more important federal laws.

FEDERAL LEGISLATION AND REGULATIONS

AFFECTING TRANSPORTATION/ENERGY RELATIONSHIPS

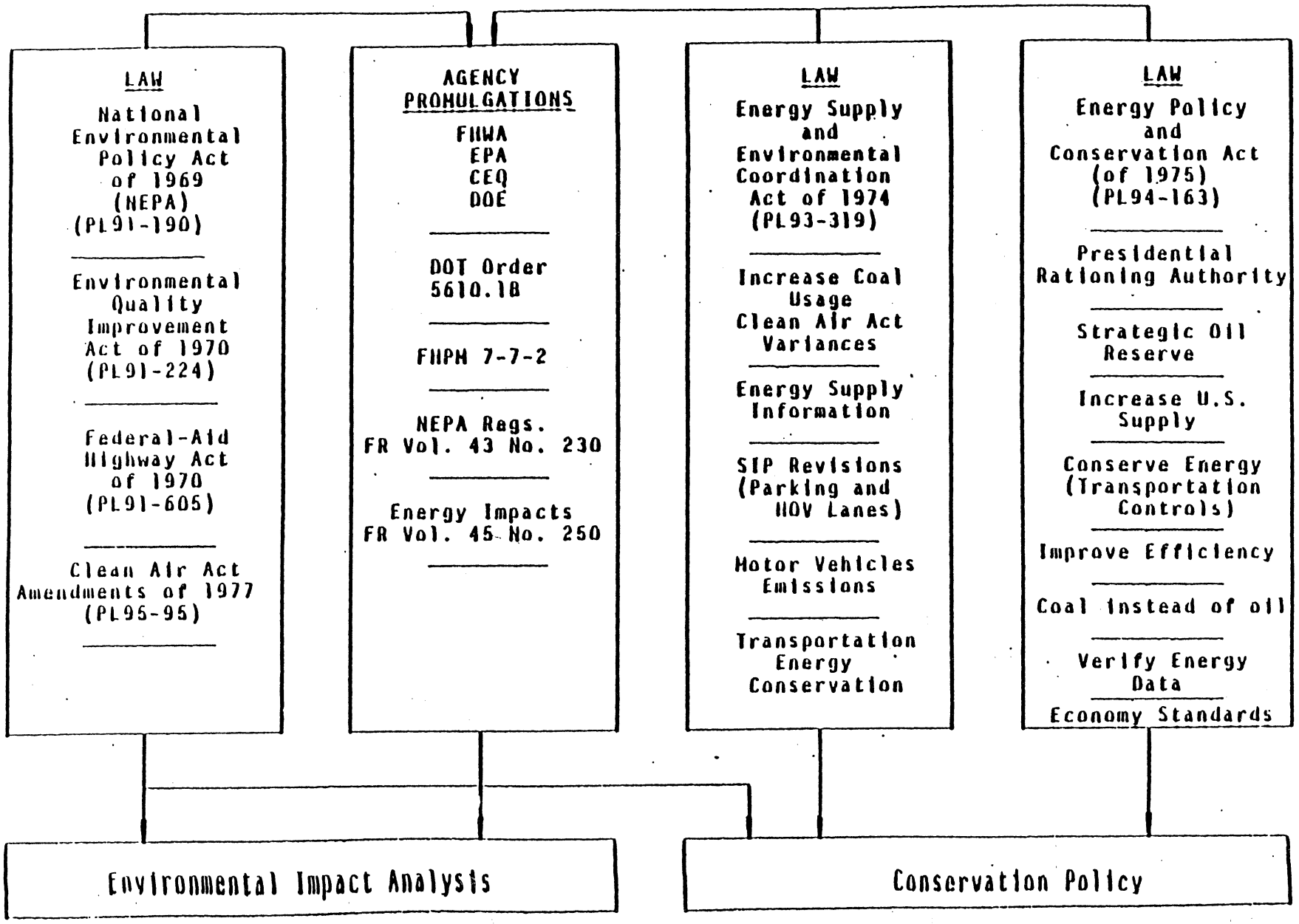


Figure 5

ENERGY ANALYSIS

Energy Units

Transportation may be defined as the moving of goods and/or people. To perform this act, certain impeding forces (gravity, friction, etc.) must be overcome. This requires the expenditure of energy. Energy is defined as the ability to do work. A typical unit of work, for example, is a foot-pound, and a substance - say a fuel - capable of producting one foot-pound of work may be said to contain one foot-pound of energy.

Energy can be classified in many forms such as chemical, kinetic, nuclear, potential and thermal. One of the most important forms related to transportation is the chemical energy inherent in fuels. This is determined by equating it with the fuel's heating or thermal energy value. Classical experiments have determined the correlation between thermal energy and mechanical energy (foot-pound) and in fact, the units for all forms of energy are convertible to each other.

Commonly used units of energy are the British Thermal Unit (Btu) in the English System and Joule (j) in the International System of Units (SI). Still in considerable use is the kwh (kilowatt-hour) which usually describes electrical energy. "Equivalent" barrels of oil or "equivalent" gallons of gasoline are often used as more understandable units for transportation energy analyses.

Considerations in an Analysis

In general, the purpose of an energy analysis is to provide meaningful comparisons between alternatives, including the "no build" alternative. This requires careful consideration of the factors involved in analyzing the energy impacts of each alternative. Figure 7 provides an overview of the considerations in an energy analysis.

The relative lack of specific data tends to promote simplification of portions of the analysis, and this may be proper, provided due attention has been paid to the following considerations. A complete energy analysis must:

1. Consider the total transportation system.

2. Compare alternatives providing equal levels of transportation service. This requires the proper identification of diverted, induced and new growth travel.

3. Consider both direct and indirect energy.

4. Consider the difference between the actual and potential transportation service provided by each alternative.

5. Consider the ease with which materials lend themselves to recycling.

Measures of Effectiveness (M.O.E.s)

Currently there are no legislatively mandated standards to determine the level of significance of an energy impact.

CONSIDERATIONS IN AN ENERGY ANALYSIS

Objectives
-or-
what we must produce

INTRODUCTION AND ORGANIZATION
Transportation & Energy - Legal Requirements - Envir. Impact

New Words & Ideas
Concept of Energy

ENERGY - LANUGAGE AND CONCEPTS
BTU, KWH, Energy-Related Terminology, Energy Concepts

Planning
-or-
How do we begin

PLANNING AN ENERGY STUDY
Definition and comparisons of Alternatives
For a System or For a Project

Constructing the study
-or-
How and what input data we need

DIRECT ENERGY

Vehicle Oriented	Service Oriented
Vehicle type	Traffic Flow
Fuel Type	
Speed	Travel Type
Road Geometry	
	Load Factors
Road Condition	Cargo Wt.
Cold Starts	
Idling	
Trip length	

INDIRECT ENERGY

Materials & Construction	Operation & Maintenance	Peripheral Effects
Vehicle Manuf.	Useful Lives:	Project-Induced Energy
Facility Constr.	Vehicles	Energy Production for Large-Consumption Projects:
Roads	Facilities	Sources
Rail Lines	Routine Maint.	Siting
Stations	Repair/Repl.	Land-use preempted
Docks	Auxil.Equip.	Bioenergy
Airports		Sources
Pipelines		Sites

Analysis
-or-
How we find what we want

ANALYSIS
Processing Data -- Filling in With Reasonable Estimates -- Obtaining Values

Results
-or-
What we think will happen and what to do about it

ENERGY REPORT
Checklist
Format
Presentation
Summary, Conclusion & Opinion

FIGURE 7

Generally, using less energy is better than using more, but this is only true if both alternates provide the same level of service.

Three different measures of effectiveness have been devised for analysis. They are: Total Project Energy, Energy Payback Period and Energy Efficiency.

1. The total project energy is the sum of the direct and indirect energy consumption for each alternative over the entire study period. This is a common basis of comparison in many cases and the lowest value indicates the most energy efficient alternative if the alternatives provide the same level of transportation service.

2. The energy payback period is the amount of time it takes to recover the quantity of energy expended for the construction of a project. It is determined by dividing the construction energy by the annual direct energy savings due to the project. If the project uses more energy than the no build alternative, there is no annual energy savings and the payback period is infinity. This MOE provides a method of determining the time it takes to obtain a return on the (construction) investment.

A payback period of under 7 years is excellent and is considered as a superior investment. A payback period of greater than 20 years will generally be beyond the foreseeable future of the project, and therefore not a good investment. A payback period of between 7 and 20 years is considered as not significant.

3. The energy efficiency is the total project energy divided by the total travel it took to generate that energy consumption. It is generally reported in units of Btu/VMT.

This is the only MOE that directly accounts for the level of service. Competing projects may involve different levels of development of a transportation corridor which may draw different volumes of traffic from the surrounding system. Obviously, the largest project will draw the greatest volume of traffic and consume the largest gross quantity of energy. However, such a project may reduce congestion and allow the most efficient traffic flow on a Btu/mile or Btu/trip basis.

A transportation project's energy efficiency can be compared to the national average efficiency for a fleet with the same vehicle mix. A project with a greater efficiency than the national average (i.e., less Btu/VMT than the national average) will have a positive impact on national energy consumption while one with a lesser efficiency than the national average will have a negative impact. The project with the best energy efficiency is the most desirable.

Computer Capabilities

The Highway Energy Analysis Program (HEAP) is a computer model that will determine the total energy consumption for different roadway alternates. It calculates the direct and indirect energy due to traffic and the indirect energy associated with roadway maintenance and construction. It is based on the data and methodologies presented in the 1983 version of "Energy and Transportation Systems."

The HEAP model will:

- analyze the energy consumed for a project with up to six alternates each with up to 30 roadway segments (links), with each link having up to eight different traffic conditions.

- determine the energy consumption for any analysis time span between the years 1980 and 2010.

- allow the input of different levels of traffic information - from a very detailed speed tacograph to generalized alternate-wide VMT figures.

- allow the input of traffic volumes at both the beginning year and end year of the analysis period. Traffic volumes for other years are interpolated from these values.

For highway transportation energy, the new Highway Energy Analysis Program (HEAP) will output the following information for each alternative:

1. A summary of the direct and indirect energy for the project.

2. The average energy efficiency of this project in units of Btu/VMT. This can be compared to a national average for the project vehicle mix and time period.

The energy payback period, if applicable.

CONSERVATION OF ENERGY

Petroleum is a finite resource that in the near future will require more energy to extract from the earth than it will provide. Various estimates have been made which indicate that petroleum supplies will no longer be adequate to supply transportation needs sometime in the next few decades.

The important fact is that the long-term petroleum supply is decreasing and alternative fuels must be developed. This requires time, and conservation is the best immediate strategy for prolonging the available supply and providing time.

The various laws, regulations and policies were covered in the previous section of this report that directly or indirectly involves conservation. The most important law is "The Energy Policy and Conservation Act of 1975" which set average vehicle fleet mileage for future years. It has done more to conserve petroleum energy than any strategy presently being used.

Table I provides estimates of fuel savings from "Highway Energy Conservation Strategies."

Conservation of energy in facility planning, construction, operation and maintenance also needs to be considered and practiced. Facility includes the buildings (office, rest stops, maintenance) and the highway (landscape, lights, signs, etc.)

TABLE I

SUMMARY OF HIGHWAY ENERGY CONSERVATION STRATEGIES

Program Area	Elements Included	*Estimated Saving Total Direct Transp. Energy
1. Vehicle Technology Improvements	° Downsizing model lines ° Design Improvements - Reduce weight - Reduce drag - Improve transmissions & drive trains	10-20%
2. Ridesharing	° Ridesharing matching program ° Ridesharing marketing ° Employer programs ° HOV incentives	2-5%
3. Traffic Flow Improvements	° Traffic signal improvements ° One-way streets ° Reversible lanes ° Intersection widening ° Ramp metering ° Freeway surveillance & control	1-4%
4. Other Transportation System Management Strategies	° Fringe parking ° Alternative Work Schedule ° Priority lanes for HOV's ° Pedestrian & Bicycle improvements ° Pricing, parking & highway facilities	1-4%
5. Goods Movement Efficiency Improvements	° Improved routing & scheduling of urban goods delivery ° Truck size & weight changes ° Truck deregulation ° TOFC	1-4%
6. Transit Improvements	° Modal shifts to transit through: - Park and ride - Improved service - Marketing - Preferential highway lanes - Fare reduction ° Improved Routing & Scheduling ° Improved maintenance ° Vehicle rehabilitation	1-3%
7. Construction and Maintenance	° Improved highway maintenance ° RRR ° Substitute sulfur-based materials for asphalt ° Pavement recycling	1-3%
8. 55 mile per hour speed limit	° Better enforcement and compliance to achieve fuel saving and reduced facilities	0-2%
9. Improved Driving Habits & Vehicle Maintenance	° Radial tires ° Higher tire inflation ° Improved maintenance ° Travel planning trip linking	1-5%
10. Rationing	° Private autos ° Taxis/trucks	15-30%
11. Pricing, Decontrol	° Gas Tax ° Parking fees/policies ° Road pricing	5-25%

In many cases, buildings were constructed before energy became expensive and designers did not optimize the energy efficiency features. However, conservation can be achieved by things such as using fluorescent lights, turning the thermostat down for heat and up for air conditioning, improving insulation, sealing cracks and using thermal windows.

Conservation can also be applied to recycling pavements, hardware items (guardrail, signs, tires, lighting standards, right-of-way fence, etc.), using indigenous plants for landscaping, and planning and maintenance of the roadway itself. Recent price reductions in photovoltaics have made this free form of solar energy capable of supplementing or even replacing diesel generated power at remote facilities.

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Title: Land Use, Transportation and Air Quality Sensitivity Analysis

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Denver, CC 80211

Transportation Research Board
70th Annual Meeting
January 13-17, 1991
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ABSTRACT

This study documents the effect on air quality of a higher density alternative land use scenario which concentrated a high percentage of the employment growth expected between 1989 and 2010 along transit corridors, as compared to the expected lower density suburban development typical in the Denver region. The lower density suburban growth development pattern was served by a circumferential highway adopted as part of the Regional Transportation Plan. In the higher density scenario, the circumferential was deleted with the exception of those segments already constructed or reasonably committed. Both scenarios included a rapid transit system. An HOV lane system was also substituted for other freeway improvements proposed as part of the Regional Transportation Plan. A traditional four-step transportation model and air quality dispersion model was exercised. While transit patronage increased significantly, vehicle miles of travel remained relatively unchanged. The study found that carbon monoxide levels would increase under the higher density land use case, but would remain well below the federal standard. Other pollutant levels would not vary significantly between the two scenarios. Changing development patterns by concentrating much of the 1989-2010 employment growth along transit corridors as assumed in this study did not improve air quality.

INTRODUCTION

Purpose

The relationship between population and employment distribution patterns, resultant transportation demand, and air quality impacts is the subject of much speculation and debate. Some have hypothesized that the low density, single family character of typical suburban development has compelled many individuals to become dependent upon the single occupant vehicle for accessing both work and non-work destinations. These individuals believe this dependence on the single occupant vehicle results in more vehicle miles of travel (VMT) and air quality degradation. Others believe that the growth of employment opportunities in many suburban locations reduces the distance individuals must travel, leading to reduced travel demands and air quality improvement. These individuals believe that the reduced driving distances, combined with a dispersion of population, employment, and resulting pollution over a larger area, results in a dilution of pollutants and a net reduction in pollutant concentrations. This paper provides the transportation and air quality results of a test case comparing the effect on air quality of a higher density Alternative Land Use/Transportation Scenario (alternative scenario) to the effect of a lower density suburban development scenario based on the 2010 Regional Development Framework and Regional Transportation Plan (2010 RTP scenario). The Alternative Scenario included a reduced highway network from the system called for in the 2010 RTP.

