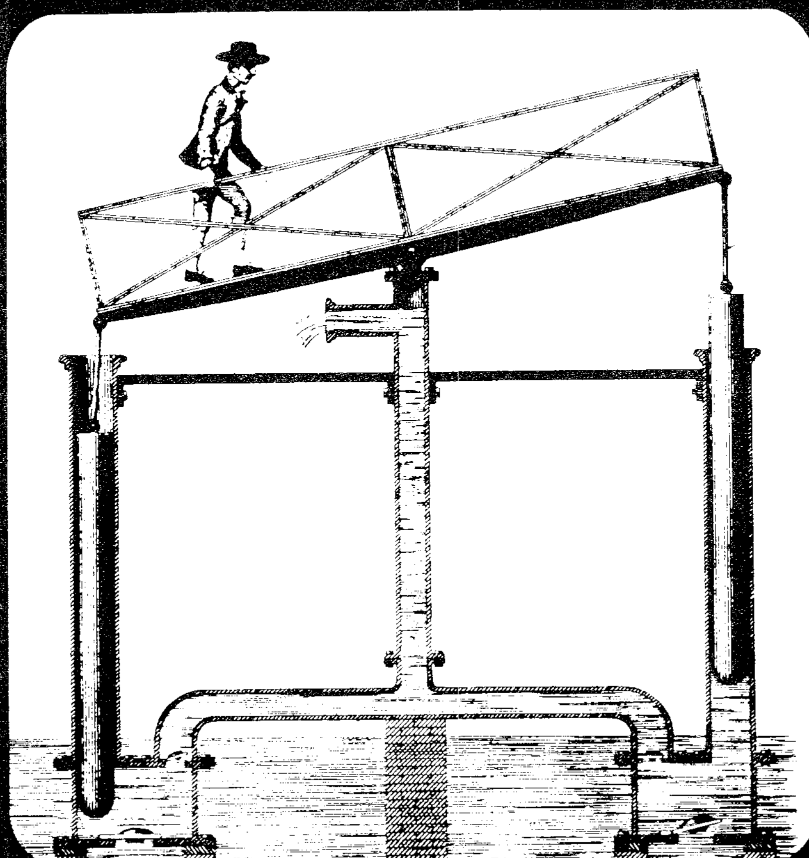
An Analysis of CO "Hotspot" Phenomena
in Several California Air Basins
(Final Report)



Department of Civil Engineering

University of California, Davis

April 5, 1994

Excerpts from the executive summary of ...

"An Analysis of CO "Hotspot" Phenomena in Several California Air Basins"

by Dr. Daniel P.Y. Chang, et al
Professor
Department of Civil & Environmental Engineering
University of California, Davis

"There is considerable uncertainty regarding actual on-road emissions, in addition to the meteorological uncertainties associated with micro-scale modeling under episode conditions, so that use of dispersion models to predict relative changes for the 8-hour standard is not warranted. The uncertainty in the vehicular emissions is systematic in nature. By using an inventory comparison approach, the direction of the impact (i.e. an increase or decrease) should be captured."

"Our review of the meteorological conditions during which CO can be expected to lead to 8-hr exceedances in Lynwood, as well as other air basins (San Jose/Santo Clara and Sacramento), indicates that project-specific micro-scale studies are not appropriate given the current modeling methodologies."

"At this time, a CO management methodology based upon reduction of total estimated CC emissions within units of one to several kilometers on a side (corresponding to normal air district emission inventories) appear to be appropriate for determining the impacts of transportation-related emission sources over periods corresponding to the 8-hr ambient air quality standard. Efforts should be placed on improving the accuracy of the emissions estimates."

"Project specific micro-scale studies for the 8-hr averaging period are not recommended. As an alternative, comparison of existing and future project emission estimates could be undertaken at a grid scale of 1 or 2 kilometers in order to determine whether CO emissions would increase, remain the same or improve. Such a comparison could be used to determine conformity and would be consistent with the State Implementation Plan (SIP)."

An Analysis of CO "Hotspot" Phenomena in Several California Air Basins

(Final Report)

by

Daniel P.Y. Chang[1]

Quanlu Wang[2]

and

Misook Kang[3]

University of California, Davis

Prepared for the

Office of Project Planning & Design

California Department of Transportation

April 1994

[1]Department of Civil & Environmental Engineering
[2]Institute of Transportation Studies
[3]Department of Land, Air & Water Resources

Table of Contents

List of Figures

List of Tables

Acronyms

AQMD - Air Quality Management District
CARB - California Air Resources Board
CO - Carbon monoxide
DRI - Desert Research Institute
DWM - Diagnostic Windfield Model
EPA - United States Environmental Protection Agency
EPF - Emissions Persistence Factor
GM - General Motors Corporation
GRI - Gas Research Institute
LTS - Lynwood Tethersonde
LYNN or AQMD - SCAQMD Lynwood Monitoring Station
MPF - Meteorological Persistence Factor
NAAQS - National Ambient Air Quality Standard
NG - Natural Gas
PIC - Particle-in-cell convective diffusion model
PMCP - perfluoromethylcyclopentane tracer
SIP - State Implementation Plan
SAC - Metropolitan Sacramento
SoCAB - South Coast Air Basin
SCAG - South Coast Association of Governments
SCAQMD - South Coast Air Quality Management District
SJSC - San Jose/Santa Clara
SLAMS - State and Local Air Monitoring Stations
SMAQMD - Sacramento Metropolitan Air Quality Management District
TPF - .otal Persistence Factor
UAM - Urban Airshed Model
VTS - Vernon Tethersonde

m/s - meters per second
tpd - tons per day

Acknowledgements

The authors wish to thank several individuals who provided valuable information for the study: Dr. Satoru Mitsutomi, Mssrs. Joe Casmassi, Lou Mott and Rene Bermudaz (SCAQMD); Mssrs. Dick Duker, Dario Levaggi and Michael Kim (BAAQMD); Mr. John Ching and Ms. Martha Lee (SMAQMD); Mr. John Batchelder (CARB); Dr. John Bowen (DRI); and Mr. Paul Benson (Caltrans). In addition, Mr. Simon Washington (Institute for Transportation Studies, UCD) assisted with a portion of the information gathered for the Lynwood area and Professor John Carroll, Atmospheric Sciences Graduate Group (UCD) provided insights on buoyancy phenomena. We also wish to thank our project officer, Mr. Steve Borroum (Caltrans), for numerous useful discussions that provided a focus for the study and for his patience. Ms. Susan Shaheen provided editorial comments and Ms. Tulia Cobian-Garcia prepared the final manuscript.

Executive Summary

Introduction

Continued exceedances of the eight-hour (8-hr) ambient standard for Carbon Monoxide (CO), nine parts per million (ppm), in major metropolitan areas requires that new projects lead to improvements in air quality. However, it is questionable whether meaningful detailed (microscale) analyses of the 8-hr impacts of a transportation project can be conducted with existing tools. A major goal of this study is to investigate the appropriateness of conducting project-specific microscale studies related to the 8-hr ambient CO standard.

An assessment of recent studies that affect our current understanding of the factors that lead to exceedances of the 8-hr CO standard was undertaken. Our study includes a review of: 1) several existing reports on the CO "hotspot phenomena," 2) an examination of the spatial extent of the phenomena and 3) an examination of the differences and similarities among CO episodes in three different areas in California: South Coast Air Basin (SoCAB), San Jose/Santa Clara area (SJSC) and Metropolitan Sacramento (SAC). <u>The review is limited in scope and is not a comprehensive review of the literature on CO studies</u>. A qualitative study of the effects of heat release on dispersion from roadways was also performed. Based on our reviews and analysis, we recommend procedures to determine appropriate "background levels" and to estimate impacts on the 8-hr standard.

Literature Review Findings

The existing studies reviewed include: 1) an intensive monitoring and tracer study of the Lynwood area sponsored by the California Air Resources Board (CARB) in 1989 entitled, "Determination of Source Contributions to High Ambient Carbon Monoxide Concentrations and Categorization of Carbon Monoxide Potential;" 2) a follow-up CARB study conducted by the Desert Research Institute (DRI) entitled, "Analysis of Data From Lynwood Carbon Monoxide Study," (Bowen et al., 1993); 3) studies of nighttime CO maxima conducted in the Santa Clara/San Jose (SJSC) area by the Bay Area Air Quality Management District (BAAQMD) during the late 70s and early 80s (Perardi et al., 1984; Duker et al., 1984); 4) a recent study conducted by the Sacramento Metropolitan AQMD (SMAQMD) regarding nighttime CO maxima (Ireson and Shepard, 1992); 5) miscellaneous literature addressing buoyancy phenomena, including studies conducted by Caltrans in the mid-70s above freeways in the SoCAB (Bemis, 1977).

In summary, we concur with the assessment of Bowen et al. (1993) that, "the occurrences of high CO concentrations in the Lynwood area are a result of a combination of 5 key factors which are themselves independent: source regions, transport routes, terrain, meteorological conditions, and different sub-periods of CO concentrations. Emissions from local sources within 5 km or less of LYNN appear to be more important than those transported from larger but more distant sources." The Bowen et al. study's statistical empirical orthogonal function (EOF) analysis of the data obtained during the 1989-90 intensive study suggests a local source of emissions in the immediate vicinity of the station; i.e., a source less than 100 meters (m) to the north may have contributed as much as 3 ppm to the total CO concentration. Based upon a site visit of the SCAQMD's Lynwood station, we found that the station did not fit the definition of a "neighborhood scale" station, and it is much closer to the definitions of microscale or "middle scale."

Motor vehicles are the major source of CO emissions in Lynwood. The baseline emissions from on-road mobile sources in the SoCAB is approximately 5000 tons per day (tpd) in comparison to total basin-wide stationary source emissions of about 200 tpd (SCAQMD, 1992). The early morning peak at Lynwood is more closely correlated with emission rates from vehicular sources, than the nighttime peak; however, both peaks may be augmented by non-vehicular contributions. We noted that CO emissions from stationary sources such as refineries, airports, power plants, and Natural Gas (NG) consumption in and around Lynwood [within 10 kilometers (km)] may be significant in contributing to a higher background level CO concentration in Lynwood relative to the SoCAB as a whole. The analyses of trajectories arriving in Lynwood during the nighttime CO episodes typically originated from the West or South in the mid- to late afternoon. A significant portion of the nighttime CO maximum observed at Lynwood may not be the result of local on-road vehicular emissions, but a portion may be due to distributed local sources such as "cold starts" from nearby parking areas and from gas-fired appliances coupled with very low mixing depth and wind speed over periods of several hours, i.e., evening to early morning hours.

From about 1978 through 1986, BAAQMD conducted studies of nighttime CO maxima. The majority of these studies occurred in the region between Santa Clara and San Jose (SCSJ). The BAAQMD found that CO levels were much higher than previously thought in residential neighborhoods on stable winter nights. The BAAQMD also found that the spatial extent of the "CO cloud" occupied as much as 43 square miles on stagnant nights. Within that area, the decrease of CO levels from "hotspots" (i.e., areas of high traffic density) to "coldspots" (i.e., residential areas or parks removed from high density traffic areas) was only about 30%. The BAAQMD developed a special sampler for measurement of ^{14}CO. The ^{14}CO measurements further indicate that residential wood-fired combustion is a significant source of CO during the nighttime periods (Levaggi, 1989).

The Sacramento Metropolitan Air Quality Management District (SMAQMD) also conducted a CO study during the fall and winter of 1990. Sacramento County provides an interesting contrast to both Lynwood and SJSC because the temperature gradient was even more strongly stable. The Sacramento metropolitan area has a lower density of sources with relatively low emission source areas between some monitors. The most striking observation we found was that peak concentrations of CO in downtown Sacramento were observed arriving, with an attenuated concentration, several hours later at the Sacramento Metropolitan Airport (SMA). Figures 11a and 11b, on p. 54, 55 and p. 56 of the report, illustrate the time sequence of events at the 13th and T intersection, Broderick and SMA monitors (Figure 11a), as well as the transport path (Figure 11b). These analyses indicate that when an inversion is sufficiently strong, even with a moderate wind speed (2.5 m/s) vertical diffusion is severely limited and transport occurs along the surface.