This study was conducted at the request of the Governor's office to respond to a question raised at the Governor's Roundtable on transportation issues. The study was conducted under the guidance of a task force comprised of transportation and air quality planners from the Regional Transportation District (RTD), the Air Pollution Control Division of the State Health Department, the Colorado Highway Department (CDOH), the then-Chairman of the Denver Regional Council of Governments (DRCOG) Regional Planning Advisory Committee, and the DRCOG.

Specifically the population and employment scenario tested was developed by the task force. The RTD and CDOH respectively defined the transit and highway systems. The DRCOG applied the Regional Transportation Model to estimate travel and traffic patterns. The Colorado Department of Health Air Pollution Control Division estimated the air quality effects.

Background

Since World War II the Denver area has mirrored a national trend towards suburban development. This trend began in the 1950's with the development of low density (typically three or four dwelling units per acre), single-family suburban developments; continued in the 1960's with the construction of large regional shopping centers to provide retail services to the suburbanizing population; and was joined in the 1970's by a general movement of employment opportunities to suburban areas. Between 1959 and 1985, the proportion of the region's households living in lower density suburban areas increased from 42 percent to 82 percent of the area's total households, while employment in suburban areas increased from 44 percent of the total to 62 percent.

The resultant suburbanization of population and employment has led to different patterns of urban travel. This has included (1) a dramatic increase in circumferential travel between suburban areas as compared to radial travel to the Denver Central Business District, (2) a higher percentage of travel remaining inside suburban travel sheds, and (3) little use of transit in travel between suburban locations.

The trend towards suburban development has occurred at a time of significant changes in our lifestyle. Current travel patterns and suburban development has been influenced by, and has in turn influenced, many other factors including:

- Between 1959 and 1985, vehicle ownership in the metro area has increased from 1.16 to 1.83 vehicles per household. Increased vehicle ownership allowed for suburban development, and suburban development necessitated increased vehicle ownership.

- Average income per person has increased in real (1967) dollars from $3,839 to $4,592 between 1970 and 1984. Increased income allowed for increased movement to single family homes in suburbia, increased vehicle ownership, and increased trip making.

- Average household size has fallen from 3.47 in 1960 to 2.53 in 1985. The decline in household size has been a factor in the reduced average vehicle occupancy rates seen on our highways.

- Employment to population ratio has increased from 0.417 to 0.563 between 1970 and 1984. This is a reflection of an increased number of two wage earners per household. Two workers per household makes it more difficult to live close to work as it is unlikely both workers are employed at the same location. Two workers per household also concentrates trips in the peak period rather than spreading them throughout the day, increasing demand on the network. Two workers per household also places a premium on time and places extra demands on the household, thus making the use of transit or carpooling more difficult. For example, in two income households there is a greater need for daycare services. The need to link home, daycare centers, and work locations in trip making means the use of alternative modes is more difficult.

- Vehicle trips per person have increased from 2.23 to 3.11 between 1959 and 1985. During this time period work trips increased from 24 percent of all trips to 35 percent, reflecting the higher percentages of women working. While the increase in trip making has been most dramatic for work trips, which increased in number from 0.54 per person in 1959 to 1.09 in 1985, non-work trips have also increased, with shopping trips increasing from 0.42 trips per person to 0.50 and other trips from 1.27 per person to 1.52. Some of these vehicle trips may have occurred earlier as walking trips; however, it appears the majority of them are new trips which reflect rising incomes and more choices and opportunities to make trips.

- Recent surveys have shown that individuals believe they have less time for leisure activities and that the pace of life seems to be speeding up. As such, time appears to be a more valuable commodity.

The effect of the above forces has been to dramatically decrease the use of modes of transportation other than the single occupant vehicle. Nationally, statistics for journey to work show drive alone increased from 65.6 percent in 1975 to 72.6 percent in 1985 (see Table 1). The Denver area has mirrored the national trend with auto passengers falling from 41 percent of total household trips in 1959 to 25 percent in 1985. During this time period transit patronage fell from 4 percent of total riders to 3 percent. Auto drivers increased from 55 percent to 72 percent of all person trips. In the Denver area, average work trip auto occupancy has declined from 1.24 to 1.13 between 1959 and 1985. Based on selected auto occupancy counts, it appears that average work trip auto occupancy in the Denver area may now be less than 1.10.

Table 1

Change In U.S. Travel Modes

Work Trip Travel Mode	1975	1985
Drive Alone	65.6%	72.6%
Carpool	19.3%	14.0%
Public Transit	6.0%	5.2%
Other	9.1%	8.2%

Source: American Housing Survey, U.S. Census Bureau

The above changes have led to a dramatic increase in vehicle miles of travel (VMT). Between 1959 and 1985, VMT in the Denver metro area increased by 300 percent from 8 million per day to 32 million per day. VMT per capita increased from 8.6 to 17.6 miles per day over the same time period.

While mobile sources are a significant contributor to air pollution, air quality in the Denver region has been improving despite increases in the amount of automobile travel. Cleaner engines mandated by the federal government, the use of oxygenated fuels, and inspection and maintenance of engines have been major factors in reducing the amount of pollution emitted by automobile travel.

Use of the auto is a major contributor to the air quality problems of the Denver area. It is important to understand the magnitude of the problem, past trends in air quality, and the relative contribution of the various modes of transportation facilities. Over the last 15 years, the number of days when the Denver area air quality violated the federal clean air standards has dramatically decreased. During the early 1970's carbon monoxide standards were exceeded on approximately 150 days per year. In 1988, the Denver area violated the federal air quality standards for carbon monoxide on six days. Unfortunately, the air pollution readings on the worst days have remained high. While no PM10 reading higher than the 24 hour standard for was measured, values measured were very close to the national standard. The severity and extent of the PM10 problem needs further study and monitoring. The ozone standard was met, but not exceeded. No violations of the nitrogen-dioxide or sulfur-dioxide

standards were measured. The region is currently classified as a non-attainment area for carbon monoxide, PM10 and ozone.

While there is no health standard for visibility, the "brown cloud" remains a matter of regional concern. The Brown Cloud Study reported that the brown cloud existed between 10 and 15 percent of winter days in 1987. Monitoring data is not available to identify long term trends of the brown cloud.

Transportation sources account for 75 to 90 percent of the carbon monoxide emissions, slightly more than half of the hydro-carbon emissions which are a precursor to ozone, 36 percent of the nitrogen-dioxide, and 30 percent of the PM10.

The adopted regional development plan for the Denver region calls for a continuation of current trends towards suburbanization. This is reflected in the 2010 Regional Transportation Plan (RTP) which provides a circumferential beltway (470) and supporting roadways to service suburban development and the non-radial travel patterns which are becoming dominant. The 2010 RTP roadway system was defined based on projected need. The planned transit system comprises 100 miles of rapid transit corridors and a large background bus network. The 2010 RTP has been questioned by some because: (1) resources do not currently exist to construct the plan, and (2) the perception among the environmental community that low density suburban development, which generates the travel demand estimates upon which the 2010 RTP was based, exacerbates air pollution.

Methodology

Can air pollution be reduced through changes in the low density suburban land use pattern proposed for the Denver area? Can reduction in planned roadway improvements lead to lower auto use and greater use of alternative modes? In order to answer questions concerning the relationship between land use development patterns, transportation demand, and resulting air quality, a sensitivity analysis of the air quality effects of changes in population and employment patterns was conducted.

The 2010 Regional Transportation Plan (RTP) is based upon travel demands associated with a suburban low-density market-driven 2010 Regional Development Framework scenario. For this exercise, an alternative higher density development pattern was defined. While the regional control totals on population and employment growth were maintained, more of the new growth was concentrated in the rapid transit corridors. The rapid transit corridors defined in the 2010 RTP are shown in Figure 1. It was estimated that market forces would lead to approximately 40 percent of new employment and 20 percent of new population locating within one mile of a rapid transit alignment or one and one-half miles of a rapid transit station. For the air quality sensitivity test, it was assumed that growth in the transit corridors would double to include approximately 80 percent of new employment and 40 percent of new population. It is important to note that very few people will walk more than one-third of a mile. Therefore, the majority of those living or working within a "transit corridor" were still dependent upon feeder buses to access the rail system. This higher density alternative scenario was matched with a transportation system comprised of a much reduced highway network, the rapid transit system adopted as part of the 2010 RTP, and a supplemental high occupancy vehicle lane network. The 2000 RTP thoroughfare network served as a basis for defining the alternative

scenario highway network. It was supplemented by selected additional elements of E-470, and roadways necessary to access the New Denver Airport. The major facilities assumed in the two highway systems are compared on Figure 2. The rapid transit system technology was assumed to be a light rail transit system. A supplemental HOV lane network was defined on major freeways (Figure 3). The same transportation systems management actions were modeled for the alternative case as for the 2010 RTP case. Higher parking costs under the alternative scenario in the Denver Central Business District reflected higher employment densities expected. Suburban parking costs were generally not assumed to be in place. No changes in other parameters such as auto operating costs or trip generation were made.

Capital cost estimates were developed of the two transportation systems. The capital cost of the general purpose and HOV lanes called for in the 2010 RTP would be $8.9 billion. The capital cost of the general purpose and HOV lanes in the alternative network would be $6.6 billion. Capital costs for the highway/HOV systems are then reduced by $2.3 billion between the 2010 RTP and the alternative network. The transit system capital costs are harder to gauge as they are very dependent upon technology chosen. The published capital cost of the adopted rapid transit system of $2.3 billion is based upon a mixture of rail and busways. The rough cost estimate of $3.1 billion was made by DRCOG for the alternative rapid transit based on an all rail system. Overall, 2010 RTP capital costs would be approximately $1.5 billion more than the alternative network. Governmental expenditures for annual operation and maintenance costs would decrease from about $1.3 billion for the 2010 RTP to $1.2 billion for the alternative network. Construction of either case would require a significant increase in revenues over those available today.

The regional travel model was run and the resultant highway assignment was used in projecting ambient air quality levels associated with the higher density sensitivity land use test case. The results were compared to those associated with the 2010 RTP. Pollutants tested included carbon monoxide, ozone, nitrogen dioxide, and PM10.

DESCRIPTION OF DEVELOPMENT SCENARIOS

Lower Density Suburban Development Pattern

Two alternative development patterns were defined. The base case was the development scenario defined in the 2010 Regional Transportation Plan and the 2010 Regional Development Framework and generally would occur assuming present land use controls and a general lack of governmental intervention in the marketplace-driven land development decision-making process. The result is a land use pattern typified by:

- The majority of new growth occurring outside the City and County of Denver.
- Growth in the City and County of Denver occurring in a few areas such as the Denver Central Business District, the Platte Valley, the New Airport Area, and the Stapleton site.
- Suburban residential development occurring at low densities (typically single family dwellings at three and four dwelling units per acre).

Figure 1

Rapid Transit Corridors

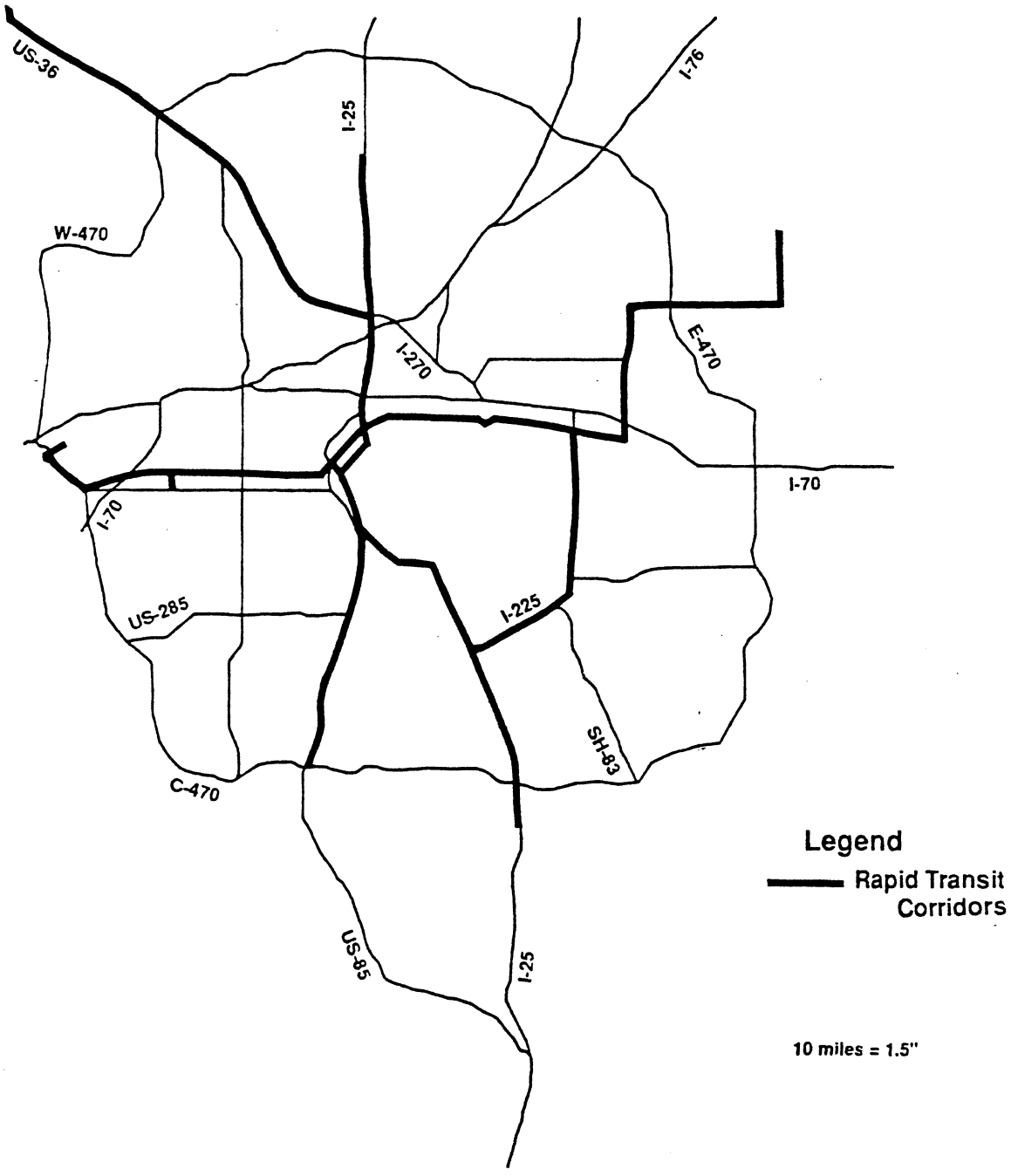
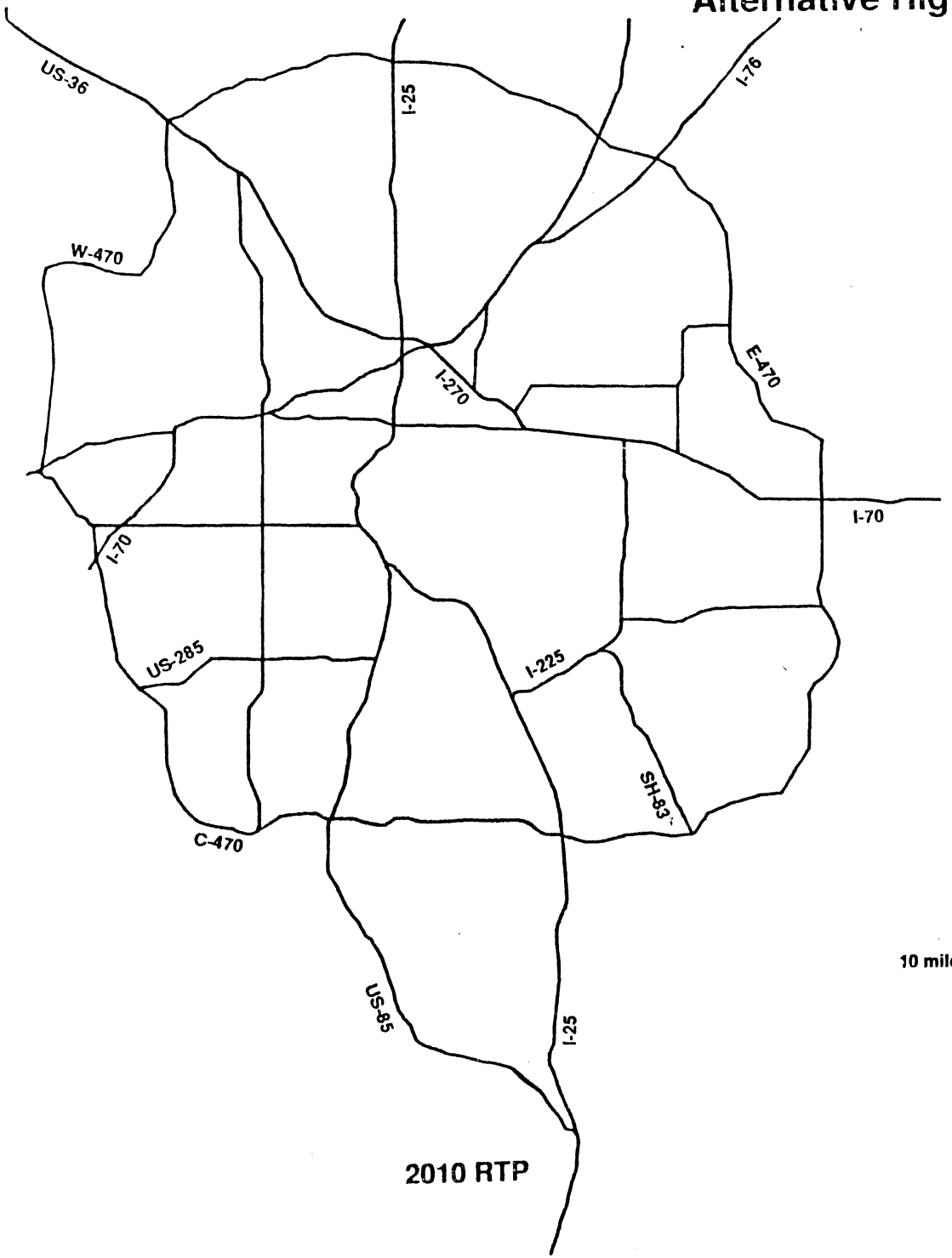