We noted that several features were common among the various sites. First, the highest CO episodes occurred under stable, low wind speed, radiation inversion and winter night conditions. Second, the morning CO peaks were associated with high traffic counts expected during morning rush hours. Third, evening CO peaks did not match with the evening traffic peaks; we found the peak nighttime CO lagging up to several hours. We believe that a buildup of CO into a relatively small volume occurs due to low wind speed and limited mixing depth; buildup can be augmented by widespread commercial/residential combustion and indirect sources during nighttime hours.

We also noted that the region around Lynwood affected by high CO concentration appeared to be more localized than in the case of San Jose/Santa Clara. Large geographic areas of SJSC appeared to experience relatively more uniform concentrations during the nighttime. In the SJSC case, the presence of residential wood combustion is also evident. Up to 25% residential wood burning in the Palo Alto area and as little as 5% to as much as 50% in some locations in San Jose was reported. Although we noted that the absolute concentration of ^{14}CO was lower in SoCAB air, it was non-negligible, ranging from 7% to 32% of the CO during the periods studied, however, the source of ^{14}CO was not given.

We noted that the mixing depths at Sacramento were limited by extremely strong surface-based inversions. Vertical mixing appears to have been almost totally suppressed, and buoyancy-driven vertical motion appears to have been confined to a much thinner region. We also found that horizontal transport by the mean wind had a smaller effect on reducing concentrations, and the pollutant "cloud" was evident after having been transported distances of 10 km.

Analysis of Buoyancy Effects

One puzzling facet of CO episodes is that they do not occur more frequently in the immediate vicinity of large emission sources, e.g., areas of high traffic volumes associated with major intersections or freeway interchanges. We believe that part of the explanation for this observation is the influence of meteorological conditions associated with episodes, i.e., calm conditions accompanied by a highly stable atmosphere. In our study, we presented energy conservation arguments illustrating that when wind speed tends toward zero, heat releases from emission source areas generate their own buoyancy-induced wind. Figure 13, on p. 63, illustrates the predicted average rise in temperature of the air associated with a crosswind velocity component of 0.1 m/s across varying numbers of traffic lanes. A number of simplifying assumptions were made in performing this computation; e.g., all of the heat from the fuel was assumed to result in heating of the air up to a height of 2 m above the roadway. However, the purpose of the illustration is to emphasize the "heating of air" phenomenon, not the exact temperature increase. The numbers on the curves correspond to the assumed fuel efficiency of the vehicle (kilometers per liter of fuel), and the symbols correspond to different assumptions about the traffic density per lane (cars passing a fixed point per second - 0.5/s = 1800/hr).

Temperature increases of 40 °C are not observed in reality, though temperature increases of about one degree have been documented from a moderately heavy traffic (5462 vehicles/hr over four lanes) simulation (Chock, 1977) even in moderate winds. The reason that very large temperature increases are never observed is that buoyancy-induced airflows rise from the surface, while corresponding horizontally-induced flows move toward the roadway at a rate greater than 0.1 m/s and replace the rising air mass. In the case of isolated vehicles, we also would not expect the same amount of buoyant rise because the surrounding air would mix into the plume more rapidly, dilute the air mass and limit its rise.

Following the method given by Shieh (1978), we calculated trajectories of "puffs" of buoyant air released into a "free" atmosphere. We numerically integrated the equations of continuity, momentum and energy. These crude calculations indicate that, conceivably, under conditions of moderate traffic density and essentially calm and stable conditions (wind speed, u, less than or equal to 0.25 m/s) a noticeable "lifting" of the plume to the 10 m or greater elevation is possible at distances as small as 10 to 20 m in the downwind direction. Buoyancy may be a key factor in explaining why higher concentrations of CO are not measured in the vicinity of higher density emission sources during episode conditions.

Existing research on CO modeling acknowledges that dispersion due to buoyancy becomes more significant under stable atmospheric conditions, as wind speed diminishes (Dabbert, 1976; Chock, 1977). Methods have been suggested (Chock, 1978) or developed (Benson, 1982) that partially account for the phenomenon. Nevertheless, the most commonly used Gaussian dispersion models for modeling vehicle impacts (e.g., CALINE3 or CALINE4) and even the less widely applied numerical grid models have shortcomings when the wind speed diminishes below approximately 0.5 to 1 m/s because most methodologies do not explicitly account for along-wind diffusion or plume rise. These shortcomings become important exactly under the conditions that correspond to high CO episodes. Consequently, if microscale modeling is to be used for conformity analyses, we conclude that further research and model development are warranted.

Predictions Based on Total Persistence Factor

Another method of modeling CO concentrations utilizes the concept of "persistence factors" (Nokes and Benson, 1985; Cooper, 1989; Cooper, 1992; SCAG, 1992) to take short-term microscale predictions (i.e., 1-hr averages) and adjust them to longer periods of time (i.e., 8-hr averages). These approaches are appealing because they are simple to apply and are based, partially, upon historical observations. However, the persistence factor approach is statistical in nature. We include a simplified discussion of one commonly used approach to persistence factors, as well as its possible implications when using data gathered from the nearest permanent monitoring station.

Ideally, a Total Persistence Factor (TPF) captures the joint probability that emissions (e.g., traffic counts) and adverse meteorological conditions (e.g., wind speed, direction and mixing depth) "persist" to result in an 8-hr maximum CO observation. A TPF calculated from observations can be conceptualized as reflecting a probability that a modeled 1-hr maximum concentration will result in an 8-hr maximum observation. It is important to note that a TPF defined in this way inherently assumes that the temporal distributions of emissions and the meteorological conditions are the same at the modeled site as they are at the monitoring station.

The bimodal nature and lack of correlation of CO peak concentrations with traffic counts in the evening/nighttime period suggests that emission patterns and possibly even meteorological conditions that lead to nighttime exceedances differ from those that occur during the early morning. Therefore, application of a single persistence factor to 1-hr maximum "worst case" concentration predictions can be inappropriate as far as the underlying physical situation is concerned; i.e., the conditions that led to the observed "worst case" morning peak may have been independent of the conditions that led to the "worst case" evening peak.

An example of the nature of the problem is given by the early morning CO maximum observed at the Lynwood station on January 9th (see Figure 4a, on p. 18). We observed that the early morning CO maximum was preceded by a very small evening peak on the 9th and the morning peak was dispersed before the nighttime peak on the 10th. We presume that the vehicular persistence factor for the morning peak was probably high, while the meteorological persistence factor was low. For the evening/nighttime peak on the 10th, we deduce that the reverse was likely true; i.e., the traffic persistence was low, while the meteorological persistence was high. If the morning peak traffic is modeled and an evening peak TPF is applied, an unrealistically conservative value would result. We note that the persistence factor approach is probabilistic in nature, and it is not at all clear that the probability distributions from one time period to another are consistent.

Utilization of CO data from the nearest monitoring station can pose a problem, first, if the monitoring station does not fit the description of a neighborhood scale station, and second, if the project has a significant predicted impact on the monitoring station. In the latter case, the station cannot also serve as a "background" station because there would be a double counting of the impact of the proposed emission source. On the other hand, if a monitoring station does fit the criteria of a neighborhood station, then there is no guarantee that the observed TPF provides a correct representation of a project's EPF, but only the combined EPF of dominant emission sources in the area in general! To the extent that the project's EPF and the area's EPF are correlated, a reasonable prediction <u>may</u> result. Consequently, there are shortcomings to the TPF method, and we recognize that in striving for a simple methodology for predicting impacts, compromises have been made that increase the uncertainty of the predictions.

We recommend that if the persistence factor approach is utilized, a study be performed to determine: 1) whether the choice of modeled "worst case" condition (e.g. 1 m/s wind speed, neutral stability) is appropriate for predicting the episode conditions and 2) whether a separation of the evening/nighttime and early morning peaks is necessary in developing the persistence factor; i.e., since a specific project may have a greater impact during one time period than another, and since the TPF for the two periods may differ from one another.

Monitoring for Background CO

The SCAQMD has indicated that use of the Urban Airshed Model (UAM) model provided good estimates of the 8-hr CO averages for all monitoring stations in the SoCAB except for the Lynwood monitor (Mitsutomi, 1993); and even in the Lynwood case, a modeled value of 18.5 ppm was obtained that corresponded to the measured value of 21.8 ppm (December 7, 1989), i.e., within approximately 15%. For reasons explained in the review of the Lynwood study, local indirect emissions may have influenced the readings of the Lynwood monitor. Given the good performance of the UAM model, there is no apparent need for <u>project-specific</u> monitoring of background in those air basins where the UAM capability exists. The UAM predictions can be verified at existing permanent monitoring stations that satisfy the neighborhood scale criteria. What is required are: 1) a good emissions database and 2) a meteorological network to provide the information to drive the wind field and mixing depths used in the UAM.

Selection of a background monitoring station should strictly adhere to the U.S. Environmental Protection Agency (USEPA) criteria for a neighborhood scale station. Several air districts utilize their existing monitoring network with supplemental special studies and meteorological experience to prepare concentration contours (isopleth diagrams). These serve as the basis for determination of "background" for CO impact analyses. The isopleths are generally selected to be representative of "worst case" observations, and all of the stations employed may or may not meet the neighborhood scale station siting criteria. (We believe that local districts attempt to eliminate microscale stations from the isopleth analysis.) For that reason, we recommend that larger districts that have the staff expertise to run the UAM and that have collected an emissions inventory for photochemical modeling purposes, eventually convert to using a Diagnostic Wind field Model (DWM) and UAM to supplement the determination of CO background in locations where permanent monitors do not exist. We recognize that supplemental meteorological studies may need to be undertaken to refine mixing depth estimation and to provide more accurate wind field input to the DWM.

Discussion of Conformity Determination for 8-Hr CO Standard

Prediction of the impacts from CO over 8-hour periods cannot be accurately performed with the existing microscale dispersion models commonly used for vehicular sources, e.g., CALINE3 or CALINE4. One reason for this is that the <u>continuous</u> Gaussian models were not designed for wind speeds below approximately 0.5 m/s. Second, buoyant sources of CO are not accurately handled in current models for episode meteorology. Although use of a grid-type model (e.g., UAM) is theoretically possible, the grid would have to be made much finer, perhaps as little as 5 to 10 m on a side and 2 to 5 m in the vertical. Parameterization of diffusivity and inclusion of buoyancy effects must still be introduced, and enhanced accuracy would require good characterization of mixing depth. The resolution of the emissions inventory must be correspondingly fine in order to apply it to local microscale impacts, similar to those that occur at the Lynwood monitor. Attaining a fine emissions inventory would be highly labor intensive and impractical in that case. We believe that further research concerning the parameterization of the appropriate horizontal diffusivities to be used in this model would need to be undertaken for conditions typical of episodes. Consequently, we believe that the use of UAM or other small scale 3-D grid models are not a practical solution for improving prediction of microscale level impacts at this time.

Use of UAM to predict "background" CO levels applicable to areas of 1 or 2 km grid squares seems feasible; however, higher resolution of mixing depths near the surface would be helpful since mixing depths appear to be critical to the "episode" condition. The use of UAM for defining "background" concentrations for microscale studies, in place of site-specific monitoring, may be more cost-effective and just as accurate because a consistent inventory would be applied to any additional microscale modeling. The UAM model accuracy can be strengthened with improved meteorological information, i.e., wind speed, direction and mixing depth.

A more cost-effective and methodologically consistent alternative for attainment planning purpo·es would be to manage 8-hr exceedances by comparison of estimated project emissions with estimated current emissions (i.e., from an emissions grid size corresponding to the current CO inventory, typically about 1 or 2 km). Thus, if the estimated emissions produced total emissions, in a given grid square equal to or less than the existing situation and basinwide as well, it could be allowed to proceed. There is considerable uncertainty regarding actual on-road emissions, in addition to the meteorological uncertainties associated with microscale modeling under episode conditions, so that use of dispersion models to predict relative changes for the 8-hr standard is not warranted. The uncertainty in the vehicular emissions is systematic in nature. By using an inventory comparison approach, the direction of the impact (i.e. an increase or decrease) should be captured.