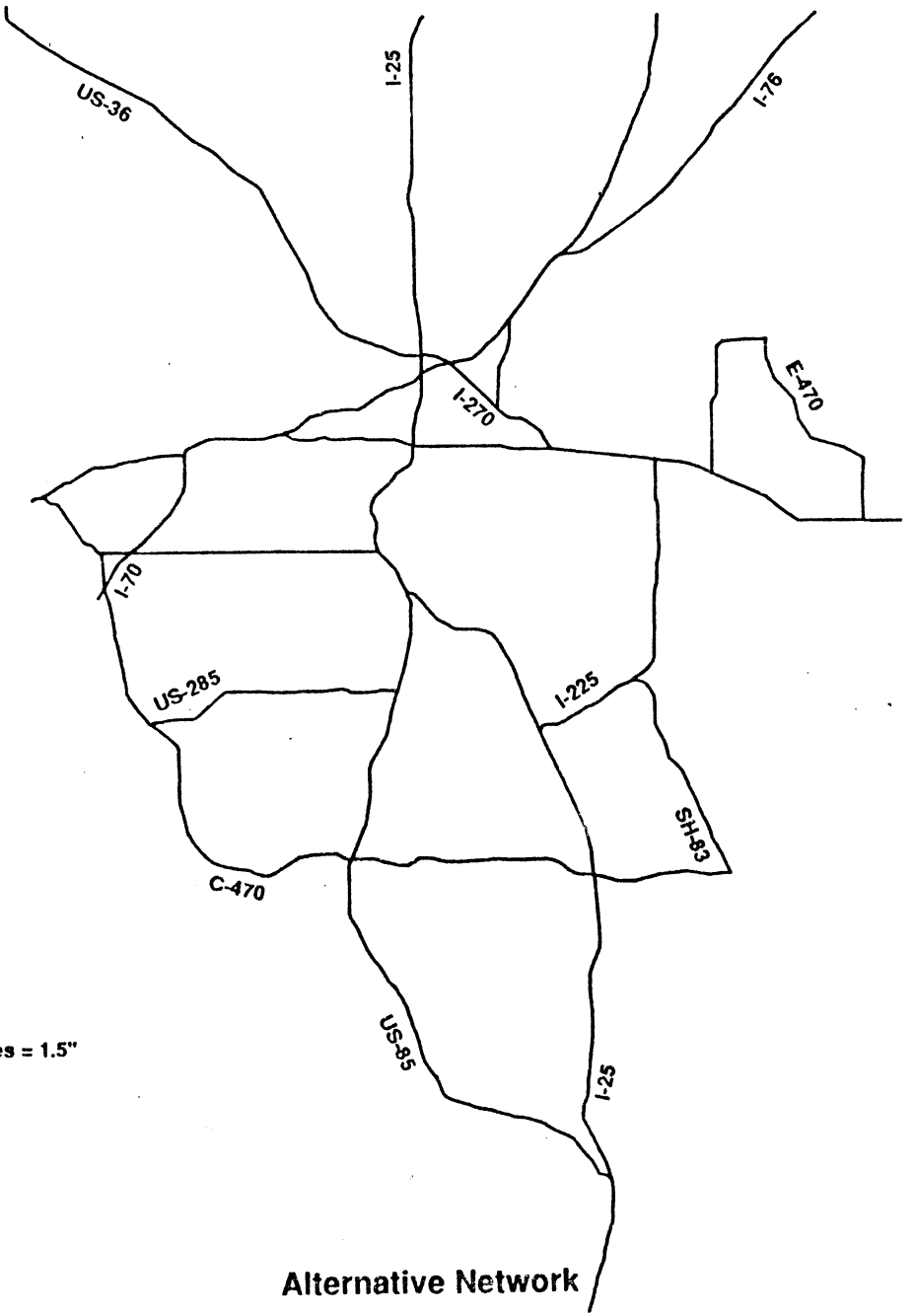
Figure 2

Alternative Highway Systems



2010 RTP

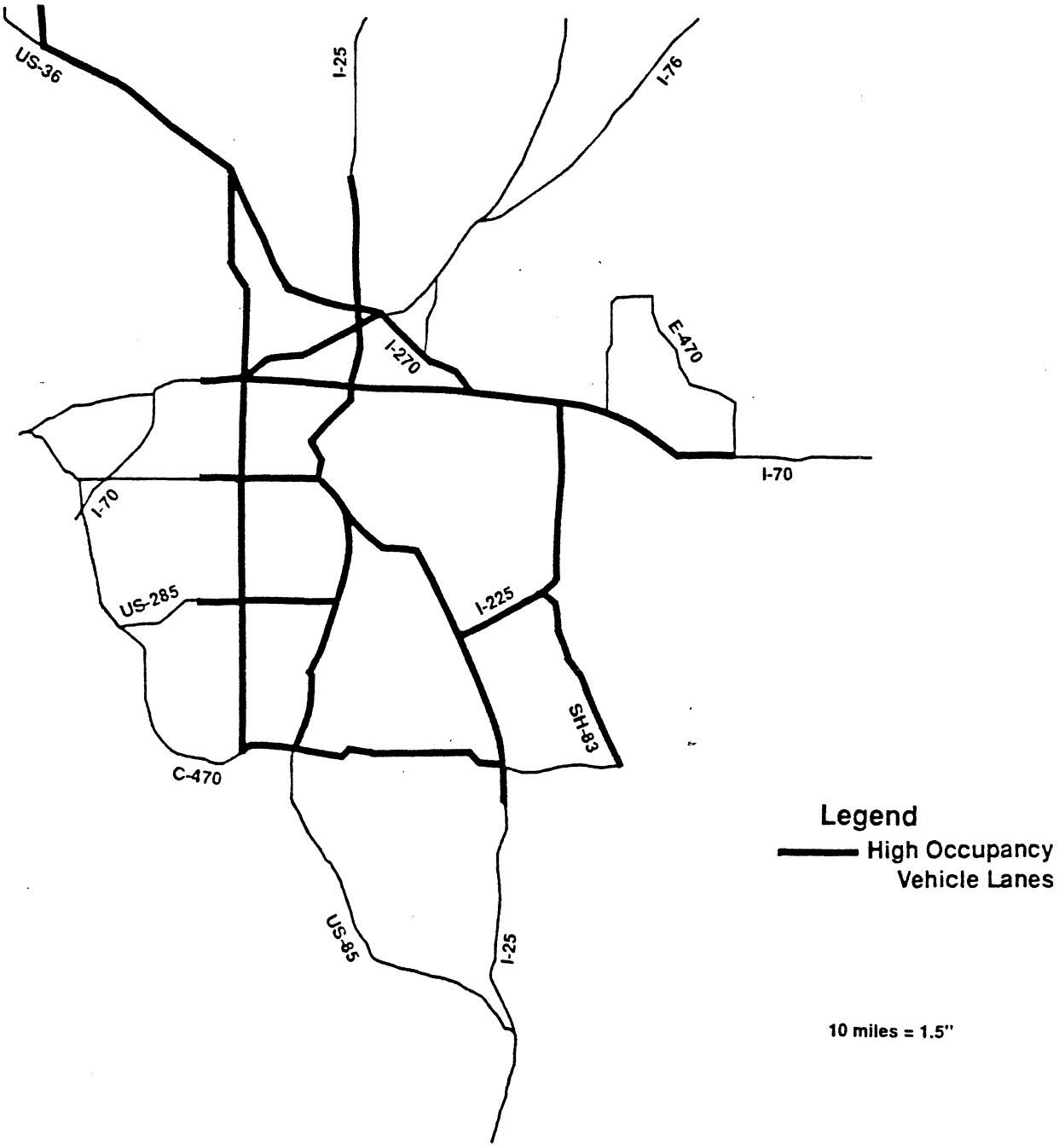
10 miles = 1.5"



Alternative Network

Figure 3

High Occupancy Vehicle System



- Approximately 40 percent of the employment growth and 20 percent of the population growth occurring within the transit corridors. The transit corridors alignments were defined by RTD as part of the HB 1249 planning effort. For purposes of this study, the transit corridors were then defined as one mile on each side of the alignment, or within 1.5 miles of a transit station.

Higher Density Transit Corridor Development Pattern

The base for defining the alternative scenario was the land use pattern put forth by a working group formed during the Governor's Transportation Roundtable effort and consisting of staff members from the U.S. Environmental Protection Agency, the Air Pollution Control Division, and the Metropolitan Air Quality Council. In interpreting this proposal, it appeared that it would lead to an approximate doubling of the amount of employment growth which would otherwise occur within the transit corridors. As such, it was decided to have approximately 80 percent of the employment growth from 1985 to 2010 occur within the transit corridors. An additional assumption was made by the study task force that population growth within the transit corridors would also approximately double from 20 percent of the growth to 40 percent. This required that 195,000 future residents and 226,600 future employees be shifted from other areas into the transit corridors.

The relatively short (20 year) time horizon used in this study did not allow for major redevelopment to occur. As such, the study group assumed that the existing urban fabric would remain in place. As such, the study dealt only with the growth increment. Not moving existing residences or jobs to the transit corridors had a substantial effect on how much impact the alternative scenario would have in that 69 percent of the population anticipated in 2010 is already in place, as are 59 percent of the employment locations. Therefore, the percent of 2010 total development actually transferred to the transit corridor zones was only 7 percent of the population and 13 percent of the employment. The vast majority of development was assumed to be in the same location for both scenarios.

The assumption to place 80 percent of the new employment and only 40 percent of the new residential development in the transit corridors had the effect of concentrating employment much more strongly than residential growth in transit corridors. This assumption was made because the land use/transportation/air quality study task force believed there would be a greater possibility of concentrating employment in higher density nodes and strips than of concentrating residential development.

Comparison Of Development Scenarios

Table 2 shows the net effect on land use distribution by analysis areas between the low density 2010 RTP scenario and the higher density alternative scenario. Development within the rapid transit corridors increased by 20.5 and 22.0 percent, respectively, for population and employment. The Denver Central Business District population was increased by 31.1 percent and employment by 23.3 percent. CBD employment is critical in that it is a major determinant of transit patronage. The percent of population and employment living outside of transit corridors declined by 12 percent and 32.7 percent, respectively.

Table 2

Development by Analysis Areas
Population/Employment

	2010 Plan		2010 LU/AQ Alternative		% Change	
Geographic Area	Pop.	Empl.	Pop.	Empl.	Pop.	Empl.
Rapid Transit Corridors	950,890	1,028,007	1,145,741	1,254,617	20.5	22.0
Denver CBD	14,971	164,650	19,628	202,975	31.1	23.3
Remainder of Transit Corridors	935,919	863,357	1,126,113	1,051,642	20.3	21.8
Outside of Rapid Transit Corridors	1,629,010	692,693	1,434,166	466,305	-12.0	-32.7
TOTAL	2,579,900	1,720,700	2,579,907	1,720,922	0.0	0.0

In general, future development growth was removed from the 470 beltway corridor or from areas beyond the beltway and in outlying centers such as Longmont and Castle Rock and moved to the transit corridors. Figure 4 summarizes the additions and deletions by Regional Statistical Areas (RSA). The figures confirm that the changes concentrate additional growth in the central area of the region. A review of the zonal data sets reveals that the population changes are somewhat more compact, while some employment additions occur at the end of the corridors such as Santa Fe at C-470 or Golden. The population reductions clearly occur in a ring around the region. The employment reduction is more evenly dispersed and less focused on the ring.

Table 3 shows the changes in population and employment by regional statistical area. RSA 505, in eastern Aurora, had the greatest reductions in both population (32,228) and employment (27,581). The Denver CBD, RSA 412, has the most employment added (38,326). Two RSAs in Denver have the most population added, RSA 404, with Montbello and Green Valley Ranch, gains 13,939, while RSA 405 along the west transit corridor gains 13,975. Since only 20 percent of the region's employment growth will occur outside the transit corridors in the higher density alternative scenario, many more zones show employment reductions than population reductions. Reductions in the 470 beltway corridor show clearly, with the I-76 corridor and the US-36 corridors also standing out.