Conclusions

Emissions corresponding to the nighttime peak and exceedance of the 8-hr standard at the Lynwood site do not appear to be attributable to local on-road motor vehicle sources alone. An elevated background concentration relative to other stations is probable at the Lynwood station because of the geographic distribution of sources surrounding it. Furthermore, the possible impact of natural gas combustion cannot be dismissed at this point. Although we found no direct evidence for the importance of other sources, several bits of circumstantial evidence were found.

We found that the CO "hotspot" phenomenon in Lynwood appears to occupy a smaller geographic area (roughly about 0.5 km in diameter) than in San Jose/Santa Clara, but the meteorological conditions that lead to CO episodes are not limited to one geographical area of the State. We noted in cases of extremely stable conditions, mixing is limited so strongly that horizontal transport was apparent (SMAQMD study). However, we believe that long-range transport alone is unlikely to lead to an 8-hour exceedance.

Our review of the meteorological conditions during which CO can be expected to lead to 8-hr exceedances in Lynwood, as well as other air basins (San Jose/Santa Clara and Sacramento), indicates that project-specific microscale studies are not appropriate given the current modeling methodologies. Conditions leading to CO exceedances correspond to very light or non-measurable wind speed (by conventional instrumentation) and extremely stable inversions that cannot be handled accurately with the continuous Gaussian plume models currently applied. Buoyancy effects are predicted to become important as wind speed diminishes, especially below about 1.0 m/s. Energy conservation and momentum conservation suggest that "plume rise" phenomena can become significant for multi-lane heavily trafficked corridors, so that both the Gaussian and grid-type models may need to take it into account.

We found that application of the "persistence" concept is useful as an initial estimate relating 1-hr neighborhood scale CO concentration predictions to 8-hr time periods because CO can be treated as a conservative pollutant. However, because the TPF may vary both temporally and spatially, use of a single value may not provide a good estimate of impacts and is not recommended.

We conclude that use of the UAM for determination of "background" would be more cost-effective than project specific on-site monitoring for CO. However, we note that the UAM predictions are sensitive to mixing depth under episode conditions, and the accuracy of the UAM predictions would be improved with better near surface temperature profile data in determining the mixing heights to be used. We also believe that additional tethersonde studies or a larger number of vertical temperature measurements at existing permanent monitoring stations would be desirable.

At this time, a CO management methodology based upon reduction of total estimated CO emissions within units of one to several kilometers on a side (corresponding to normal air district emission inventories) appear to be appropriate for determining the impacts of transportation-related emission sources over periods corresponding to the 8-hr ambient air quality standard. Efforts should be placed on improving the accuracy of the emissions estimates.

Recommendations

Project specific microscale studies for the 8-hr averaging period are not recommended. As an alternative, comparison of existing and future project emission estimates could be undertaken at a grid scale of 1 or 2 kilometers in order to determine whether CO emissions would increase, remain the same or improve. Such a comparison could be used to determine conformity and would be consistent with the State Implementation Plan (SIP).

Further effort to determine whether buoyancy phenomena are important under CO episode conditions are warranted. We recommend that a more sophisticated 2-D computational modeling effort, one that does not entail parameterization of entrainment, be undertaken to determine whether the "puff" plume rise method applied in this study has given reasonable results.

We recommend that the approach of using a "grid" model, UAM, in conjunction with a diagnostic wind field model, to predict "background" concentrations over 8-hour periods be pursued further by other air districts, and a study be undertaken to validate this method by comparing the resulting data with historic data from permanent neighborhood scale stations. We believe that such a methodology would be more consistent with estimates currently used for attainment planning purposes.

Better resolution of mixing depth is desirable, and it is recommended that a program to obtain near surface vertical temperature profiles be undertaken. Simultaneous measurement of mixing depth (by tethersonde) at several locations during periods of episode meteorology, high stability and low wind should be undertaken, e.g., near a freeway away from other major heat sources, among high rise buildings, a residential area, etc. We conclude that a standard methodology for integrating such information that produces contours of mixing depth for use with the UAM model would be useful.

We also recommend developing a statistical method for determining the representativeness of siting for a given monitoring station. A specific monitoring station may appear to satisfy the "neighborhood scale" siting criteria, but it may be unduly influenced by local conditions. If mixing depth, wind speed (these could be measured or modeled) and emission source strength can be computed, it should be possible to undertake a statistical analysis (hourly during the periods leading to exceedances) to examine outliers in relation to existing monitoring stations. We believe that the application of such a technique could provide a means for determining whether a station fits such a model or where the model is weak; e.g., the model produces large underestimates of emissions. We recommend that such a study be carried out in collaboration with several of the air districts. This recommendation hinges upon improved ability to estimate mixing depths under episode conditions, i.e. upon the previous recommendation.

Limited studies of space heating, as possible CO emission sources (during periods of limited ventilation), should be undertaken, e.g., measurement of CO concentration and exhaust temperature in post office boiler exhaust and roof vents of gas-fired heaters near the Lynwood monitor. If there is evidence for gross underestimation of emission factors, then a program to determine in-use emission factors should also be undertaken.

Carbon monoxide is produced by the body and has only recently been recognized to have a possible role as a neuro-transmitter (Barinaga, 1993; Verma et al., 1993). There has been no evidence of chronic illness resulting from ambient level CO exposure (USEPA, 1984). It is also one of the best understood of the criteria air pollutants in terms of health effects of sensitive populations. Models of exposure and resulting carboxyhemoglobin levels have been developed so that dose-response relationships are well-defined. Given this level of understanding, we recommend that the selection of receptors for purposes of determining conformity, should be based on realistic possibilities for exposures.

Introduction

Conformity of transportation projects with applicable air quality standards is required by the Clean Air Act Amendments of 1990. Continued exceedances of the eight-hour (8-hr) ambient standard for CO (9 ppm) in major metropolitan areas requires that new projects lead to improvements in air quality. However, it is questionable whether meaningful detailed (microscale) analyses of the 8-hr impacts of a transportation project can be conducted with existing tools, particularly within the context of an implementation plan that of necessity projects emissions several years into the future. Conventional wisdom would regard the 8-hr standard as being more closely related to mesoscale phenomena. A major goal of this study was to investigate the appropriateness of conducting project-specific microscale studies related to the 8-hr ambient CO standard.

An assessment of the current state of our understanding of the factors that lead to exceedances of the 8-hr CO standard was undertaken. Several analyses were conducted including 1) a review of several existing reports of CO "hotspot phenomena;" 2) an examination of the spatial extent of the phenomena, i.e., local (microscale) versus area-wide (neighborhood scale); 3) an examination of the differences and similarities among CO episodes in three different areas, South Coast Air Basin (SoCAB), San Jose/Santa Clara area (SJSC), Metropolitan Sacramento (SAC); and 4) a qualitative study of the effects of heat release on dispersion from roadways. Typical microscale analyses require that background levels of pollutant be determined. Thus, suggestions regarding steps that could be taken to determine appropriate background levels were also examined. These suggestions were made in light of the recent guidance document, "Carbon Monoxide Transportation Project Protocol," issued by the Southern California Association of Governments (SCAG, 1992).

Report Organization

The report has been organized with the following arrangement of sections: 1) Introduction; 2) Background; 3) Organization; Review of Literature; 4) Sources of CO Emission; 5) Analysis of Buoyancy Effects; 6) Predictions Based on Total Persistence Factor; 7) Monitoring for Background CO; 8) Discussion; 9) Conclusions; 10) Recommendations; 11) Appendix A - CO Health Effects; 12) Appendix B - Description of Puff Model Used to Compute Hypothetical Trajectories; 13) Appendix C - Sources of CO in the Vicinity of Lynwood: and Appendix D - Comments Received on Draft Final Report and Responses. The section dealing with review of the literature also includes some observations from a site-visit of the Lynwood area. Observations regarding sources are summarized in the body of the report, while Appendix C addresses details of the estimation procedure used for sources of CO primarily specific to the Lynwood area. The section dealing with buoyancy effects resulted from the observation that source regions with the highest emissions were not always those with the highest measured CO concentration. Buoyancy of emissions is proposed as one possible explanation. The brief discussion of persistence factors addresses the potential pitfalls of that methodology when dealing with site-specific individual project projections; this discussion has a bearing on modeling and monitor siting objectives. Details of the puff model are provided in Appendix B. The section on monitoring is brief because a case is made for use of a grid model, Urban Airshed Model (UAM), in lieu of site-specific monitoring for determination of "background." The discussion and conclusions sections summarize the implications of the analyses. Appendix A addresses the basis for the national ambient air quality standard (NAAQS) for CO and was presented to provide individuals charged with the selection of "receptors" with a technical basis for their choices.

Background

A South Coast Air Quality Management District (SCAQMD) monitoring station located in the city of Lynwood consistently records the highest measured 8-hr average CO concentrations in the Los Angeles air basin. However, the traffic volume in the immediate vicinity of the station is less than that at many other stations located in the basin. The anomaly presented by the Lynwood station has been investigated by both the California Air Resources Board (CARB) and the SCAQMD (Aerovironment, 1991). Although a significant amount of data have been accumulated and analyzed, an understanding of the reasons for high CO readings at the Lynwood station (about 50 percent higher than at other stations within the basin) remains incomplete. Furthermore, there are reports from other agencies of CO levels at suburban residential sites that approach or occasionally exceed those in downtown urban areas (Perardi et al., 1984; Duker et al., 1984). Whether such residential sites represent microscale "hotspots" caused by localized sources of emissions or are representative of a "neighborhood scale" exposure of the population is in need of further clarification.

Several existing studies of the CO "hotspot" phenomenon were reviewed. These included: 1) an intensive monitoring and tracer study of the Lynwood area sponsored by the CARB in 1989 entitled "Determination of Source Contributions to High Ambient Carbon Monoxide Concentrations and Categorization of Carbon Monoxide Potential"; 2) a follow-up CARB study conducted by the Desert Research Institute (DRI) entitled, "Analysis of Data From Lynwood Carbon Monoxide Study," to further analyze the data collected in intensive 1989-90 (Bowen et al., 1993); 3) studies of night-time CO maxima conducted in the San Jose area by the Bay Area Air Quality Management District (BAAQMD) during the late 70s and early 80s (Perardi et al., 1984; Duker et al., 1984); 4) a recent study conducted by the Sacramento Metropolitan AQMD (SMAQMD) regarding night-time CO maxima (Ireson and Shepard, 1992); 5) miscellaneous literature dealing with buoyancy phenomena including studies conducted by Caltrans in the mid-70s above freeways in the basin (Bemis, 1977). The current report does not contain an exhaustive review and analysis of the CO literature.

Several questions are addressed in the present analysis: 1) Are high 8-hr CO levels a phenomenon that is common in other air basins or is Lynwood somehow unique? 2) Is transport from higher source emission areas a possible explanation for the observations or do local sources contribute significantly to the measured concentrations? 3) Why are concentrations in other more heavily trafficked areas in the basin <u>not</u> reporting higher CO concentrations when meteorological conditions become similar to those at Lynwood? 4) What are the implications of the observed CO levels to microscale modeling of 8-hr impacts of CO? 5) What are the implications of these observations on the determination of "background" CO levels?

As a basis for forming working hypotheses to explain the observations, we assumed the following statements to be accurate:

1. There are no known physical mechanisms for CO concentration, expressed on a mole or volume fraction basis (parts per million by volume [ppm]), to increase in the absence of additional sources of emission. CO does not behave as a concentrated dense gas and diffusive processes will always reduce its concentration.

2. The occurrence of the CO exceedances correspond to nighttime and early morning hours. The timing of the rise of CO concentration precludes photochemical generation of CO from conversion of unburned organic compounds. Although photochemical oxidation processes might contribute as much as ten percent more CO than accounted for by primary emissions, this mechanism is not operative during the nighttime or early morning period and cannot be an explanation for the observations.

3. Oxidation of CO is even less rapid than the oxidation of unburned organics and on the time scale of eight hours, CO can be considered a conservative pollutant.

The implications of the above statements are that increases in concentration must result either from additional CO emissions, from transport of higher concentrations from other source areas (that are not detected by the surface monitoring network), or as a result of measurement error.

A number of hypotheses were generated at the beginning of this study based on the above possibilities. For example, a local source of CO, such as residential gas-fired appliances or home heating and cooking may be sources of local non-vehicular CO emissions. Alternatively, transport of CO emissions aloft may occur with subsequent downward transport to the surface in Lynwood. Or it might be that the Lynwood monitoring station is located near vehicular activity (on and off-road such as parking lots) so that microscale impacts are measured, not those representative of a neighborhood scale.

To explore the above hypotheses, an investigation was undertaken of additional sources of CO other than on-road vehicular activity. The representativeness of the siting and the data obtained at the Lynwood monitoring station were examined. The possibility of transport from other source areas was examined. Lastly, to understand the lower values of CO measured at other sites with much higher traffic-related emissions, the possible effects of buoyant rise of exhaust emissions were also examined.

Review of Literature

Lynwood Intensive Study

During the Fall and Winter of 1989-90 an intensive collaborative study was carried out by Aerovironment, Inc. (1991) entitled, "Determination of Source Contributions to High Ambient Carbon Monoxide Concentrations and Categorization of Carbon Monoxide Potential." The study was conducted on behalf of CARB, SCAQMD and General Motors (GM) for the purpose of determining the reasons for the relatively higher values of ambient CO observed in Lynwood compared to the rest of the South Coast air basin (SoCAB). Subsequently under CARB sponsorship, DRI conducted further analysis of the data collected. The two studies will be reviewed together and simply referred to as the "intensive" study throughout this report. Because large quantities of data were generated, the summary and conclusions from the DRI analysis (Bowen et al., 1993) are drawn upon heavily in this literature review, and only selected data are shown to illustrate particular points. Interested readers are referred to the two reports for details.

Intensive measurements were collected during stagnation periods in the SoCAB. Maps illustrating the location of CO measurement locations are shown in Figures 1 and 2 (on p. 6-7), adapted from the Aerovironment report (Aerovironment, 1991). The reader should be aware that the maps have been compressed in the east-west direction, the scale shown only applies to the east-west dimension, and the circle labeled HS3/AQ1 in Figure 2 (on p. 7) corresponds to a collocated bag sampler at the SCAQMD LYNN station, AQ1 (also denoted as AQMD in other tables and figures). Particular attention will be given to two episodes that exceeded the 8-hr NAAQS for CO (Dec. 19-20, 1989 and Jan. 8-10, 1990). "Bag samples were collected for CO at sites near Lynwood and in the western SoCAB. Perfluorocarbon tracers were released at four locations near Lynwood and bag samples were collected and analyzed. Meteorological variables were measured with tethersondes at Lynwood and Vernon and traffic counts at five surface streets by Caltrans and six freeway locations by Newport Traffic Studies. CO analyzers were installed in GM rover vehicles to measure instantaneous CO concentrations on streets in the area." (Bowen et al., 1993.)

"The overall objectives of the study were to 1) determine why CO concentrations are higher at Lynwood (LYNN) than at any other monitoring location; 2) determine the relative contributions of local and areawide sources; and 3) determine the relative influence of meteorology, topography, and motor vehicle fleet characteristics on the CO concentrations at Lynwood." (Bowen et al., 1993.)

Figure 1. Map illustrating locations of samplers used throughout SoCAB during the 1989-90 intensive study. (Adapted from AeroVironment, 1991.)

CO Monitoring Stations

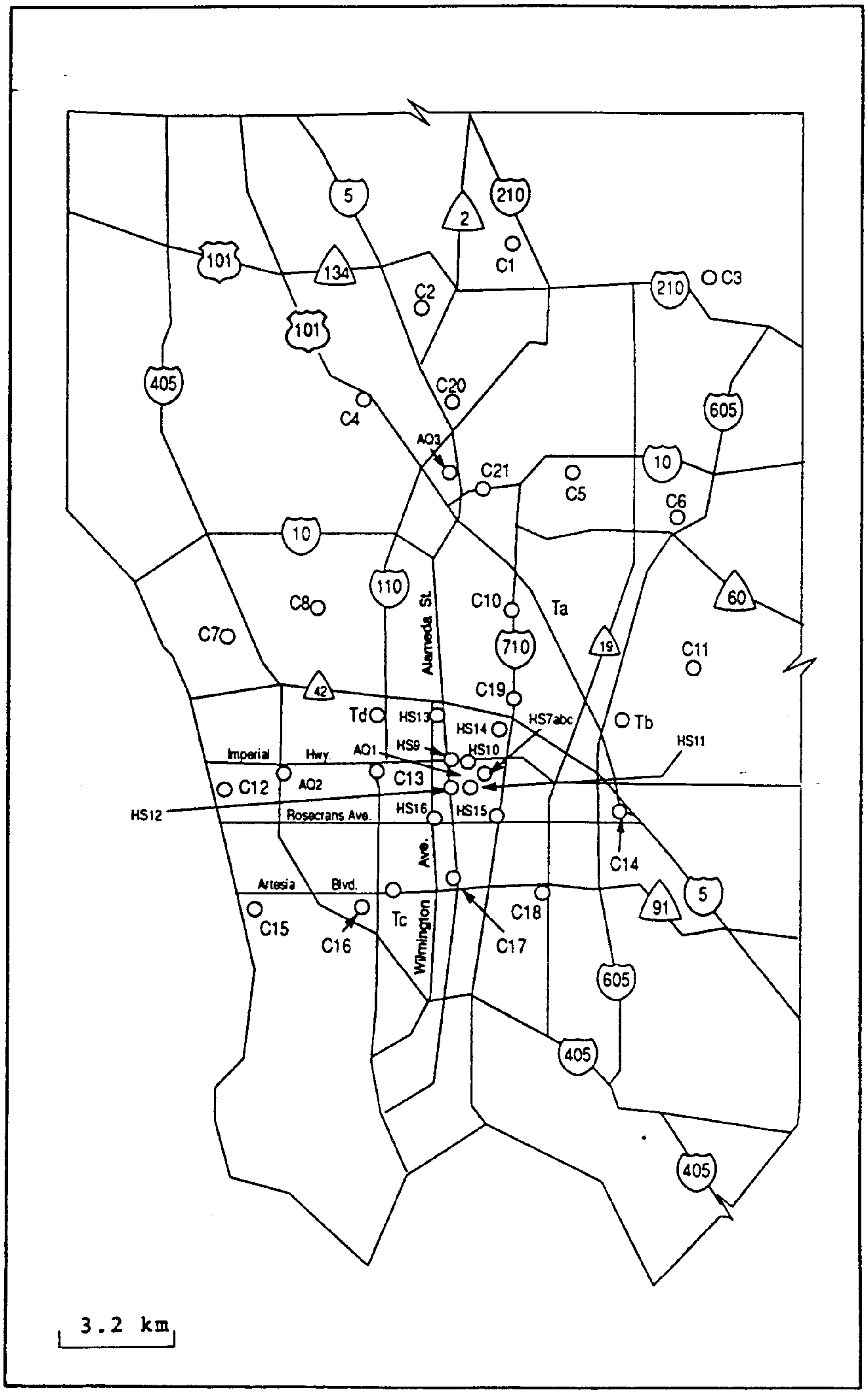
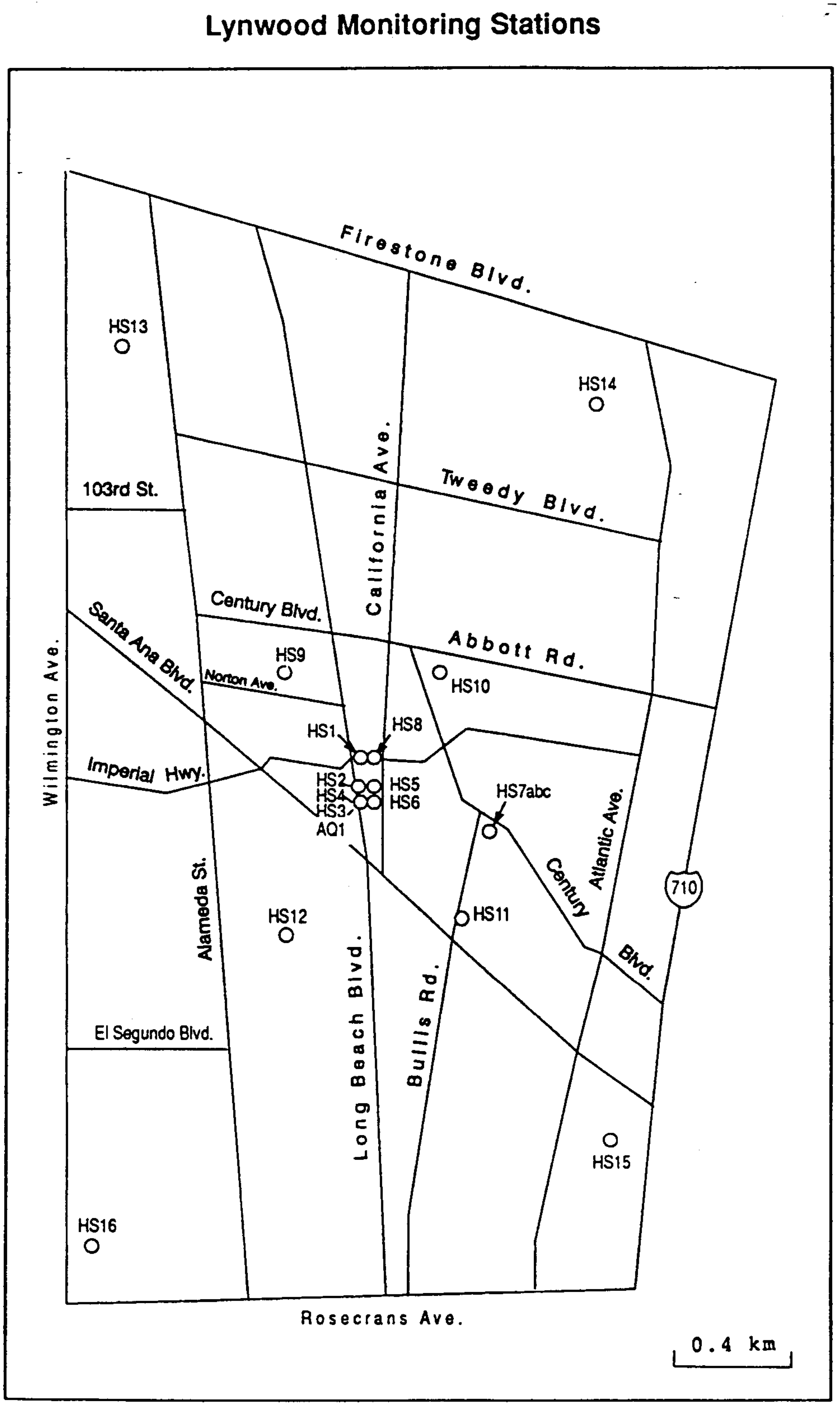


Figure 2. Map illustrating locations of samplers used in the immediate vicinity of Lynwood during the 1989-90 intensive study. (Adapted from AeroVironment, 1991.)