A check was made of population and employment densities in that concern was expressed by the working group that densities needed to be "reasonable". The highest population densities do not exceed 50 persons per acre or about 18 housing units per acre. This is approximately the density of Capitol Hill. The task force decided not to increase employment densities beyond those found in the Denver Technological Center. An examination of current land use patterns found many areas along the rapid transit corridors which could be developed (or

Figure 4

Distribution Shift

from 2010 RDF to Alternative Scenario

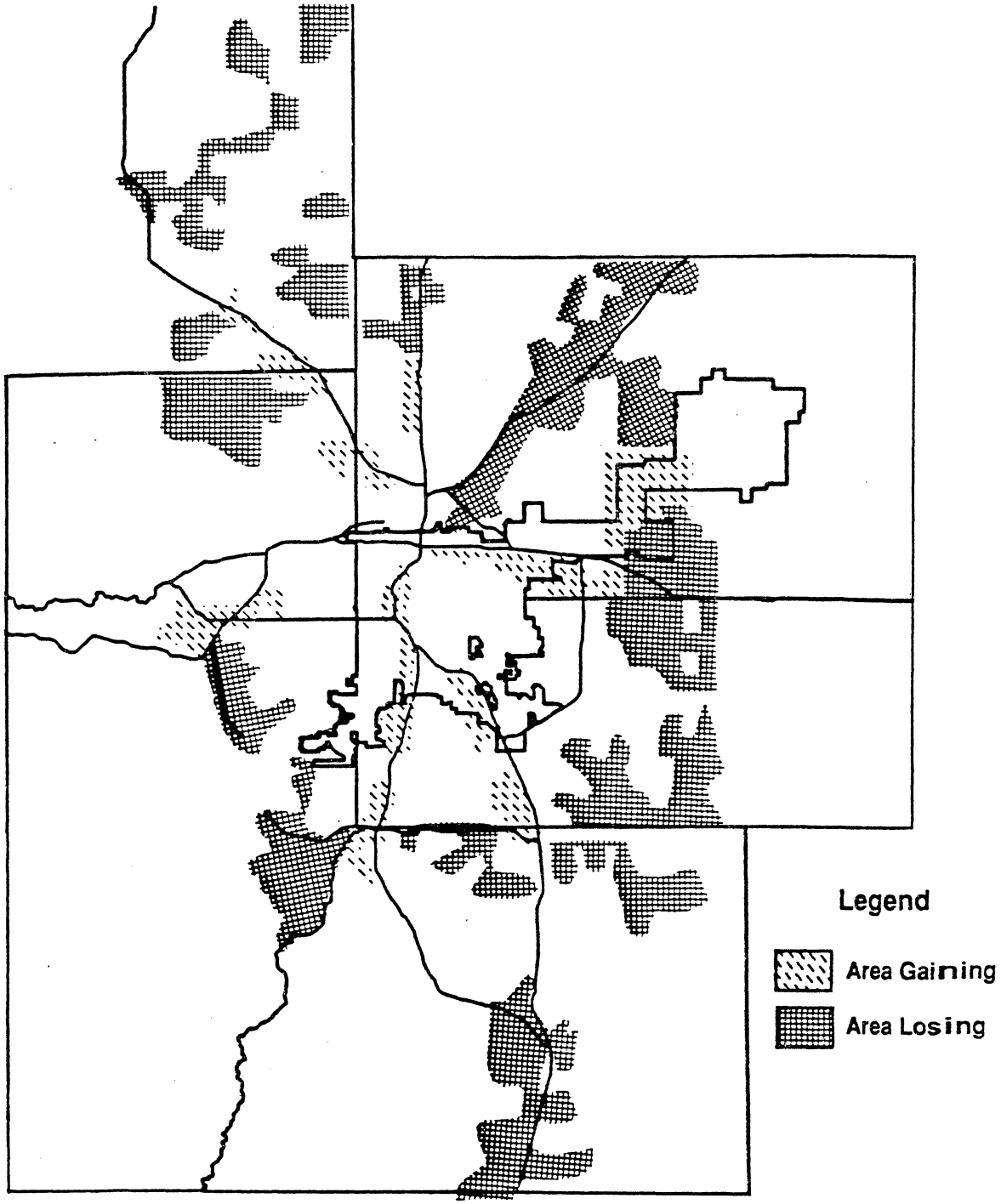


Table 3

CHANGE IN POPULATION AND EMPLOYMENT BY REGIONAL STATISTICAL AREAS

Regional Statistical Area		Population			Employment		
		2010 RDP	Alt.	Diff.	2010 RDP	Alt.	Diff.
ADAMS							
301	ADAMS-NORTHWEST	72400	48100	-24300	29000	16200	-12800
302	ADAMS-NORTH CENTRAL	53500	35500	-18000	30400	19100	-11300
303	ADAMS PLAINS	13500	12300	-1200	7000	1800	-5200
304	ADAMS-WEST	90600	101100	10500	29700	41400	11700
305	ADAMS-CLEAR CREEK VALLEY	35400	44300	8900	32800	35800	3000
306	NORTHGLENN-THORNTON	75900	83700	7800	29100	33300	4200
307	ADAMS-SOUTH CENTRAL	41800	37000	-4800	33900	23200	-10700
308	ADAMS-NORTH AURORA	50000	55400	5400	56400	64800	8400
	ADAMS COUNTY TOTAL	433100	417400	-15700	248300	235600	-12700
ARAPAHOE							
501	ARAPAHOE ENCLAVES	17400	18200	800	20900	21500	600
502	AURORA-WEST	80600	91500	10900	33500	33500	0
503	AURORA-CENTRAL	64800	73000	8200	37000	37000	0
504	AURORA-EAST	70500	66500	-4000	20700	8500	-12200
505	ARAPAHOE PLAINS	70700	38500	-32200	33300	5800	-27500
506	ENGLEWOOD	34900	45400	10500	35400	44400	9000
507	LITTLETON	45000	57000	12000	41300	49200	7900
508	ARAPAHOE-SOUTHGLENN	99600	110100	10500	49600	59400	9800
509	ARAPAHOE-CENTENNIAL AIRP	29600	35000	5400	73400	74700	1300
510	AURORA-SMOKY HILL	66400	45500	-20900	16900	4000	-12900
	ARAPAHOE COUNTY TOTAL	579500	580700	1200	362000	338000	-24000
BOULDER							
101	BOULDER-MOUNTAIN	13400	13400	0	3500	3500	0
102	LONGMONT	86600	82600	-4000	40800	30400	-10400
103	BOULDER CITY-PERIPHERY	25000	24900	-100	25800	19800	-6000
104	BOULDER CITY-NORTH	43700	42600	-1100	47300	47300	0
105	BOULDER CITY-SOUTH	58400	58400	0	22000	22000	0
106	BOULDER-TRI-CITIES	74900	69700	-5200	41800	36800	-5000
	BOULDER COUNTY TOTAL	302000	291600	-10400	181200	159800	-21400
DENVER							
401	DENVER-NORTHWEST	57000	57400	400	27000	30700	3700
402	DENVER-NORTH CENTRAL	44100	45700	1600	53500	64000	10500
403	DENVER-PARK HILL	27500	32500	5000	17000	26400	9400
404	DENVER-NORTHEAST	48900	62800	13900	63200	72300	9100
405	DENVER-WEST CENTRAL	65500	79500	14000	56900	76400	19500
406	DENVER-CENTRAL	51700	51700	0	30200	30200	0
407	DENVER-EAST CENTRAL	63900	63900	0	43400	43400	0
408	DENVER-SOUTHWEST	74100	72200	-1900	22500	22500	0
409	DENVER-SOUTH CENTRAL	51600	62100	10500	30400	40400	10000
410	DENVER-SOUTHEAST	54800	61400	6600	31500	34500	3000
411	DENVER-TECH CENTER	17900	24900	7000	32000	36500	4500
412	DENVER-CBD	16100	21900	5800	164700	203000	38300
	DENVER COUNTY TOTAL	573100	636000	62900	572300	680300	108000
DOUGLAS							
601	DOUGLAS-MOUNTAIN	17800	15700	-2100	4200	4200	0
602	DOUGLAS-HIGHLANDS RANCH	58700	49700	-9000	18500	19800	1300
603	PARKER	69900	46900	-23000	23900	13400	-10500
604	CASTLE ROCK	44800	39800	-5000	27900	6800	-21100
605	DOUGLAS-SOUTHEAST	4500	4500	0	1000	1000	0
	DOUGLAS COUNTY TOTAL	195700	156600	-39100	75500	45200	-30300
JEFFERSON							
201	JEFFERSON-NORTHWEST	3400	3400	0	1100	1100	0
202	STANDLEY LAKE	101200	95900	-5300	31600	35000	3400
203	ARVADA	74400	74400	0	32300	24300	-8000
204	GOLDEN	42700	39700	-3000	31000	31000	0
205	WHEAT RIDGE	30700	30700	0	18800	18800	0
206	EVERGREEN	31000	31000	0	13900	16900	3000
207	LAKEWOOD-WEST	66000	70700	4700	47800	50900	3100
208	LAKEWOOD-EAST	83700	93400	9700	44500	44500	0
209	JEFFERSON-SOUTH	16300	16300	0	10400	10400	0
210	JEFFERSON-SOUTHEAST	97100	92100	-5000	50000	28900	-21100
	JEFFERSON COUNTY TOTAL	546500	547600	1100	281400	261800	-19600
	TOTAL ALL RSAs	2629900	2629900	0	1720700	1720700	0

redeveloped) at higher densities. Significant development opportunities exist as the planned rapid transit corridors avoid currently developed areas in favor of alignments along existing railroad tracks or freeway facilities.

The shift is population and employment from the circumferential ring road and the outlying communities to the transit corridors is graphically represented in Figure 4.

EFFECT ON TRANSPORTATION DEMAND

Travel demand estimates were made for the 2010 Regional Development Framework development case and for the alternative higher density, transit corridor-oriented development case described in the previous chapter. The regional travel model was used to project travel demand and resultant impacts on transit ridership and auto use.

Transportation System Supply Characteristics

In order to develop travel demand estimates, it is necessary to make a number of basic assumptions concerning the transportation system supply characteristics. These supply characteristics include the extent and layout of the rapid transit system as well as the background bus system, the extent and layout of the highway system, and similar information concerning the high occupancy vehicle lane system. The transportation network of highways, high occupancy vehicle lanes, and transit facilities for use in testing the higher density alternative scenario was defined by the Land Use/Transportation/Air Quality Working Group.

The highway system is basically the former Year 2000 Regional Transportation Plan Thoroughfare Network modified based on current knowledge regarding the implementation of transportation improvements. Modifications made included increasing the number of lanes where more lanes were already in existence than indicated on the year 2000 RTP; changing alignments where detailed studies indicated changes are needed or desirable; and inclusion of new roads to serve the new Denver International Airport located to the east of the Rocky Mountain Arsenal. In addition, a number of laneage increases were proposed to the inner-freeway system to provide a minimal set of improvements to these facilities. Definition of the alternative highway system was made by the Colorado Department of Highways and reviewed by the Land Use/Transportation/Air Quality Working Group.

The transit system was based upon the currently adopted year 2010 Regional Transportation Plan Transit Element. It consisted of approximately 100 miles of light rail transit system supplemented by a large network of bus routes. Additional stations were identified on the rail lines to maximize development potential along the rail facilities. The transit network was defined by the Regional Transportation District (RTD). For purposes of modeling, the rapid transit system was assumed to have the characteristics of a light rail system (minimum of three-minute headways, acceleration/deceleration and maximum speeds of LRT vehicles, and person-carrying capacity of LRT vehicles).

Based on surveys of current behavior, walk access to transit was limited to one-third mile. Therefore, only a portion of the population and employment reallocated to transit corridors was provided with direct walk access. The remainder was assumed to rely on feeder bus service or auto access to park-and-ride lots.

Transit fare assumptions basically mimic current day average transit fares by service type. An important assumption was that the rapid transit lines will have a fare similar to today's existing express bus fare (i.e., $1.25 cash price in peak periods).

Auto operating costs mimic those in place during the early 1980s. As such, no additional gasoline taxes or other vehicle taxes were assumed to be in place under the alternative scenario as compared to base case. It was also assumed that future increases in gasoline prices will be offset by improvements in fuel efficiency.

Parking costs in the Denver CBD were calculated based upon a relationship to employment density: the higher the employment density, the higher the parking cost. The average all day parking cost in the Denver CBD was calculated as: 1985 – $4.11, 2010 RTP – $6.60, and 2010 LU/AQ – $7.24. As such, the higher CBD employment densities projected in the LU/AQ scenario resulted in a 10 percent increase in projected parking costs over the 2010 RTP scenario. In addition to the Denver CBD, parking costs were assumed at the new airport and at the CU Health Sciences Center. Parking costs were not assumed in suburban areas as the employment density was too low to justify parking costs under either scenario.

Transportation Modeling Process

The regional travel model set maintained by DRCOG is a standard four-step model set utilizing the programs and procedures recommended within the UMTA/FHWA developed Urban Transportation Planning System (UTPS). The model set, originally developed based on a 1971 home interview survey, has been updated extensively using the 1980 Census Urban Transportation Planning Package (UTPP) and information from the 1985 small sample house-hold survey and 1986 on-board bus survey. The four steps comprising this process are:

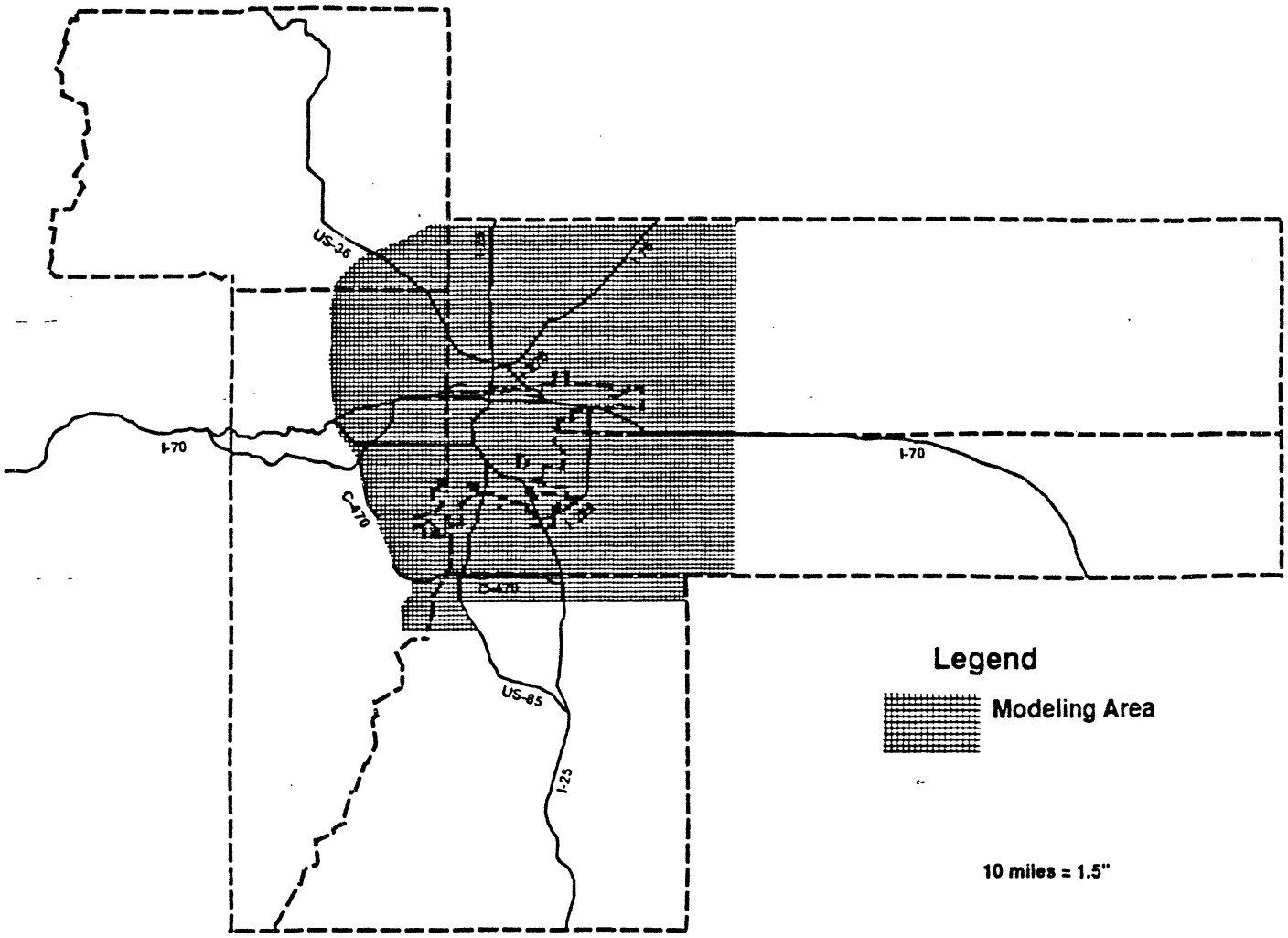
- Trip Generation – determination of how many trips will be made;
- Trip Distribution – determination of the link between origins and destinations of trips;
- Mode Choice – the determination of which mode of transportation will be used for the trip; and
- Trip Assignment – the determination of the most desirable travel paths between the origin and destination of the trip (by mode).

The travel model does not cover the entire region. The area covered is shown on Figure 5 and excludes Boulder, Longmont, and Castle Rock as well as most of the rural and mountainous portions of the Denver region.

Trip Generation

Trip generation -- the determination of how many trips will be made -- involves estimates of trip productions (beginning mainly at home) and trip attractions (trips ending mainly at employment locations). The total number of internal person trips in the modeling area increased by roughly one-half percent from 8,453,300 to 8,491,600 between the 2010 plan

Figure 5
Model Area



case and the alternative scenario. This increase was caused by the assumption that a more concentrated development scenario would result in fewer residents and less employment be located in the small growth centers and rural areas surrounding the Denver urbanized area. Instead, these persons and jobs would be within the modeling area. Table 4 displays assumed population and employment within the modeling area, as well as the resultant work and total internal person trips. The increase in trip making occurs mainly in the home-based work trip purpose which is most susceptible to diversion to transit or carpooling. Trip making per person per day decreased slightly (0.7 percent) from 3.83 to 3.80.

Table 4

Regional Trip Generation

	2010 RTP LU	LU/AQ Alternative	Percent Change
Population	2,206,000	2,232,000	1.2%
Employment	1,527,000	1,575,000	3.1%
Home-Based Work Person Trips	2,227,000	2,300,000	3.3%
Total Internal Person Trips*	8,453,300	8,491,600	0.5%

*Excludes truck trips and internal/external trips.

The total number of internal person trips was relatively insensitive to changes in the development pattern. The trip generation model used assumes that the total number of trips generated per family can be explained by the income and household size of the family. Some transportation planners have speculated that automobile trips can be converted to walk trips at high enough densities. This relationship is not included in the trip generation model as:

- The quantitative relationship between density and trip making is only speculative as no quantitative relationships have been established.

- Increased density in and of itself may not decrease trip making. In addition to increased density, a diversity of land uses on a microscale would appear necessary. Current land use patterns are centralizing and separating land uses rather than integrating them. For example, in the 1950's the corner grocery store disappeared making way for the supermarket. Recently, some supermarkets are disappearing, being replaced by a few mega-grocery stores. The same trends can be seen in hardware stores and other land uses. The impact on VMT of this change in marketing is unknown. The mega-stores are often grouped together providing opportunities to shop for a diversity of items (groceries, drugs, books, hardware) in one general location. This may make trip chaining more likely, offsetting some of the additional distance driven. In order to convert the entire shopping trip for auto back to walk, it would be necessary to go back to the corner grocery store. This implies a change in lifestyle, in which individuals would need to be willing to give up the diversity of goods

and low prices associated with mass marketing. It also implies extremely high densities at the residential end in order to have sufficient numbers of families within easy walking distance of stores.

Trip Distribution

A set of gravity models were used to distribute trips between origins and destinations. Person trips are distributed for both peak and off-peak periods based on composite impedance measures of spacial separation of zones. The composite impedance is a function of drive alone, shared ride, and transit travel times and travel costs calculated using a parallel resistance formula. Truck and Internal-External trips are distributed based on off-peak period roadway travel time.

The average trip length of 8.5 miles did not change between the two land use scenarios. However, this lack of change on a daily basis masks changes by time of day. The rearrangement of development and congestion in the peak periods caused trip lengths to decrease by 4.1 percent during the A.M. peak period (from 9.4 to 9.0 miles) and 4.8 percent during the P.M. peak period (from 8.4 to 7.9 miles). This indicates that real gains were made in reducing the length of the work trip. These decreases were offset by an increase of 3.6 percent (from 8.3 to 8.6 miles) during the off-peak period. The increase during the off-peak may be reflective of a greater separation of activity areas and residents under the alternative scenario than the 2010 RDF/RTP scenario. For example, the ratio of population to employment in the non-rapid transit corridors increases substantially from 2.3 to 3.0. This is not offset by a large corresponding decrease within the transit corridors (the ratio changes only from 0.94 to 0.92). As such, longer trips may be necessary for those remaining in the areas outside the rapid transit corridors.

The travel model used bases its estimates of travel destinations partially on employment locations. The trip attraction model uses estimates of retail and total employment. In moving employment into rapid transit corridors, the model assumed that service jobs were also being concentrated. Differentiating service jobs and redistributing them separately might have reduced non-work travel.

Tables 5 and 6 show the trip distribution between analysis areas. Note that work trips destined to the Denver CBD and the remainder of the transit corridors increase by 29.6 percent and 20.4 percent respectively.

Work trips destined outside the rapid transit corridors decrease 32.1 percent. Non-work trips to transit corridors not in the CBD increase 21.3 percent while trips to areas outside rapid transit corridors decrease 22.5 percent. However, the increase in work trips is only 3.2 percent for the entire modeling area.

Mode Split

The mode split model was used to divide the trips into mode specific (transit, drive alone, and shared ride – 2 and 3 plus carpools) trips based on the alternative transportation network description. The mode split model is a three dimensional logit model (drive alone, shared ride, and transit). The mode split model takes into account in- and out-of-vehicle travel time, and

Table 5

TRIP DISTRIBUTION
(2010 Plan/LU-AQ Alternative)

Home-Based Work

Trip Origin	Trip Destination							
	Denver CBD		Rapid Transit Corridors Outside CBD		Outside Rapid Transit Corridors		**Total Modeling Area**	
	2010 Plan	**LU/AQ**	**2010 Plan**	**LU/AQ**	**2010 Plan**	**LU/AQ**	**2010 Plan**	**LU/AQ**
Denver CBD	2,857	3,900	4,633	6,670	2,041	1,944	9,531	12,514
Rapid Transit Corridors Outside CBD	104,742	154,456	543,381	743,423	231,052	193,735	879,175	1,091,614
Outside Rapid Transit Corridor	132,778	153,132	667,735	713,824	539,537	329,027	1,340,050	1,195,983
Total Modeling Area	240,377	311,488	1,215,749	1,463,917	772,630	534,706	2,228,756	2,300,111

Non Work

Trip Origin	Trip Destination							
	Denver CBD		Rapid Transit Corridors Outside CBD		Outside Rapid Transit Corridors		**Total Modeling Area**	
	2010 Plan	**LU/AQ**	**2010 Plan**	**LU/AQ**	**2010 Plan**	**LU/AQ**	**2010 Plan**	**LU/AQ**
Denver CBD	45,115	52,267	85,795	99,645	49,812	43,178	180,722	195,090
Rapid Transit Corridors Outside CBD	140,673	149,848	1,717,658	2,239,161	661,282	601,570	2,519,613	2,990,579
Outside Rapid Transit Corridor	130,215	118,080	975,816	1,032,792	1,946,560	1,415,703	3,052,591	2,566,575
Total Modeling Area	316,003	320,195	2,779,269	3,371,598	1,657,654	2,060,451	5,752,926	5,752,244

Table 6

Percent Change in Trip Distribution
(LU/AQ Alternative compared to 2010 Plan)

Home-Base Work:

Trip Origin	Trip Destination			
	Denver CBD	Rapid Transit Corridors Outside CBD	Outside Rapid Transit Corridors	Total Modeling Area
Denver CBD	36.5%	44.0%	-4.8%	31.3%
Rapid Transit Corridors Outside CBD	47.5%	36.8%	-4.8%	31.3%
Outside Rapid Transit Corridor	15.3%	6.9%	-39.0%	-10.8%
Total Modeling Area	29.6%	20.4%	-32.1%	3.2%

Non-Work:

Trip Origin	Trip Destination			
	Denver CBD	Rapid Transit Corridors Outside CBD	Outside Rapid Transit Corridors	Total Modeling Area
Denver CBD	15.9%	16.1%	-13.3%	8.0%
Rapid Transit Corridors Outside CBD	6.5%	30.4%	-9.0%	18.7%
Outside Rapid Transit Corridor	-9.3%	5.8%	-27.3%	-15.9%
Total Modeling Area	1.3%	21.3%	-22.5%	0.0%

monetary costs such as parking fees, transit fares, and auto operating costs. Out-of-vehicle travel time is weighted by 2.5. The implied value of travel time between home and work is $5.60 per hour. The mode split model is run for both peak and off-peak periods.

Changing land use assumptions from the 2010 RDF to the alternative scenario increased the potential for walk access to transit. Households with walk access to either bus or rail transit increased from 58.3 percent to 63.6 percent or a gain of 61,900 households having walk access. Employment locations with access increased from 66 percent to 71.3 percent or a gain of 112,300 employees having access. In-vehicle travel times were calculated to test how long it would take for area residents to go to work or other destinations using transit. The reported travel times do not include time to walk to a line, wait for a bus, or transfer between

transit lines. This test indicated that in the alternative scenario, 34 percent of the work trips and 35 percent of all trips could be completed in under 40 minutes by walking to a bus or rail transit line. A summary is shown in Table 7.

Table 7

Cumulative Percent of Trips by In-Vehicle Transit Travel Time

	(Alternative Network)	
Time	Work Trips	Total Trips
Under 20 minutes	17.9%	23.3%
20 - 39	34.4%	35.4%
40 - 59	40.4%	39.2%

Transit patronage increases 26.9 percent from 316,000 to 402,000 daily between the 2010 RTP case and the 2010 alternative scenario. A significant proportion of the increase is additional work trips taking place on transit which increases from 149,000 to 216,400, or 44.8 percent. Overall mode share increases from 4.0 percent to 4.8 percent. Work trip mode share increases from 6.7 percent to 9.4 percent. The above patronage estimates for the 2010 RTP and the 2010 Land Use/Transportation/Air Quality Alternative both show a significant increase from the current day transit ridership of approximately 135,000 patrons per day, or roughly 2.6 percent of internal trip making. Ridership on the rapid transit system has increased from 110,300 under the 2010 RTP case to 185,000 under the 2010 LU/AQ scenario. Table 8 reports transit patronage by Regional Analysis Area. Most of the increase in transit usage occurred in trips to non-CBD destinations in rapid transit corridors, implying that the rapid transit system is better serving non-CBD trips in the alternative scenario.

Table 8

Transit Patronage by Analysis Area

Area	2010 RTP	2010 LU/AQ Alternative	Change
Rapid Transit Corridors Denver CBD	130,300	164,400	+ 26%
Rapid Transit Corridors Outside CBD	75,600	151,900	+109%
Outside Rapid Transit Corridor	110,100	85,700	- 22%
TOTAL	316,000	402,000	+ 27%

A comparison of annual transit trips per capita with other cities can also be made to check the reasonableness of the forecasts (see Table 9). The number of transit trips per capita per year in Denver increases from 37 currently to 65 under the plan case and 83 under the alternative scenario. This can be compared to Atlanta which has 65 trips/capita/year and the San Francisco CMSA which has 84. Ridership under the 2010 RTP case is then roughly equivalent to a low density city (Atlanta) with a rapid transit system. Under the higher density alternative scenario transit ridership increases to about that found in the San Francisco area.

Table 9

Annual Transit Trips Per Capita

Houston (1985)	21
Denver (1985)	37
Miami (1985)	39
Portland (1985)	49
Seattle (1985)	49
Atlanta (1985)	65
San Francisco (CMSA)(1985)	84
Chicago (1985)	105
San Francisco (Central)(1985)	232
New York (1985)	309
Denver (2010 RTP)	65
Denver (2010 LU/AQ)	83

In order to estimate the effects of the HOV system on auto occupancy, the work mode choice module was supplemented with an HOV choice model. The non-work mode choice modules were not similarly supplemented as it was assumed that the majority of non-work trips occur outside of the peak periods, when HOV restrictions would be in place, and thus would not be significantly affected by the HOV system. Surveys in other cities having HOV lanes supported this approach as little use of HOV lanes by nonworkers actually takes place. In addition, non-work auto occupancy is most highly affected by family size as these are mostly families traveling together. The work mode choice model incorporates drive alone, HOV, and transit travel times and costs into its probability function, and divides work trips into Drive Alone, Shared Ride 2, Shared Ride 3-plus, and Transit. Time savings using an HOV lane as compared to a general purpose lane are factored into the decision-making process. After incorporating the effects of the HOV system, it was found that the HOV system did not have a significant effect on regional work auto occupancy; however, the HOV system did increase the number of persons in three-plus person work-purpose carpools by 11.5 percent over the 2010 RTP, from 152,200 to 169,700 persons per day.

The auto occupancy model used does not reflect increased densities. Other factors than density probably play a much greater role in inducing people to rideshare, including: auto ownership and availability, working for a large company, and working in close proximity to

other individuals in the same household. Auto occupancy for non-work trips is a function of family size and, as such, should be relatively constant.

Network Assignment and Analysis

The federally released computer programs were used by DRCOG for building and processing both the highway and transit networks at the traffic zone level. On the highway side, diversion off freeway facilities onto arterials is accomplished using congestion diversion curves to calculate travel times under congested circumstances. Congested speeds from the peak highway assignments are compared to initial estimates of the speeds used in trip distribution/mode split calculations. This typically results in two to three model reruns before highway-side equilibration was reached. Similarly, a check was made to insure adequate transit capacity for projected demand. Assigned transit passenger volumes were translated by RTD staff to bus fleet size using RTD policy-adopted loading standards and vehicle capacities.

Vehicle miles of travel (VMT) between the two scenarios are effectively unchanged despite the slight increase in population and employment in the LU/AQ scenario. Both scenarios generated approximately 63.5 million VMT daily. VMT in land use/air quality alternative was 0.2 percent higher than in the 2010 RTP scenario. This can be compared to the increase of population of 1.3 percent and increase in employment of 3.1 percent in the modeling area in the land use/air quality alternative. Table 10 shows the percent of the system operating over capacity. The percent of VMT experiencing congestion increases from 32 percent to 45.1 percent. The average speeds decrease by 9 to 10 percent during the peak periods. This increases daily vehicle hours of travel (VHT) by approximately 8 percent.

Table 10

Percent of System Operating Over Capacity (Level of Service E-F)

Peak Period Level-of-Service	2010 RTP	2010 LU/AQ	
Freeways:			
% of Roadway Mileage	24.8%	28.6%	
% of VMT	33.6%	53.6%	
Arterials:			
% of Roadway Mileage	13.2%	15.8%	
% of VMT	30.5%	38.6%	
Overall:			
% of Roadway Mileage	14.6%	17.2%	
% of VMT	32.0%	45.1%	
AM Peak Avg. Speed	23.8 mph	21.4 mph	-10.1%
PM Peak Avg. Speed	22.3 mph	20.3 mph	- 9.0%
All Day Avg. Speed	26.7 mph	24.7 mph	- 7.3%
Daily VHT	2,382,000	2,575,500	+ 8.1%

EFFECT ON AIR QUALITY

This chapter summarizes the results of the air quality estimates modeling for the two scenarios considered in the Land Use/Air Quality Sensitivity Analysis. The Alternative Land Use/Air Quality scenario and the 2010 RTP scenario were modeled by the Colorado Health Department to determine the ozone, carbon monoxide, PM10, and nitrogen dioxide ambient air quality levels associated with each scenario.

Carbon Monoxide

The levels of carbon monoxide associated with each scenario are indicated in Table 11. The Denver Central Business District (CBD) remains the site with the highest concentrations. The relevant federal standard for carbon monoxide is 9 ppm over an eight hour period.

Table 11

Carbon Monoxide Concentrations

2010 RTP	Alt. Scenario	Standard
4.8 ppm	6.5 ppm	9 ppm

The Alternative Land Use/Air Quality Scenario results in significantly higher levels of carbon monoxide since there is more congestion in the Denver CBD under this scenario than with the 2010 RTP scenario. However, neither scenario violates the federal standard.