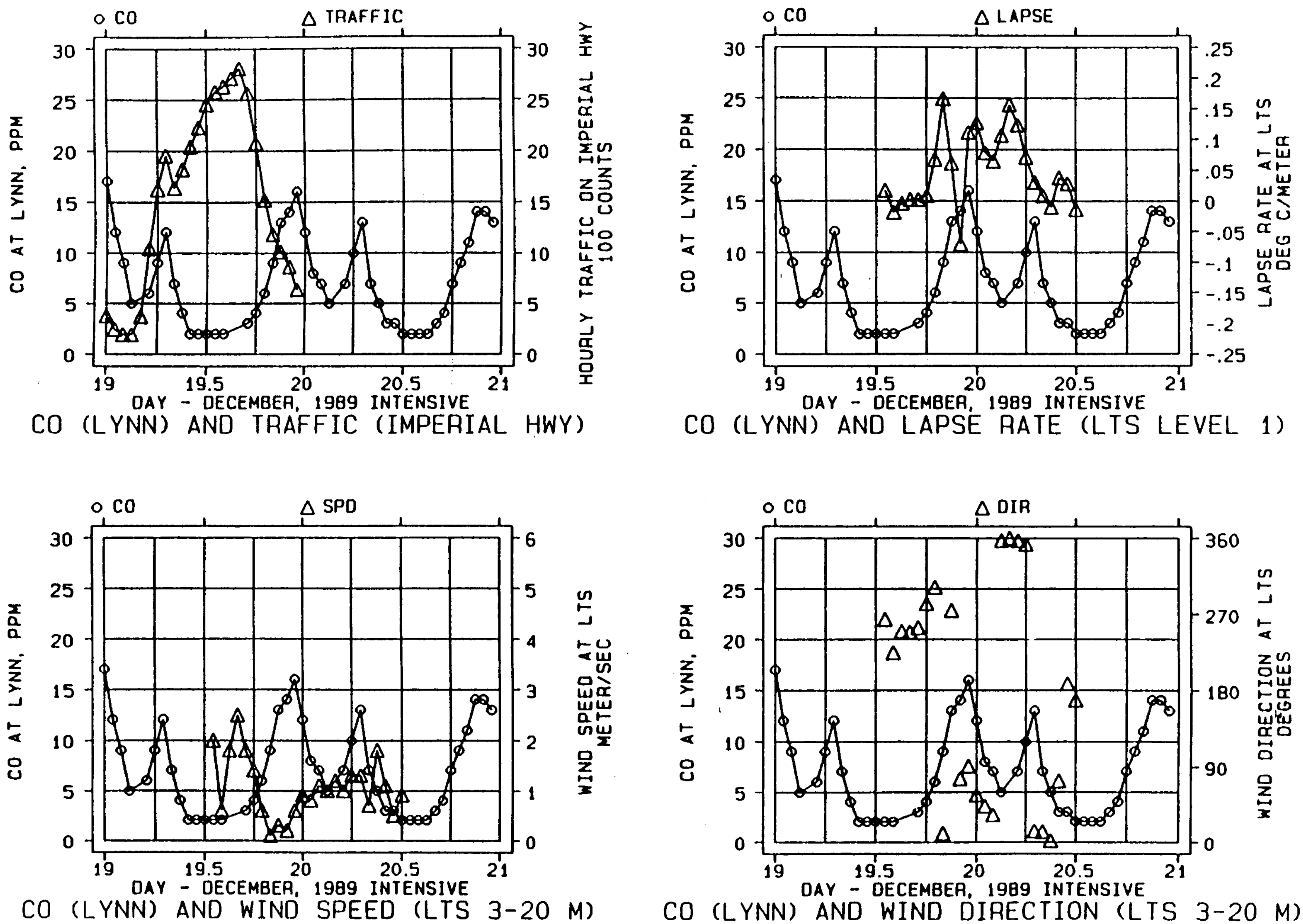
The DRI conducted a thorough examination of the available data and concluded that, "Data collected at a number of bag sampling sites, mostly within the 1 to 4 km distance of Lynwood, had questionable validity. The sites did not exhibit the morning and evening maxima in CO concentrations evident at all SCAQMD monitoring stations and some other bag sample sites. Their maxima were either missing or at times that differed appreciably from the times at the SCAQMD sites. Even if local sources influenced CO concentrations near the suspicious sites, the diurnal pattern of morning and evening CO maxima should still have been present as in other parts of the SoCAB. The only possible explanation for the difference in diurnal variation is the mistiming of samples, which may have been caused by malfunctioning samplers. The mistiming of samples also limited the usefulness of many of the tracer samples as proper timing was critical for their validity. Some problems were found in data collected by the GM rover vehicles. The samples collected during periods of high traffic volume, which were not necessarily during the highest CO concentrations, were biased high when compared to station measurements, indicating that local traffic affected measurements made by the vehicles." (Bowen et al., 1993.)

"Bag sample data, including mistimed data, and SCAQMD data were used to investigate the locations of high CO concentrations in the SoCAB. These data confirmed that CO concentrations were higher in the vicinity of LYNN than at other locations of the SoCAB. A closer inspection of SCAQMD data indicated that CO concentrations at LYNN were generally but not always the highest of the two daily maxima in the SoCAB. LYNN was the only site with consistently high CO concentrations and it was confirmed that the high CO concentrations measured at that site are representative of concentrations in the immediate vicinity." (Bowen et al., 1993)

We have extracted summary plots of CO at the LYNN station, intersection traffic counts at the Imperial Highway, wind speed and lapse rate at the Lynwood tethersonde (LTS) from the DRI report to contrast with "bubble" plots from the Aerovironment report illustrating the spatially measured CO concentrations during the December 19-20 and January 8-10 episodes. Of particular note in Figures 3a and 4a (on pages 9 and 18) are the occurrences of diurnal CO peak concentrations which correlated with traffic counts in the early morning 0500 to 0900 hours, but not with evening/nighttime CO peak 1800 to 0200 which typically exhibited decreasing traffic counts as CO increased. The nighttime peaks are seen to be associated with stable conditions (dT/dz as large as 0.2 °C/m), and lower wind speeds (of times below the starting threshold of the anemometers 0.2 m/s). The winds appear to generally originate from northerly directions, i.e. from Imperial, during the nighttime maxima.[1] The nighttime maxima are

[1] During very light wind conditions, the wind vane may not have been indicating direction correctly; however, a subsequent windfield modeling effort did not indicate inconsistency.

Figure 3c. Morning CO monitoring station readings 12/20/89, 0800, immediate vicinity. (Adapted from AeroVironment, 1991.)



of about the same magnitude on December 19th, 20th and January 9th and do not appear to have a direct correlation with traffic whereas the January 9th early morning maximum is clearly associated with the traffic counts at the intersection of Long Beach Blvd. and Imperial Hwy. We note that either the nighttime or the early morning peak on January 9th would have led to a violation of the 8-hr standard.

Bowen et al. (1993) note, based upon upper air soundings obtained during the intensive study, that LTS showed much stronger thermal stability at night than did the site at the Vernon tethersonde (VTS). "The lapse rate in virtual potential temperature at LTS was as much as 5 times what it was at VTS. Wind speeds at LTS were about half as large as at VTS. The onset of stability was several hours after the initial increase in CO concentrations but did occur at the time that CO concentration began increasing faster. CO concentrations decreased when the atmosphere became unstable in the morning." Clearly, meteorological conditions (low wind speed and mixing depth), leading to very low ventilation in the Lynwood area, are major factors in both the nighttime and early morning CO maxima.

The Figures 3b through 3h (on pages 11-17) provide a spatial distribution of CO maxima progressing through time. They also illustrate the concern noted in the DRI study that some of the bag samplers may have been mistimed. (Note that an asterisk at a given site indicates no sample drawn at that time or missing data.) Nevertheless, what is clear is that the distribution of high CO occupies dimensions of at least approximately 0.5 kilometer around the LYNN station (Figures 3b to 3e), but less than several kilometers (Figures 3f to 3h). Figures 4b through 4j illustrate the situation during a weaker evening maximum and the subsequent development of a strong early morning maximum in the immediate vicinity of LYNN during January 8th and 9th. Figures 4k through 4n are for a stronger nighttime maximum that occurred on the 9th, but they have been selected to show the behavior throughout the region. Noticeably absent are any indications of transport, at the surface, of CO from higher concentration regions toward Lynwood (maps with smaller scale), even though some of the sampling sites are located near major vehicular source areas such as freeways. These observations are selected as examples, but they hold for both the evening/nighttime maxima, as well as the early morning maxima.

The DRI researchers applied a Diagnostic Wind Model (DWM), developed as a part of the Urban Airshed Model (UAM), to generate hourly wind fields for each intensive period. The model used initial inputs for mean wind, stability, and terrain elevations, and these were adjusted to local conditions by using wind speed and direction from SCAQMD sites and the two tethersonde sites. Bowen et al. noted that, "Terrain in the vicinity of LYNN has the least slope of any other SCAQMD site where CO is measured. The downslope direction of the gradient is toward the south at LYNN

Figure 3b. Morning CO monitoring station readings 12/20/89, 0600, immediate vicinity. (Adapted from AeroVironment, 1991.)

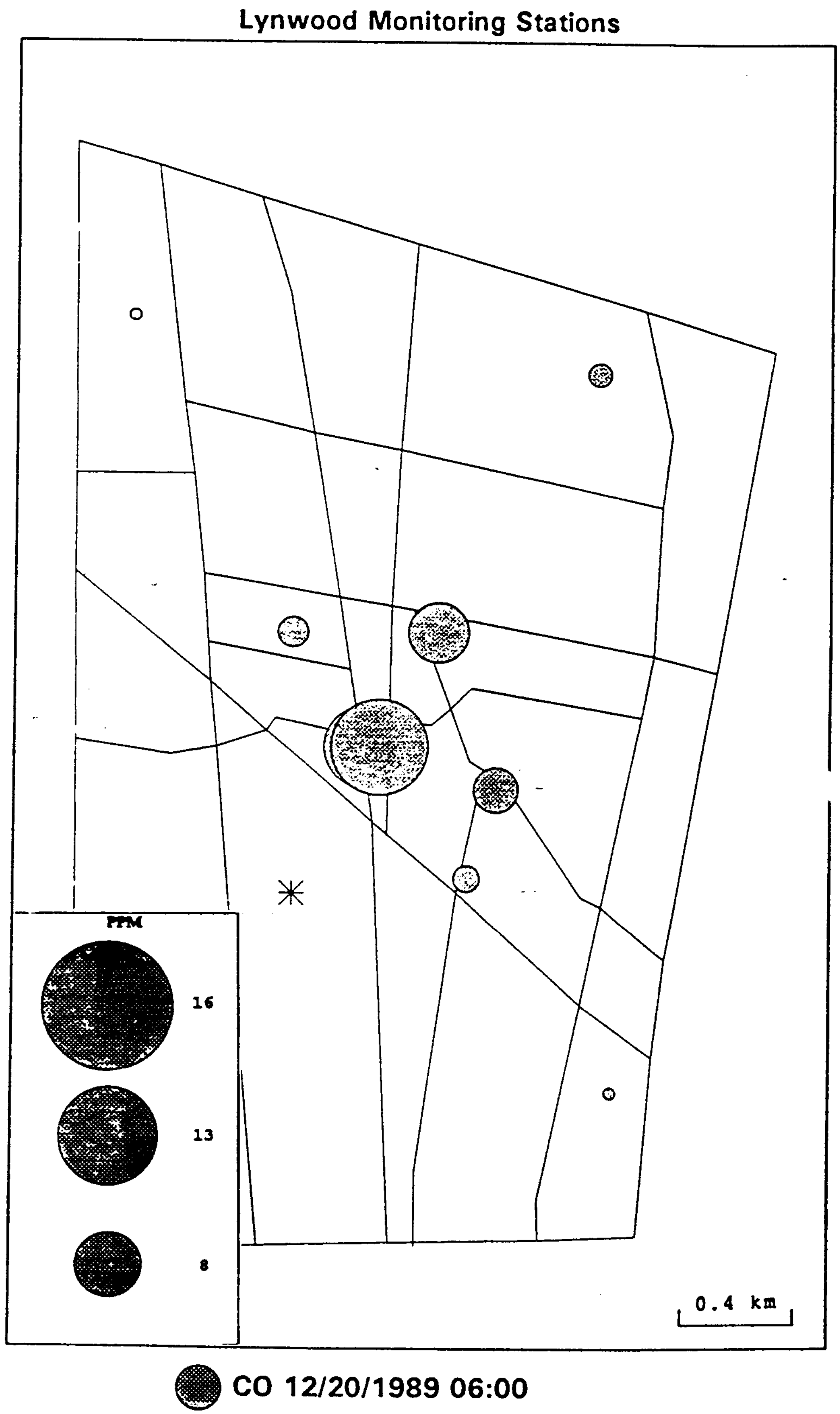


Figure 3c. Morning CO monitoring station readings 12/20/89, 0800, immediate vicinity. (Adapted from AeroVironment, 1991.)