Ozone

The currently available ozone model does not allow prediction of specific levels of ozone; however, it does predict the hydrocarbon missions that must be reduced in order to achieve the standard, or the mount of hydrocarbon emissions that can be tolerated until a violation is expected in a specific corridor between the CBD and an outlying area. These corridors are called trajectories.

Three trajectories were modeled in this exercise; from the CBD to Boulder, from the CBD to the new airport, and from the CBD to Highlands Ranch. Table 12 contains a comparison of the likelihood of a violation, if any, in each trajectory for the 2010 RTP and the alternative scenario. In both cases where a violation is possible, the expected violation would be marginal.

PM10

Model results are often best used to compare one scenario to another scenario instead of predicting absolute values. The PM10 (small particulate) model calibration indicates that the model significantly overpredicts the annual average concentration by approximately 50 percent. The model calibration also indicates that the 24-hour concentrations are about 10 percent higher than actual 1986 monitored concentrations. As such the results should be

viewed as indications of a problem needing further exploration rather than an identification of specific predicted results.

The PM10 (small particulate) modeling completed for this exercise resulted in no significant difference in concentrations between the alternatives. The alternative scenario resulted in a 2 percent higher maximum concentration than the 2010 RTP; however such a small difference is less than the range of accuracy of the model. The modeled 24-hour concentrations are presented in Table 13. Both the 2010 RTP and the alternative scenario result in significant violations of the 24-hour standard; however, the area that experiences violations is slightly larger in the 2010 RTP than the alternative scenario.

Table 12

Possibility of Ozone Violation

Scenario	CBD to:		
	Boulder	Airport	Highlands
2010 RTP	No	Yes	No
Alt. Scenario	No	No	Yes

Table 13

PM10 Concentrations - 24 Hour Average

2010 RTP	Alt. Scenario	Standard
272 mg/m3	278 mg/m3	150 mg/m3

Annual maximum concentrations are also expected to be similar for the two transportation datasets (see Table 14).

Table 14

PM10 Concentrations - Annual Average

2010 RTP	Alt. Scenario	Standard
90 mg/m3	91 mg/m3	50 mg/m3

It is apparent from the similarity in forecast concentrations for both scenarios that PM10 is not sensitive to vehicle operating characteristics. However, it is sensitive to the total VMT, which does not vary significantly between the two scenarios.

It is important to note that these values should not be compared to the results of the PM10 SIP modeling that is currently underway for the State Air Quality Implementation Plan. Different meteorological data, as well as more detailed source contribution evaluations, are being completed as part of the SIP modeling process and will result in somewhat different forecast concentrations of PM10.

Nitrogen Dioxide

Using a conservative rollback modeling technique, the projected nitrogen dioxide concentrations for the two transportation datasets at the CAMP monitoring station in the CBD were modeled. The results are summarized in Table 15.

Table 15

Nitrogen Dioxide Concentrations - Annual Average

2010 RTP	Alt. Scenario	Standard
.058 ppm	.059 ppm	.053 ppm

It should be noted that the rollback technique is not sensitive to differences in spacial distribution; therefore, the effects of the spatial difference between the two transportation datasets is not adequately analyzed. Also, since the two datasets produce concentrations that are only slightly higher than the standard, a more detailed modeling technique would be required to determine if either of these two scenarios would cause an actual exceedance of the standard.

FINDINGS AND CONCLUSIONS

Findings

Concentrating development in the transit corridors as postulated in the higher density alternative scenario would result in the following changes in the year 2010 as compared to the low density current policy scenario:

- Trip making would decrease slightly (0.7 percent) from 3.83 to 3.80 trips/person/day.
- The average trip length of 8.5 miles would not change. While peak period trip lengths would decline by between 4 and 5 percent, the off-peak trip lengths (reflecting mainly non-work trips) actually would increase by 3.6 percent.
- Transit patronage would increase 26.9 percent resulting in 402,000 rides per day. The overall mode share would increase from 4.0 to 4.8 percent. Work trip transit mode share would increase from 6.7 to 9.4 percent.
- Vehicle miles of travel would remain relatively unchanged. VMT per capita would decrease 1.0 percent.

- Average highway speeds would decrease by 9 to 10 percent during the peak periods.
- The percent of VMT experiencing congestion would increase from 32 percent to 45.1 percent.
- Carbon monoxide levels would increase, but would remain well below the federal standard in both cases.
- Violations of the PM10 standard may occur with both scenarios; however, there would be no significant difference in the degree of violation between the two scenarios.
- Marginal violations of the ozone standard may occur with both scenarios.
- Violations of the nitrogen dioxide standard may occur under both scenarios; however, additional analysis using a more accurate model should be undertaken before reaching a conclusion.

Conclusions

- Changing development patterns by concentrating employment growth along transit corridors to the degree used in this study did not improve air quality.
- The relatively short (20 year) time horizon used in this study did not allow for major redevelopment to occur. As such, the existing urban fabric was assumed to remain in place and the study dealt only with the growth increment. Not moving existing residences and jobs minimized the air quality difference measured between the two scenarios. As 69 percent of residential locations and 59 percent of the job locations in 2010 are already in place, the relative impact of even large changes in the location of projected growth is minimized.
- Even though 40 percent of the expected population growth was concentrated in the transit corridors under the alternative scenario, the larger concentration of 80 percent of employment growth in the transit corridors lead to an inbalance of population-to-employment. Both population and employment need to be equally concentrated in the transit corridors. In the alternative higher density development pattern tested, because substantial employment growth was allocated to the transit corridors without equivalent redistributed population, a greater spacial separation between population and employment resulted than in the base 2010 RDF/RTP planned suburbanization case. This spacial separation led to increased miles of travel (i.e., longer trip lengths) for non-peak period, non-work trips which eliminated much of the benefit gained in transferring peak-period drive alone work trips to transit and carpooling.
- Transit patronage increased significantly – from 316,000 to 402,000 riders per day between the 2010 RDF/RTP and 2010 LU/AQ alternative. Overall, 4.8 percent of trips in the LU/AQ alternative use transit. Factors which mitigated against a larger transit mode share included:

- Increased congestion resulting from the assumed reduced roadway network and higher land use densities in the LU/AQ alternative was of limited benefit in increasing transit patronage. In both scenarios the bulk of transit service is provided by buses operating on-street. These buses operating in mixed traffic flow were slowed proportionately due to increased arterial congestion. Bus services affected by congestion included on-street feeder services to the rail facility. Only for the rail line-haul portion of the transit trip was congestion a benefit in inducing travelers to use transit.

- Placing development within one mile of a rapid transit line did not assure good transit access. The resulting densities were too low to assure walk access to the rapid transit system. The majority of development in the corridors was still beyond walking distance to a station. Many of the residents and employees within the rapid transit corridor were dependent upon feeder buses or park and ride lots to access the rail system. Moving more employment to the immediate vicinity of a transit station (i.e., within one-third of a mile, the assumed maximum walking distance) or provision of small-area circulator buses feeding the transit station might increase transit ridership.

- Designing the bus service to feed the rapid transit system adversely impacts cross-town trip making.

- The rapid transit and HOV systems were radial in nature, mainly serving trips to and from the central area.

- Provision of transit improvements is a necessary but not sufficient condition to cause a large increase in transit ridership. Incentives to use transit such as employer subsidized bus passes, and bus priority lanes intersecting a rapid transit corridor and disincentives to use the private auto such as increased parking costs and higher fuel costs appear necessary if a large shift to alternative modes is to occur.

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Title: SPECIAL EVENTS AND CARBON MONOXIDE VIOLATIONS: TSM, CROWD CONTROL, ECONOMICS, AND SOLUTIONS TO ADVERSE AIR QUALITY IMPACTS

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ABSTRACT

This paper examines issues involved with the staging of short-term special events, including regulatory concerns, Transportation Systems Management (TSM), crowd control, carbon monoxide (CO) incidents, and economics. The paper then investigates five of these events in the Twin Cities Metropolitan Area of Minneapolis and St. Paul. While TSM efforts can improve traffic flow during special events, the unplanned nature of some of these events, lack of integrated interjurisdictional coordination, and perceived financial benefits led to CO incidents. Impacts of these incidents may be felt area-wide and have economic and policy costs not usually considered. Therefore, special efforts need to be made to control the impacts of these events on air quality levels.

INTRODUCTION

Special events require special Transportation System Management (TSM) actions to control their impact on the transportation system. While literature exists on incident and special event control for improved TSM actions, readily available information does not examine the link between special events and carbon monoxide (CO) incidents. (For purposes of this paper, an "incident" is an occurrence in which the Minnesota standard of 9.0 parts per million (ppm) or the U.S. standard of 9 ppm is exceeded or violated.) This paper characterizes three types of special events: short-term repeating, anticipated unique events, and unplanned events and their impacts in the Twin Cities Metropolitan Area. Each presents different problems for TSM and for CO control.

THREE TYPES OF SPECIAL EVENTS

Short-term Repeating Special Events

Short-term repeating special events, such as festivals, fairs, and athletic meets are considered beneficial to the economy of the area in which they are held, since they bring new visitors. They also bring unwanted side effects. These include additional costs for traffic and crowd control, in the form of special signage, added police, and overtime duty for traffic engineering and other public works personnel. A less apparent impact they bring is they can result in adverse air quality impacts.

Anticipated Unique Events

These considerations also enter into other types of special events, such as narrowing of capacity due to temporary construction, official visits of foreign dignitaries, and one-time sports events. While these types of events can considerably disrupt the transportation system, they are easier to plan for, and their impacts tend to be more controllable.

Unplanned Events

The third category of special events are ones whose impacts are not necessarily anticipated, nor the impacts fully known, because they occur without consent of the government of the affected area. Examples of these types of special events are demonstrations and warm-weather cruising by automobile drivers. While authorities do have published strategies to deal with anticipated crowds of varying sizes, minimizing the TSM and CO problems of the situation is possible only if these events repeat in the same location under similar circumstances.

PREVIOUS INFORMATION ON SPECIAL EVENTS AND TSM

The traffic management of incidents and special events has been a subject of considerable research interest in the last 10-20 years, with an emphasis on management of freeway emergencies (1). As noted by Dudek (2), special events, even with the best of planning, may still result in traffic congestion because drivers are unaware of the extent of congestion along particular roadways leading to the events, or the events themselves are one-of-a-kind. Other work published by the Transportation Research Board indicates that one special event, a system of off-site ticket sales in which a guaranteed remote lot parking spot,

bus transportation to the event, and admission were all included in one ticket, alleviated congestion (3). Recent work on special events indicates that interagency or intercity cooperation may be the key to managing the events, an approach that requires surrendering some independence for the sake of area-wide TSM (4).

SPECIAL EVENTS IN THE TWIN CITIES AREA

Short-term Repeating Special Events

Short-term repeating special events have become common in the Twin Cities area. These events only last one or a few days. Typical yearly street festivals in 1985-9 and their respective attendance levels include the Cinco de Mayo festival (8,000) across the river from downtown, the Grand Olde Days festival (300,000 on one day) along Grand Avenue in the Crocus Hill and Macalester-Groveland neighborhoods, and the Taste of Minnesota (35,000 average, 100,000 on July 4) by the Capitol near downtown, all in St. Paul. In Minneapolis the Uptown Art Festival is held each year at the high-volume Hennepin Avenue and Lake Street intersection, with a total attendance of 250,000. All of these events close off major streets to traffic. The Taste of Minnesota also leads to interruptions in access onto Interstate 94 freeway entrance ramps.

Annual short-term repeating special events that last a week or longer but have varying locations for events and parades include the Winter Carnival (15,000 average, 100,000 for parades) in St. Paul in February, and the Aquatennial Festival in July in Minneapolis. Most of the traffic for these events originate in their respective cities. The State Fair (207,000 on one day), which is not located officially in any city or county, but on a special tract of land which borders the city of St. Paul on the south and east, the Village of Falcon Heights on the north and east, and the University of Minnesota on the west, is a yearly 12-day event. Its traffic is dispersed to St. Paul and surrounding suburbs. There are also short-term repeating special events which occur every few years rather than annually. These include ones which last a few days, such as the meeting of the National Street Rod Association at the State Fairgrounds. This event also attracts mobile source activity near the intersection of Snelling and University Avenues. Like the Hennepin-Lake intersection, a monitor there periodically records CO violations.

Anticipated Unique Events

Temporary events in recent months include street closures due to sewer construction, the visit of Mikhail Gorbachev to the Twin Cities, and the Olympic Festival. Sewer construction has lasted for several years. Temporary freeway construction lasting more than a year is coordinated with the State of Minnesota Pollution Control Agency (MPCA) to ensure that CO standards are not violated. Gorbachev's visit will probably remain unique to Twin Cities history. Security considerations ensured that every aspect of the visit included TSM planning. Barring a successful bid for the Superbowl, events such as the Olympic Festival, which do not draw major crowds to any one event, will not likely occur in the near future.

Unplanned Events

Spontaneous demonstrations include marches and protests on political issues, such as U.S. involvement in Central America, and environmental ones, such as air pollution, both at the Hennepin-Lake intersection. Others, mostly political, are held in downtown Minneapolis. Celebrations also fall into this category, such as the one held adjacent to the Metrodome on the edge of downtown Minneapolis when the Minnesota Twins won the World Series. Warm-weather cruising near the Hennepin-Lake intersection occurs in the spring and early summer, when cars cruise from the intersection to Lakes Calhoun and Harriet and Lake of the Isles, some on regular city streets and some on parkways.

REGULATORY HISTORY

The Clean Air Act Amendments (CAA) of 1977 required that areas which would not meet CO standards by December 31, 1982 adopt an inspection/maintenance program (I/M) for automobile emission control systems. They would then be required to meet the standards by December 31, 1987. By mid-1990, however, the United States Environmental Protection Agency (EPA) listed over 29 areas which still did not meet CO standards and would have to have an enhanced (strengthened) I/M program.

Failure to Meet 1982 Deadline

Some 1982 areas failed to meet their deadline because they relied on the Federal Motor Vehicle Emissions Control Program (FMVECP), which tightened emission standards. Implementation of the FMVECP was delayed a year by the EPA. Other 1982 deadline areas failed to meet the deadline because they did not implement all TSM measures required by the CAA (called Transportation Control Measures or TCM's). Some 1982 areas which did not meet the deadline relied on modeling which assumed unrealistically high ambient air temperatures for vehicle operation, based on EPA procedures. (These procedures test emissions of cars at higher temperatures than they are actually driven in cold-weather states under worst-case CO conditions.)

Areas Subject to Sanctions

Areas which failed to submit an acceptable State Implementation Plan (SIP) to meet the 1982 or 1987 deadlines or failed to make good faith efforts to implement the SIP were subject to potential and actual sanctions. These sanctions were left somewhat to the discretion of the EPA under CAA provisions. Sanctions included: bans on stationary source construction; halts of federally funded transportation projects except for those of mass transit, safety, or TCM's; cutoffs of sewer construction funds; and cutoffs of program grants to air quality agencies. Lesser known ones included refusal to allow new water or sewer hookups, and refusal to give consent to bonds needed for construction of inner city housing. The EPA and Federal Highway Administration (FHWA) have often disagreed in the past as to whether the transportation sanctions are enforceable without FHWA consent.

CO NONATTAINMENT IN THE TWIN CITIES AREA

The Twin Cities Metropolitan Area surrounding the cities of Minneapolis and St. Paul has a population exceeding 2,240,850. Modeling for the SIP predicted that the FMVECP and TCM's (one-way pairs, traffic signal timing changes, and improved transit service) would enable the area to meet the 1982 deadline. Except for the Snelling-University intersection in the St. Paul Midway area, located between the two downtowns, all monitors showed the expected modeled compliance by the deadline.

Nonattainment Status of the Intersection

The MPCA with the Metropolitan Council (the metropolitan planning organization), submitted a new SIP amendment which included intersection signal timing changes for the intersection and surrounding ones. The changes would become operative when CO reached a certain level. Attached was a request to redesignate the entire seven-county Twin Cities Metropolitan Area to attainment for CO standards, except for the Snelling-University intersection, since in previous years the whole Area was designated as the CO nonattainment area to watch the Metropolitan Council's jurisdiction.

The EPA modified the request. It approved instead a cross-shaped area in St. Paul considerably larger than the intersection. In response, the MPCA, in cooperation with the Minnesota Department of Transportation (MN/DOT), posted additional CO monitors in the cross-shaped area, and at the Hennepin-Lake intersection in Minneapolis to show that the EPA was in error. Instead of compliance, a number of the monitors (including the Hennepin-Lake one) showed violations of the CO standard. At the EPA's urging and under the threat of possible EPA sewer and/or air program sanctions, the MPCA, MN/DOT, and the Metropolitan Council won legislative approval of an I/M program. It will begin in the summer of 1991.

INVESTIGATION OF CO INCIDENTS

In Spring of 1990, the author investigated five CO incidents related to special events to determine whether such incidents could be prevented in the future through improved TSM. Controlling special events at the source appeared to be a more equitable and less costly way to control CO than tightening the whole future I/M program. If so, these types of events would not tighten the I/M program's cutpoint levels to achieve a reduction in emissions. The author interviewed governmental officials, peace officers in charge of traffic management and those heading police reserve activities, and traffic engineering staff to obtain a complete picture of causes and possible preventions of the incidents.

The events, occurring in 1985 and 1989, included two incidents affecting the Snelling-University intersection monitor south of the State Fairgrounds in St. Paul, one affecting the Snelling-Larpenteur intersection monitor in Falcon Heights north of the Fairgrounds, and one at the Hennepin-Lake intersection. All other CO incidents in 1985-9 (a total of 76 in the Twin Cities area), did not appear to be related to pinpointable special events, but to general traffic, pre-holiday shopping or traffic and inversions.

STREET RODS AND CRUISING

Alteration of Pollution Equipment

Two CO incidents were clearly related to a short-term repeating special event, the meeting of the National Street Rod Association in July of 1985, and again in 1989, at the State Fairgrounds. Each meeting drew over 100,000 participants and spectators. Members drove cars whose bodies were designed to look like older classic models. The vehicles had newer engines which were altered to provide added power or other features designed to increase particular performance aspects. Pollution control equipment was sometimes removed in this process. The exact amount of excessive CO produced is not known, but removal of a catalytic converter can increase CO production by 400%. The street rods were tuned to extremely high performance standards, perhaps reducing that percentage.

Mobile Source Activity by Street Rod Owners and Traffic Control

Street rods participating in the event were based over the entire Twin Cities area, but gathered for events by cruising north on Snelling Avenue to the Fairgrounds, and west and east on University Avenue. Traffic control problems were compounded by owners of the street rods on weekday mornings, who cruised north to the Fairgrounds in advance of the gate opening. Those that arrived early at the gates assured themselves of tree-shaded positions on the grounds. The traffic resulting from maneuvering for position backed southwards to the Snelling-University intersection.

Spectators and Traffic Control

The cruising attracted spectators, who cruised in regular cars next to the street rods. Sidewalk-sitters parked near the Snelling-University intersection, walked to it, lawn chairs in tow, sitting as close to the curb as possible to see the maximum number of street rods. Spectators also drove to the Fairgrounds to view the street rods after paying an admission price of $8.00. The free viewing at the intersection was therefore more appealing for many.

The St. Paul Police's, Police Reserves', and Neighborhood Assistance Officers' efforts to control traffic by preplanning (through use of public events control guideplans) and spontaneous problem-solving (banning left-turns without official pre-permission to do so) were somewhat thwarted by spectators. Some tried to pour bleach under the tires of street rods. The bleach caused tires to warm up rapidly, producing clouds of white smoke and extremely rapid acceleration. This led to some loss of control in steering, and danger to persons on the sidewalk. Failure to respond to the requests to do "bleach burns" resulted in threats to "key" a car -- ruining the finish by scratching it with a key. In 1989 the cruising street rods and spectators were finally dispersed by Public Works department trucks, which were mobilized to water the streets. The water caused spots, temporarily marring the highly polished wax finish of the street rods.

STATE FAIR OPERATIONS

The Minnesota State Fair is the 4th largest in the nation, with the largest paid attendance of all state fairs, recording over 153,000 on a weekday in 1989, and the 207,000 noted before on a weekend day. It is owned and operated by the Minnesota State Agricultural Society, a quasi-governmental organization governed by elected representatives from county fairs. It passes its own ordinances, and contracts for police patrols. With the exception of the traffic it generates, it is an extremely popular institution with almost all Minnesotans, and with visitors from surrounding states.

Traffic Control at the Fair

During the 12 days of the Fair, traffic is directed from the Fairgrounds to the outside by a team of off-duty peace officers (licensed police) from communities around the state, headed by an off-duty Ramsey County Sheriff's officer also hired by the Fair. The rest of the year, the St. Paul Police Department patrols the grounds and tries to handle traffic from events, such as the street rods or visitors to the annual July 4th fireworks show. Falcon Heights has in the past contracted with the Ramsey County Sheriff for traffic control during the 12 days. For 1990 and future years, its contract is with Roseville, a city whose southern border is several blocks north of the Fairgrounds. Roseville is also in Ramsey County.

Most of the traffic leaving the Fairgrounds heads to the south, to St. Paul. It is headed directly at the Snelling-University intersection. This is partly due to the general solution used by the Ramsey County and Roseville police forces of "sending the traffic elsewhere." It is also due to the large crowds which find Fair ingress easiest from the Snelling Avenue exit of Interstate 94.

Parking Management at the Fair

Parking space on the Fairgrounds is inadequate, with room for at most 15,000 cars. Spaces in lots probably turn over at least once a day, but parking is free and lots often fill by 10:30 on weekends. One-third of all fairgoers are from rural areas located many hours from the Fair. They feel uncomfortable trying to find a parking space elsewhere. Like other fairgoers faced with filled on-site lots, they prefer to cruise the Fairgrounds and the surrounding neighborhood. Many make use of a St. Paul policy which permits paid parking on lawns of fair neighborhood residences during the 12 days. The off-street parking, which includes officialy tolerated curb-jumping to access the lawns, slows traffic and probably contributes to pedestrian safety problems.

The Fair has tried a number of approaches to manage the parking, from agreements with the University of Minnesota, to leasing of remote lots, to rideshare arrangements. Agreements with the University of Minnesota involve use of the parking lots adjacent to the Fairgrounds which are part of the St. Paul portion of the Twin Cities campus. (The University is similar to the Fair in that with the exception of some legislative funding approvals, it is largely independent of any jurisdiction except the State of Minnesota.) Spaces in its lots, normally in great demand, are available because the University is not in session at the time of the Fair.

Remote lots are leased by the Fair in 11 locations, serving 10,000 vehicles. Parking at them is free to the public, but there is a charge for bus service to the Fairgrounds. While buses travel between the lots and the Fairgrounds on a regular basis, arrival and departure times are not definite because the buses themselves become enmeshed in Fair traffic. The Fair is attempting to find additional remote lots. An attempt by the Fair to display a portable changeable message sign directing persons to remote lots was withdrawn after St. Paul received a complaint about the noise the generator for it made from a nearby homeowner. More remote lots are needed, especially south of the Snelling-University intersection.

Ridesharing at the Fair

The Fair has contacted Minnesota Rideshare, part of the Metropolitan Transit Commission (MTC), and the Regional Transit Board, which governs the MTC, to improve ridesharing among 2200 permanent and 3800 temporary employees during the 12 days. Providing incentives for carpooling by giving close-in spots to employees who rideshare, and working with the MTC to improve already increased bus service to the Fair are strategies it is actively pursuing.

TRAFFIC BY THE LAKES

Determining the Impact of the Aquatennial

The author also investigated the CO incident at the Hennepin-Lake monitor in Minneapolis apparently caused by an event of the Aquatennial, the Minneapolis festival centered around its lakes. After talking to the Minneapolis Police Reserves and to Minneapolis Traffic Engineering, it was apparent that the event did not cause the incident. The event was held downtown, and not near the intersection. It was unlikely that the parade sent traffic far south enough to affect the intersection.

Lake Cruising

Further discussions revealed that the day in question was a perfect July day with cooler-than-usual temperatures in the 70's. Much of the lake traffic was due to cruising, an unplanned special event that occurs frequently near the lakes. The traffic on the lake parkways was managed by the Minneapolis Park Police. (Except at upper levels of command, they are governed by the Minneapolis Park Board, a separate public entity.) Parks surrounding the lakes were closed in late evening, leading to cruising of the lake parkways. If the Minneapolis Park Police then restricted parkway traffic to stop cruising, the cars moved west to the Hennepin-Lake intersection, where they became a problem for the Minneapolis Police. Given the average two-way ADT of 32,000 through the intersection, additional traffic from the lakes tended to increase CO levels there, especially at night. Most CO incidents occur during late-night hours at this intersection.

SEWER CONSTRUCTION AND CO VIOLATIONS

One "special event" became a CO incident by surprise. In late October 1989, many monitors around the State of Minnesota recorded CO incidents as record-breaking warm air combined with a statewide inversion to trap CO. Even

"background" nonhotspot monitors recorded incidents due to traffic and the unusual meteorology. None of the incidents could be explained in any other way, with one exception.

EPA Required Sewer Construction

The one explainable CO incident occurred in downtown St. Paul. The monitor, located on a one-way street, rarely recorded CO incidents. After investigation, the MPCA staff concluded that the incident was caused by rerouting of traffic from an interstate freeway exit to avoid temporary construction near the exit. More than 16,000 additional vehicles, many driven by persons unfamiliar with the area, at slower than normal speeds, were routed past the monitor by Mn/DOT. The construction was for mandated separation of storm overflow and regular sewers, required by the EPA.

METEOROLOGY AND REPEATING AND UNPLANNED SPECIAL EVENTS

All CO incidents for monitors in the Twin Cities, St. Cloud, and Rochester, Minnesota were examined for those years in which they were in operation from 1972, the year monitoring started through 1989, the last year of verified data. The aim of the examination was to determine what the possible role of meteorology was in creating patterns of incidents, compared to that played by the special events. The sheer volume of incidents (over 1500) make it difficult to analyze the meteorology in detail. Instead, the patterns of occurrence were examined.

In examining the dates of occurrence of the incidents, the author looked at a recurring "special event" that would especially affect monitors: Christmas shopping. While five incidents did occur on the day after Thanksgiving, the busiest shopping day of the year, this is not a high number. Monitors were very likely to show violations in the period two weeks before Christmas (18 in the period from December 10-17), and in the period right before Christmas (22 from December 18-24). Hotspot monitors usually showed several violations in the latter period if they had any in the former.

Traditional explanations based on meteorology would note that while Thanksgiving can sometimes have mild weather, December is almost always very cold in Minnesota. The atmosphere is also very stable. The December mean temperature for 1959 - 1988 is 19.3, the January temperature 12.9. The atmosphere is probably not more stable. While there are occasional inversions (often statewide in nature) which are correlated with CO incidents in January, the same type of pattern does not emerge for any particular weeks. More detailed examination of temperatures and wind direction and speed would be needed to come to a definitive conclusion about the effect of Christmas shopping or other special recurring event during the period of November through January.

All CO incidents were also examined to determine their correlation with cold weather and atmospheric stability, given the popular assumption that incidents are related to winter weather. While most do occur in colder temperatures, many of the 1500 incidents occur in temperatures above 60 degrees Farenheit. In the years for which summary temperature data are available, 1987-9, there were 10 out of 52 CO incidents where the temperature was above 60.

Of these 10, 8 occurred at the Lake and Hennepin monitor, leading credence to the possibility that the unplanned special event of cruising contributed more than meteorology.

RECOMMENDATIONS: COORDINATION FOR SPECIAL EVENTS

Handling Repeating Special Events

The previously mentioned CO incident to the north of the Fair at the Snelling-Larpenteur intersection monitor in Falcon Heights occurred the day the Fair attendance recorded a record 207,000 paid attendees. The cruising from the street rods led to violations at the Snelling-University monitor in 1985 and 1989. (A monitor malfunction made it impossible to determine if a similar incident occurred in 1982.) Thus repeating special events need special attention to avoid having them cause CO incidents.

A combination of police reserve officers, traffic control agents, regular police, or off-duty officers can be mobilized to handle large special events such as parades or festivals. This is now being done in some areas. To avoid conflicts on union issues, and to ensure that integrated work is done by all forces, these personnel need to be explicitly under one command, who can choose which ones to use and how to mobilize them. This is probably not feasible for smaller unplanned events, since city budgets do not allow routine traffic direction by police, given more pressing needs of increased crimes, and more violent crimes, which are of greater importance to the victims.

Sending the Traffic Elsewhere

Whether an event is repeating or not, long-term or one day, and planned or unplanned, traffic control techniques can be improved to deal with it provided political will and funding are available. "Sending the traffic elsewhere" can work provided it is evenly dispersed so as not to cause or aggravate an existing hotspot condition. (This technique, for example, was used by the Minneapolis Police Reserves to send cruising traffic celebrating the Twins victory to sites away from downtown. They forced celebrants involuntarily in four directions onto routes leading directly to interstate highways.) It is not a good planning tool for repeating special events, which need integrated advance planning to handle unexpectedly large crowds, such as occurred with the record attendance day at the Fair in 1989.

Restricting Certain Events or Actions

Banning certain events or actions is bound to be politically unpopular. Nevertheless, if the events are virtually uncontrollable, or lead to traffic control actions, such as lawn parking, which have safety or other adverse traffic management impacts, the temptation is strong to regulate the events. Many of these events (such as the State Fair) are immensely popular with the public. As indicated below, the financial impact of doing so may also outweigh the desire for control of CO incidents. Therefore, it is necessary to carefully investigate other TSM methods, coordination of forces, and methods of neighborhood cooperation to control the CO implications, since it is probably not desirable or possible to eliminate the events. For some events, such as the street rods, increased CO levels may not be controllable except by prohibiting the event.

ECONOMICS OF EVENTS

Most special events are categorized by promoters as contributing heavily to the local economy. The Olympic Festival, for example, was expected to contribute $23 million to the local economy. Its cost, however, is harder to determine. Expenditures by state and regional agencies and the University of Minnesota to speed up construction of new facilities and provide traffic management for the Olympic Festival are expected to exceed that figure. In the case of the National Street Rod Association meet, 90% occupancy for Twin City hotels and motels was not uncommon, so its economic impact was great. The Fair, while receiving no legislative appropriations, charged admission and space rental fees for the Fair and for use of the Fairgrounds. It ended 1989 on a strong financial note. While agencies do contribute financially to traffic management efforts, the special events run by them and their financial quasi-independence may make it more difficult to reach agreements with them or require financial commitments than if they were subject to the normal fiscal and legislative controls imposed on municipalities in the state.

The calculation for the cost of Christmas shopping cannot be easily made. Spinoff effects, such as revenue for cities in terms of meter parking fees and taxes on parking ramps would have to be considered. So would the secondary impacts of increased restaurant patronage, gasoline taxes, and other unusual expenditures that affect the local and national economies.

CONCLUSIONS

The management of special events to control CO incidents varies with the type of event, its proximity to a violating monitor, and the institutional arrangements for handling the traffic. Some events appear to have traffic and crowd control impacts which are virtually uncontrollable. If held near monitors, they require special institutional arrangements to avoid CO incidents. For Christmas shopping, as done abroad, these could include shuttle buses and other ridesharing arrangements to ferry shoppers and parcels to and from the stores.