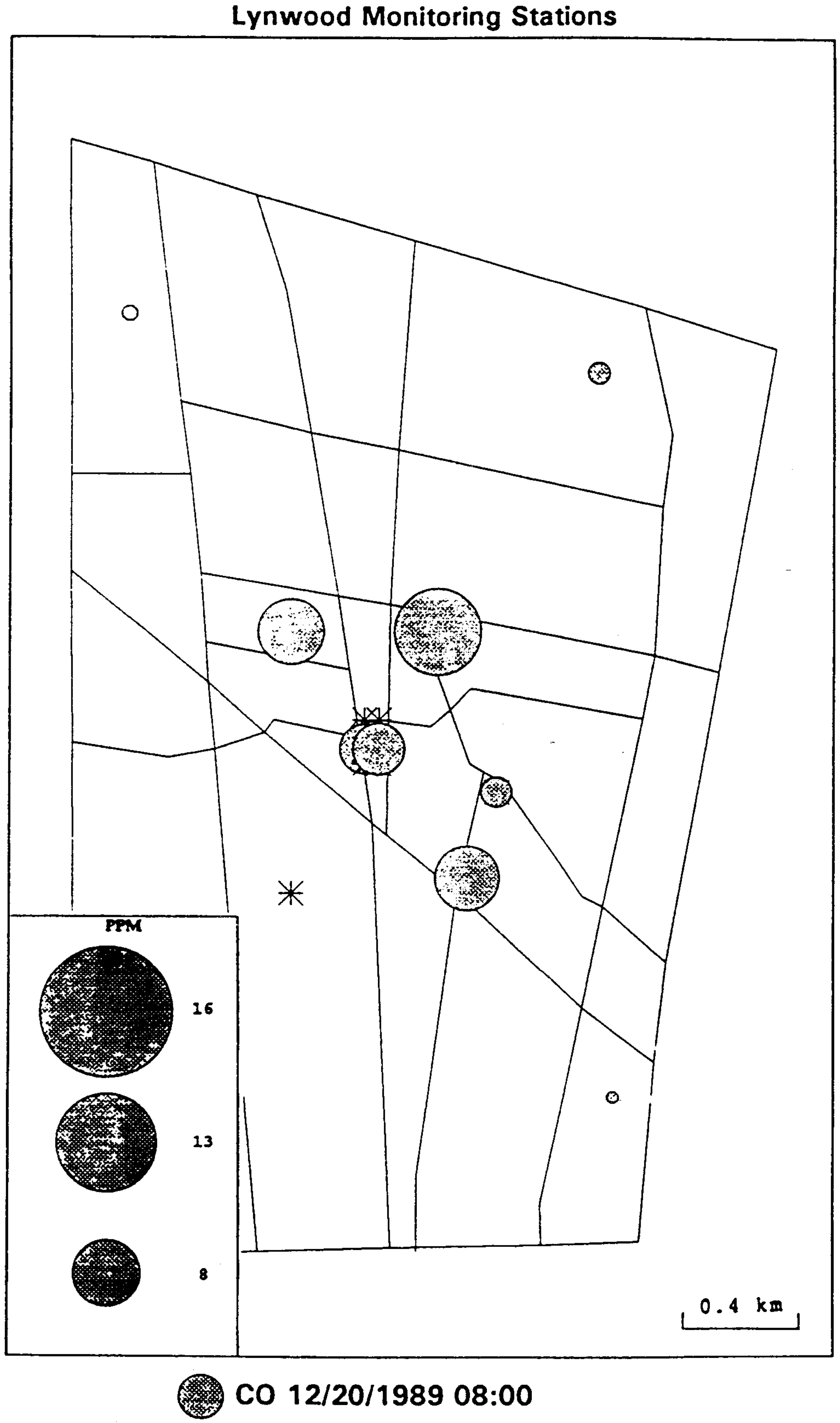


Figure 3d. Morning CO monitoring station readings 12/20/89, 1000, immediate vicinity. (Adapted from AeroVironment, 1991.)

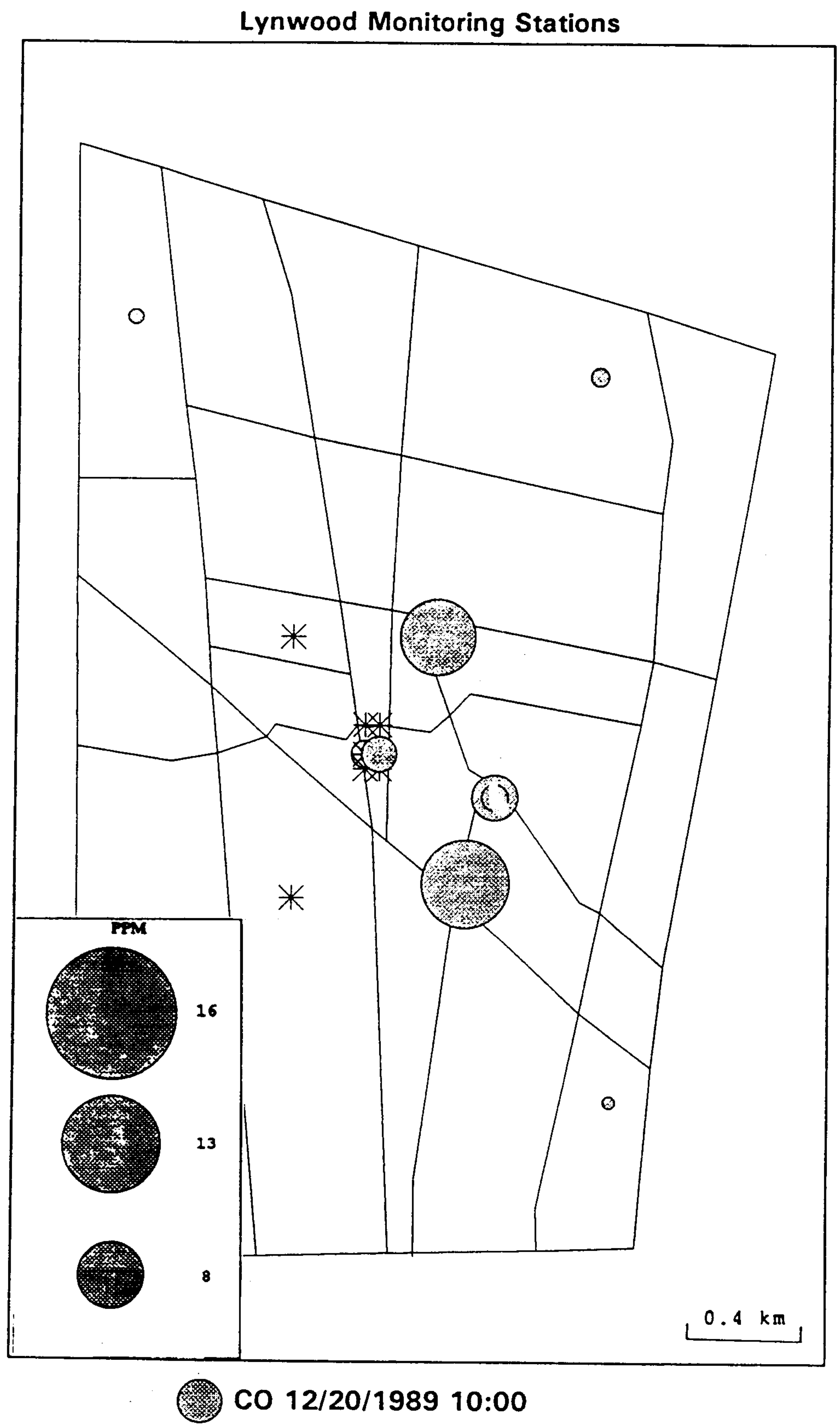


Figure 3e. Morning CO monitoring station readings 12/20/89, 1100, immediate vicinity. (Adapted from AeroVironment, 1991.)

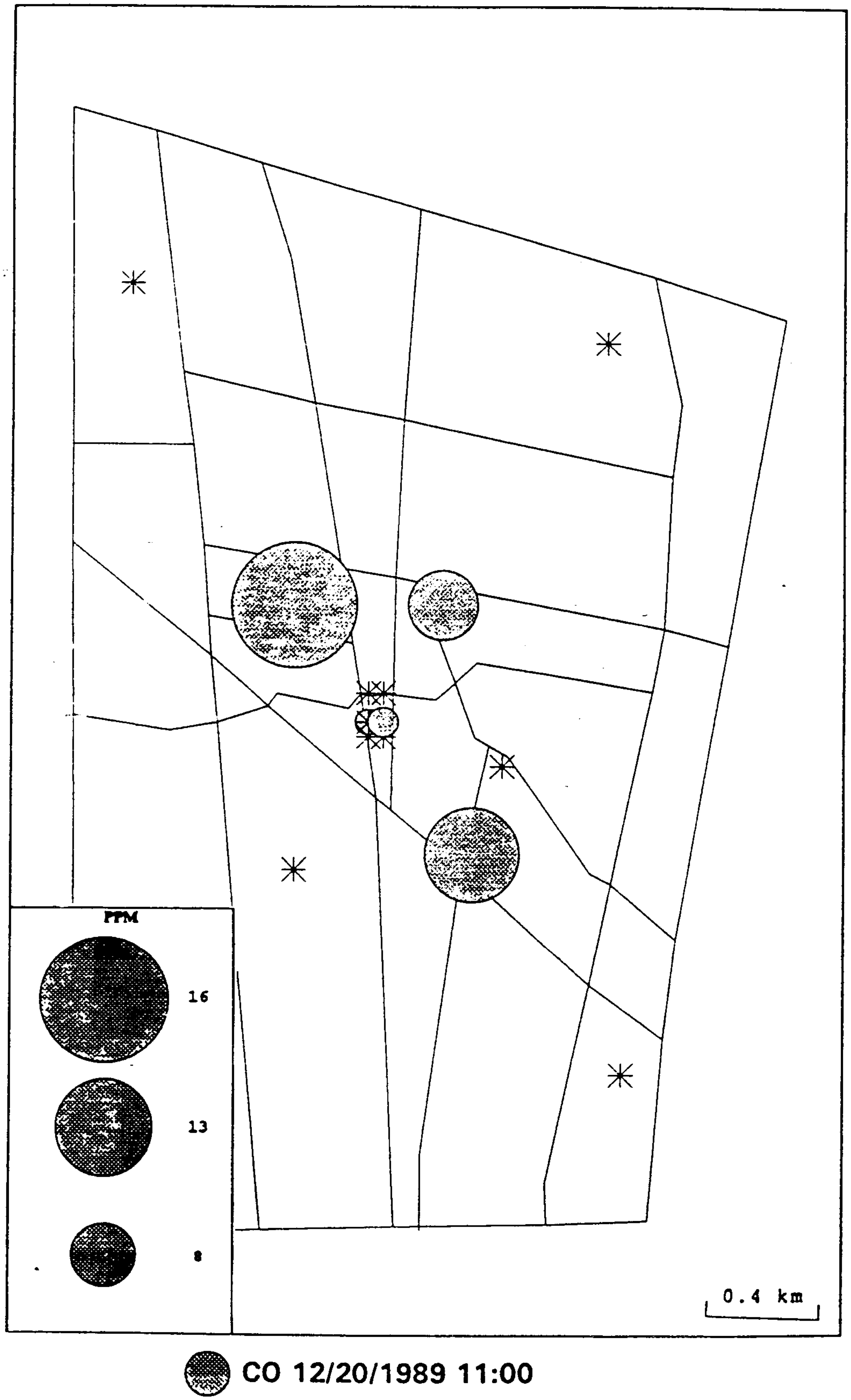


Figure 3f. Morning CO monitoring station readings 12/20/89, 0600, SoCAB. (Adapted from AeroVironment, 1991.)