These arrangements are especially critical when coordinating TSM from areas surrounded by multiple jurisdictions. Agreed-upon coordinators, a traffic management plan, and integrated police enforcement are the most important elements in preventing violations. Regular meetings of interjurisdictional task forces do much to establish good relations which can then be used when handling these events. Jurisdictions involved need to exercise some self-discipline, both in scheduling events, and dealing with their impacts on surrounding areas. They need to refrain from "sending the problem elsewhere" in hopes that it will disappear. Under certain conditions, it will reappear as a CO air quality incident. If it does, it will affect not only the area where the traffic was sent, but may result in sanctions or an overly tightened I/M program affecting jurisdictions far from the site.

Most special events will not result in a CO incident. Analysis of special events in the Twin Cities show local traffic flow problems on streets near monitors which extend onto the freeway entrance ramps, but the problems do not cause shock waves in traffic flow on the freeways. When the problems involve

both the freeways and the local streets, involve vehicles which are without operating pollution control equipment, or are during the worst-case meteorological season, the potential for incidents must of necessity increase.

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1987 CO Exceedances *

Date	Level	Temperature	Location
01-12-87	12.8 PPM	38 degrees F.	Duluth (314 W. Superior St.)
02-01-87	11.6 PPM	37 degrees F.	University & Lexington (1088 W. Univers
02-06-87	16.0 PPM	43 degrees F.	University & Lexington
02-06-87	10.2 PPM	43 degrees F.	Larpenteur & Snelling
02-06-87	13.7 PPM	43 degrees F.	University & Snelling (1549 W. Universi
02-07-87	10.6 PPM	43 degrees F.	University & Rice (117 W. University)
02-07-87	9.7 PPM	43 degrees F.	Nalpak Bldg. (333 Sibley Street)
02-09-87	10.1 PPM	41 degrees F.	University & Lexington
02-09-87	9.8 PPM	43 degrees F.	Larpenteur & Snelling
02-09-87	9.3 PPM	41 degrees F.	University & Snelling
02-19-87	9.9 PPM	38 degrees F.	University & Lexington
10-13-87	9.2 PPM	49 degrees F.	University & Lexington
11-02-87	9.9 PPM	61 degrees F.	Lake & Hennepin (3002 Hennepin Ave.)
11-13-87	12.0 PPM	41 degrees F.	Lake & Hennepin
11-13-87	11.4 PPM	43 degrees F.	St. Cloud (810 St. Germain Street)
11-13-87	9.0 PPM	48 degrees F.	University & Lexington
11-14-87	9.6 PPM	38 degrees F.	University & Lexington
11-30-87	9.2 PPM	31 degrees F.	University & Snelling
12-19-87	9.0 PPM	-------	Rochester (Broadway & 1st Street SE)
12-23-87	11.6 PPM	-------	Rochester

*The Levels reflect the highest 8-hour average exceedance for that date.

SOURCE: MINNESOTA POLLUTION CONTROL AGENCY

1988 CO Exceedances *

Date	Level	Temperature	Location
01-11-88	14.3 PPM	14 degrees F.	University & Lexington (1088 W. Unive
01-11-88	14.2 PPM	14 degrees F.	Lake & Hennepin (3002 Hennepin Ave.)
01-15-88	9.4 PPM	17 degrees F.	Lake & Hennepin
01-15-88	9.1 PPM	29 degrees F.	Lake & Hennepin
01-17-88	9.8 PPM	20 degrees F.	Lake & Hennepin
01-18-88	9.7 PPM	29 degrees F.	Lake & Hennepin
01-28-88	9.1 PPM	13 degrees F.	University & Lexington
01-28-88	9.4 PPM	8 degrees F.	Lake & Hennepin
05-20-88	10.7 PPM	78 degrees F.	Lake & Hennepin
06-05-88	9.2 PPM	78 degrees F.	Lake & Hennepin
08-15-88	9.6 PPM	94 degrees F.	Lake & Hennepin
09-17-88	9.3 PPM	81 degrees F.	Lake & Hennepin
10-14-88	9.7 PPM	58 degrees F.	Lake & Hennepin
11-03-88	9.9 PPM	48 degrees F.	Lake & Hennepin
12-19-88	9.6 PPM	34 degrees F.	Lake & Hennepin
12-30-88	9.1 PPM	14 degrees F.	Lake & Hennepin

*The Levels reflect the highest 8-hour average exceedance for that date.
SOURCE: MINNESOTA POLLUTION CONTROL AGENCY

1989 CO Exceedances *

Date	Level	Temperature	Location
01-04-89	11.4 PPM	23 degrees F.	University & Lexington (1088 W. Univers
01-04-89	9.9 PPM	28 degrees F.	Lake & Hennepin (3002 Hennepin Ave.)
03-10-89	9.9 PPM	38 degrees F.	Lake & Hennepin
03-27-89	10.1 PPM	53 degrees F.	Duluth (314 W. Superior St.)
07-08-89	9.6 PPM	79 degrees F.	Lake & Hennepin
07-20-89	10.8 PPM	76 degrees F.	University & Snelling (1549 W. Universi
07-23-89	9.7 PPM	73 degrees F.	Lake & Hennepin
07-23-89	11.3 PPM	73 degrees F.	Lake & Hennepin
09-02-89	10.3 PPM	57 degrees F.	Larpenteur & Snelling
10-23-89	9.9 PPM	55 degrees F.	Duluth
10-23-89	10.3 PPM	59 degrees F.	University & Snelling
10-23-89	9.2 PPM	72 degrees F.	Nalpak Bldg. (333 Sibley Street)
10-23-89	12.1 PPM	59 degrees F.	University & Lexington
10-24-89	10.7 PPM	58 degrees F.	Nalpak Bldg.
10-24-89	12.0 PPM	50 degrees F.	1829 Portland Avenue S.
11-24-89	9.4 PPM	30 degrees F.	Lake & Hennepin

*The Levels reflect the highest 8-hour average exceedance for that date.

SOURCE: MINNESOTA POLLUTION CONTROL AGENCY

AVERAGE TEMPERATURE (deg. F)

MINNEAPOLIS - ST. PAUL, MINNESOTA

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC	ANNUAL
*1959	10.6	17.2	32.0	47.1	60.6	70.6	74.5	75.2	63.1	44.4	[illegible]	[illegible]	[illegible]
1960	17.5	17.8	19.8	45.9	57.0	63.8	71.7	72.1	61.8	48.7	[illegible]	[illegible]	[illegible]
1961	12.0	22.5	32.0	38.5	54.7	68.1	70.6	71.3	59.1	52.2	[illegible]	[illegible]	[illegible]
1962	7.1	11.7	24.5	42.2	60.6	66.2	67.5	68.3	56.4	50.2	[illegible]	[illegible]	[illegible]
1963	2.9	12.1	34.2	47.3	55.4	69.8	73.5	68.9	62.2	46.1	[illegible]	[illegible]	[illegible]
1964	20.0	23.9	25.8	46.8	61.5	66.7	76.0	68.5	58.9	48.2	[illegible]	[illegible]	[illegible]
1965	10.0	11.8	19.5	41.8	58.7	66.5	70.5	68.6	52.6	50.7	[illegible]	[illegible]	[illegible]
1966	3.3	16.3	35.8	42.2	53.6	68.4	76.8	68.2	60.3	47.5	[illegible]	[illegible]	[illegible]
1967	14.6	8.7	29.8	44.7	52.3	66.9	68.8	66.2	60.3	46.3	[illegible]	[illegible]	[illegible]
1968	14.3	15.2	38.8	46.5	53.4	67.2	71.1	70.7	61.1	50.7	[illegible]	[illegible]	[illegible]
1969	9.4	19.3	24.1	49.3	60.6	61.8	73.6	74.2	63.0	46.5	[illegible]	[illegible]	[illegible]
1970	5.6	15.4	26.0	46.1	58.5	71.2	75.2	71.9	61.2	49.6	[illegible]	[illegible]	[illegible]
1971	6.5	17.0	28.0	47.0	55.4	71.5	68.8	69.6	62.8	51.4	[illegible]	[illegible]	[illegible]
1972	5.5	10.5	26.5	41.9	61.3	66.0	68.5	69.8	57.9	43.7	[illegible]	[illegible]	[illegible]
1973	17.4	21.6	40.2	44.4	55.2	69.5	73.8	73.4	60.1	53.8	[illegible]	[illegible]	[illegible]
1974	11.9	16.9	29.5	47.1	54.4	65.5	76.6	67.3	55.3	49.8	[illegible]	[illegible]	[illegible]
1975	14.5	15.5	22.1	38.9	60.9	68.8	76.3	71.7	57.7	52.8	[illegible]	[illegible]	[illegible]
1976	11.6	27.8	31.4	51.8	58.9	71.7	76.1	73.3	61.8	44.6	[illegible]	[illegible]	[illegible]
1977	0.3	22.7	37.5	53.0	66.9	68.4	74.8	66.1	60.5	47.1	[illegible]	[illegible]	[illegible]
1978	5.5	11.6	30.0	45.2	61.8	67.8	71.1	72.2	67.3	49.8	[illegible]	[illegible]	[illegible]
1979	3.2	10.0	26.9	44.0	55.5	67.3	73.6	69.9	63.4	46.6	[illegible]	[illegible]	[illegible]
1980	15.3	15.3	27.3	49.2	61.5	67.6	75.2	70.7	59.5	45.1	[illegible]	[illegible]	[illegible]
1981	18.0	23.4	37.7	49.1	57.1	67.0	70.9	69.3	60.0	46.7	[illegible]	[illegible]	[illegible]
1982	2.3	15.8	29.0	43.8	62.5	63.7	75.6	71.8	60.9	50.3	[illegible]	[illegible]	[illegible]
1983	19.6	26.9	34.2	42.3	54.6	68.0	77.2	76.8	62.6	48.4	[illegible]	[illegible]	[illegible]
1984	12.0	27.5	24.8	47.1	56.0	69.7	72.2	73.5	57.2	50.1	[illegible]	[illegible]	[illegible]
1985	10.1	16.5	35.6	52.1	62.2	63.9	73.9	67.6	58.6	[illegible]	[illegible]	[illegible]	[illegible]
1986	17.5	15.7	33.5	49.6	59.4	68.6	73.6	67.1	59.8	[illegible]	[illegible]	[illegible]	[illegible]
1987	21.2	31.6	36.7	53.5	63.5	72.6	76.0	69.0	62.5	[illegible]	[illegible]	[illegible]	[illegible]
1988	10.4	13.9	33.8	47.4	65.4	74.4	78.1	73.9	62.4	44.0	[illegible]	[illegible]	[illegible]
Record Mean	12.9	17.1	30.0	46.0	58.2	67.9	73.2	70.7	61.5	49.1	[illegible]	[illegible]	[illegible]
Max	21.5	28.7	38.3	55.8	68.5	77.8	83.3	80.[illegible]	[illegible]	59.0	[illegible]	[illegible]	[illegible]
Min	4.3	8.5	21.7	36.3	47.9	58.0	63.1	60.[illegible]	[illegible]	40.3	[illegible]	[illegible]	[illegible]

CO NAAQS EXCEEDANCES AND ASSOCIATED TEMPERATURE DATA
IN THE TWIN CITIES METROPOLITAN AREA (CONTINUED)

KEY:

INTERSECTIONS	CITY
U & Lex = University and Lexington Avenues	St. Paul
Larp & Snel = Larpentuer and Snelling Avenues	St. Paul
U & Snel = University and Snelling Avenues	St. Paul
333 Sibley = 333 Sibley Street	St. Paul
Lake & Henn = Lake Street and Hennepin Avenue	Minneapolis
1829 Portland = 1829 Portland Avenue	Minneapolis
U & Rice = University Avenue and Rice Street	St. Paul

1987-1989

CO NAAQS EXCEEDANCES AND ASSOCIATED TEMPERATURE DATA IN THE TWIN CITIES METROPOLITAN AREA

	------data------		----Averages----	
	8 hr CO	Temp.	8 hr CO	Temp.
1987 U & Lex	11.6	37		
1987 U & Lex	16.0	43		
1987 Larp&Snel	10.2	43		
1987 U & Snell	13.7	43		
1987 U & Rice	10.6	43		
1987 333Sibley	9.7	43		
1987 U & Lex	10.1	41		
1987 Larp&Snel	9.8	43		
1987 U & Snell	9.3	41		
1987 U & Lex	9.9	38		
1987 U & Lex	9.2	49		
1987 Lake&Henn	9.9	61		
1987 Lake&Henn	12.0	41		
1987 U & Lex	9.0	48		
1987 U & Lex	9.6	38		
1987 U & Snell	9.2	31	10.6	42.7
1988 U & Lex	14.3	14		
1988 Lake&Henn	14.2	14		
1988 Lake&Henn	9.4	17		
1988 Lake&Henn	9.1	29		
1988 Lake&Henn	9.9	20		
1988 Lake&Henn	9.7	29		
1988 U & Lex	9.1	13		
1988 Lake&Henn	9.4	8		
1988 Lake&Henn	10.7	78		
1988 Lake&Henn	9.2	78		
1988 Lake&Henn	9.6	94		
1988 Lake&Henn	9.3	91		
1988 Lake&Henn	9.7	88		
1988 Lake&Henn	9.9	48		
1988 Lake&Henn	9.6	34		
1988 Lake&Henn	9.1	14	10.1	39.3
1989 U & Lex	11.4	23		
1989 Lake&Henn	9.9	28		
1989 Lake&Henn	9.9	38		
1989 Lake&Henn	9.6	79		
1989 U & Snell	10.8	76		
1989 Lake&Henn	9.7	73		
1989 Lake&Henn	11.3	73		
1989 Larp&Snel	10.3	57		
1989 U & Snell	10.3	59		
1989 333Sibley	9.2	72		
1989 U & Lex	12.1	59		
1989 333Sibley	10.7	58		
1989 1829 Port	12.0	50		
1989 Lake&Henn	9.4	30	10.3	51.4

	--Sorted data--	
	8 hr CO	Temp.
1987 U & Lex	16.0	43
1988 U & Lex	14.3	14
1988 Lake&Henn	14.2	14
1987 U & Snell	13.7	43
1989 U & Lex	12.1	59
1987 Lake&Henn	12.0	41
1989 1829 Port	12.0	50
1987 U & Lex	11.6	37
1989 U & Lex	11.4	23
1989 Lake&Henn	11.3	73
1989 U & Snell	10.8	76
1988 Lake&Henn	10.7	78
1989 333Sibley	10.7	58
1987 U & Rice	10.6	43
1989 Larp&Snel	10.3	57
1989 U & Snell	10.3	59
1987 Larp&Snel	10.2	43
1987 U & Lex	10.1	41
1987 Lake&Henn	9.9	61
1989 Lake&Henn	9.9	38
1988 Lake&Henn	9.9	48
1987 U & Lex	9.9	38
1989 Lake&Henn	9.9	28
1987 Larp&Snel	9.8	43
1988 Lake&Henn	9.8	20
1989 Lake&Henn	9.7	73
1988 Lake&Henn	9.7	29
1987 333Sibley	9.7	43
1988 Lake&Henn	9.7	88
1988 Lake&Henn	9.6	34
1988 Lake&Henn	9.6	94
1987 U & Lex	9.6	38
1989 Lake&Henn	9.6	79
1988 Lake&Henn	9.4	8
1989 Lake&Henn	9.4	30
1988 Lake&Henn	9.4	17
1988 Lake&Henn	9.3	91
1987 U & Snell	9.3	41
1987 U & Snell	9.2	31
1988 Lake&Henn	9.2	78
1987 U & Lex	9.2	49
1989 333Sibley	9.2	72
1988 Lake&Henn	9.1	29
1988 Lake&Henn	9.1	14
1988 U & Lex	9.1	13
1987 U & Lex	9.0	48

39.7 Deg. F. (Top 10)

SOURCE: MINNESOTA POLLUTION CONTROL AGENCY