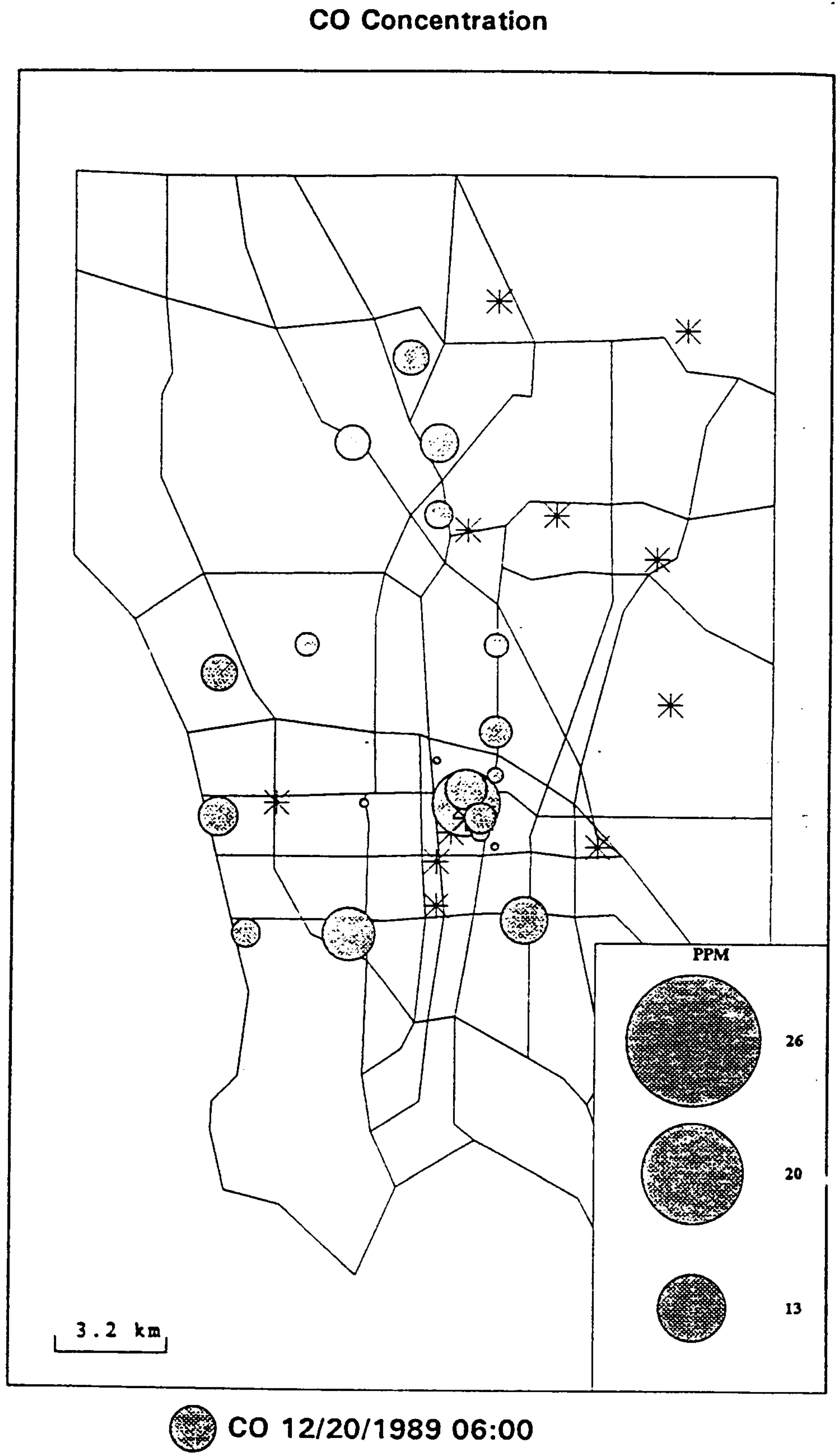


Figure 3g. Morning CO monitoring station readings 12/20/89, 0800, SoCAB. (Adapted from AeroVironment, 1991.)

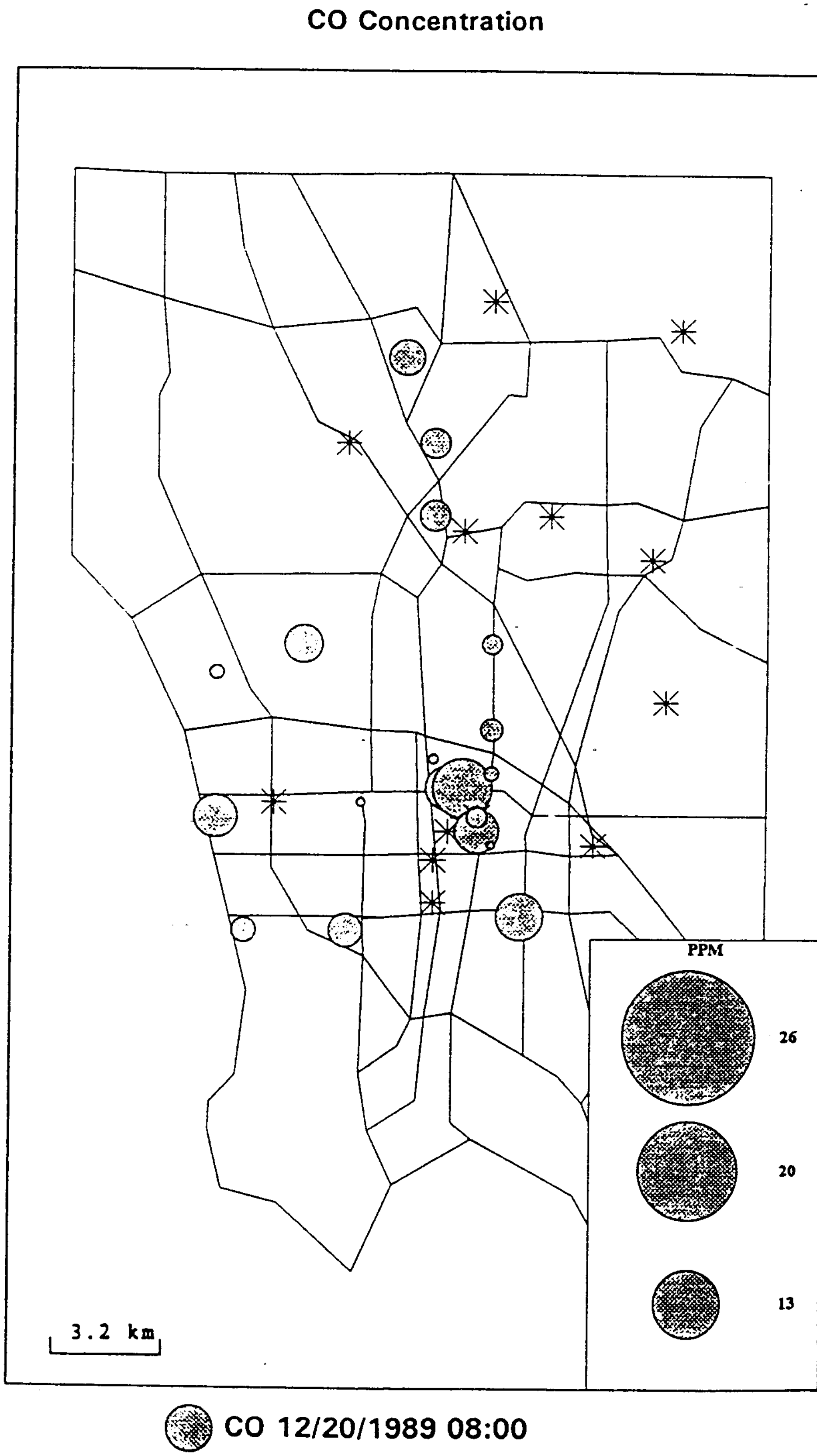


Figure 3h. Morning CO monitoring station readings 12/20/89, 1000, SoCAB. (Adapted from AeroVironment, 1991.)

CO Concentration

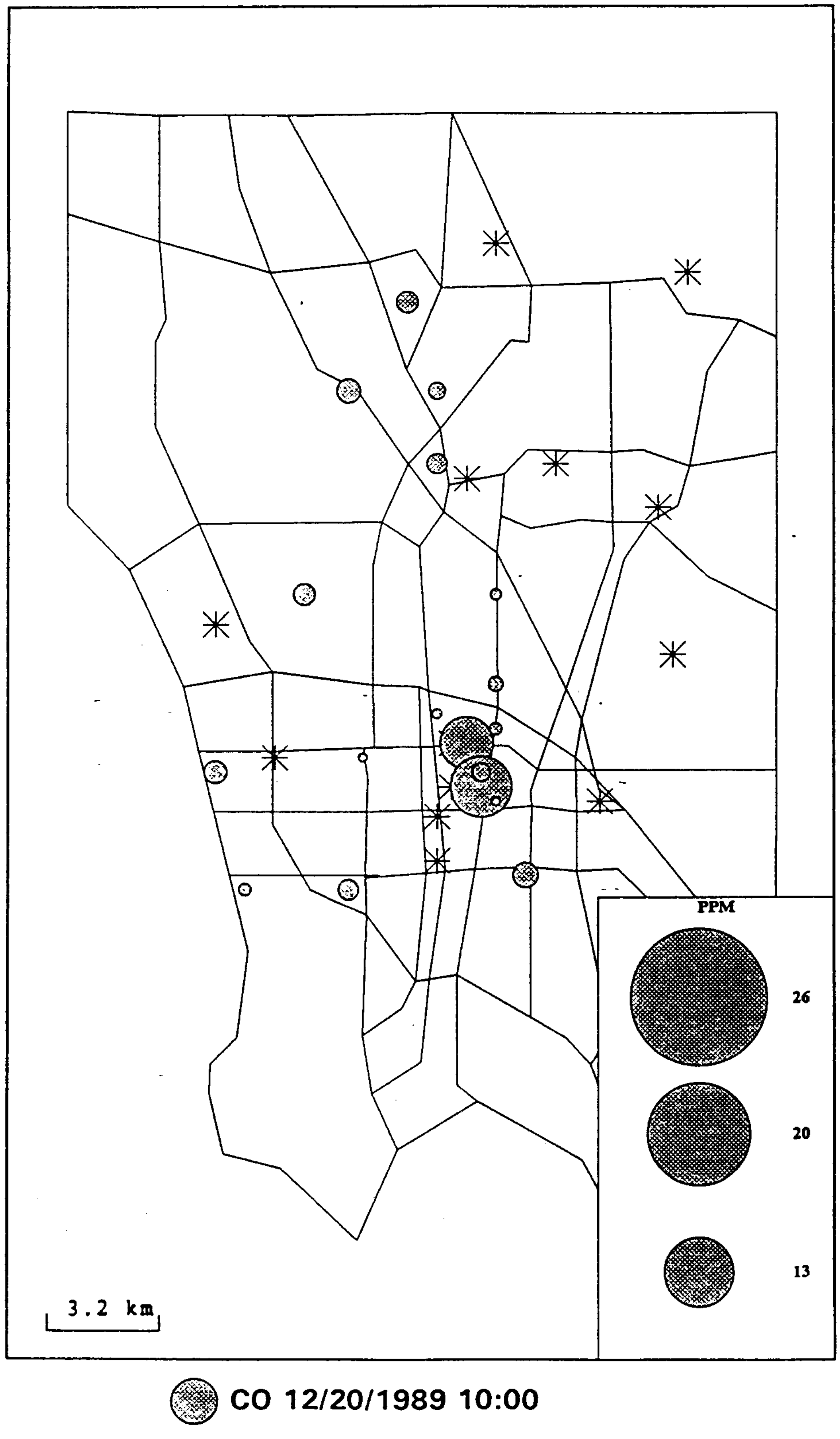


Figure 4a. CO at LYNN; Traffic on Long Beach Blvd.; Lapse Rate, Wind Speed, and Wind Direction at LTS - January, 1990. (Adapted from Bowen et al., 1993.)

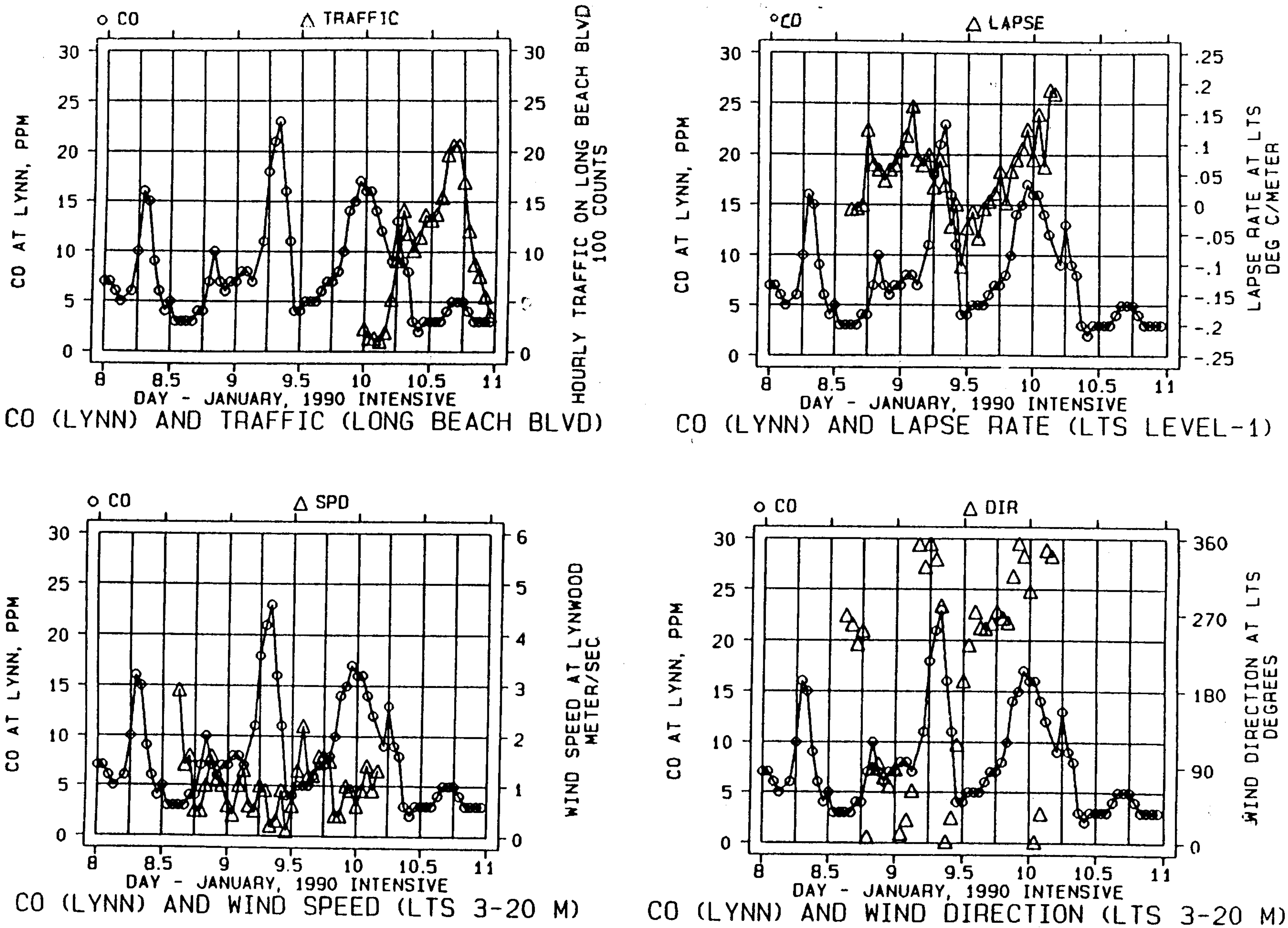


Figure 4b. Evening/nighttime CO monitoring station readings 1/8/90, 1800, immediate vicinity. (Adapted from AeroVironment, 1991.)

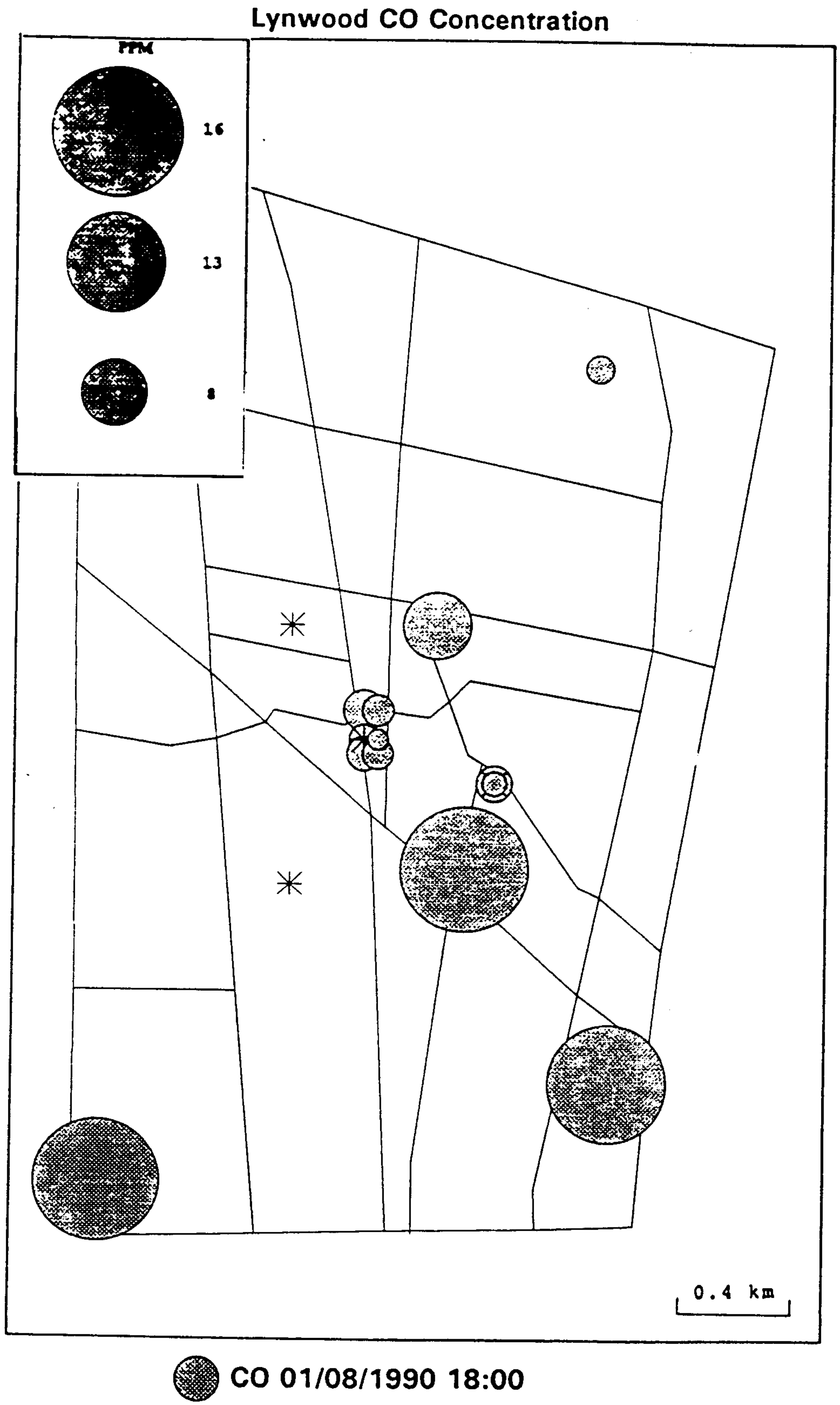


Figure 4c. Evening/nighttime CO monitoring station readings 1/8/90, 2000, immediate vicinity. (Adapted from AeroVironment, 1991.)

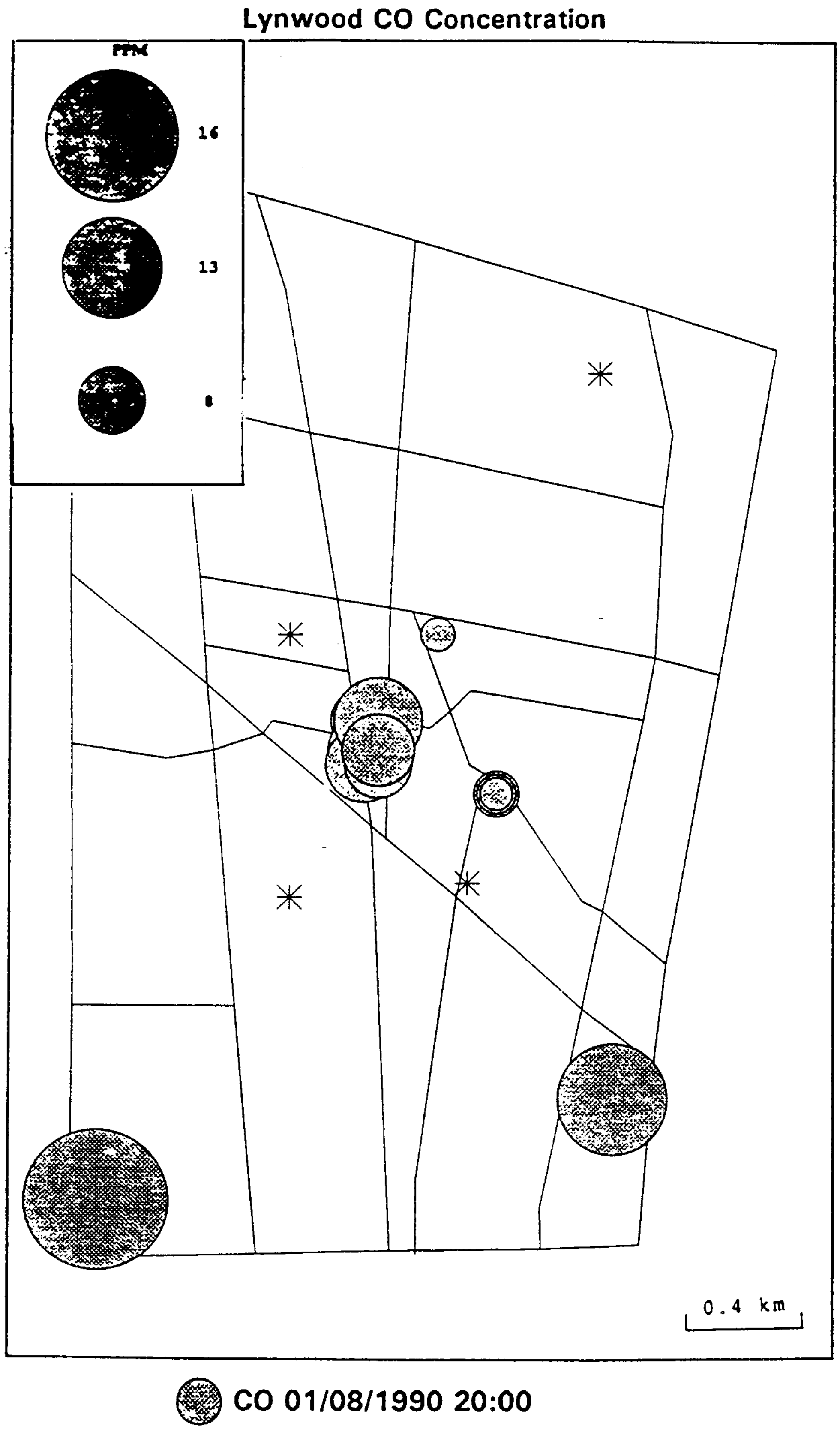


Figure 4d. Evening/nighttime CO monitoring station readings 1/8/90, 2200, immediate vicinity. (Adapted from AeroVironment, 1991.)

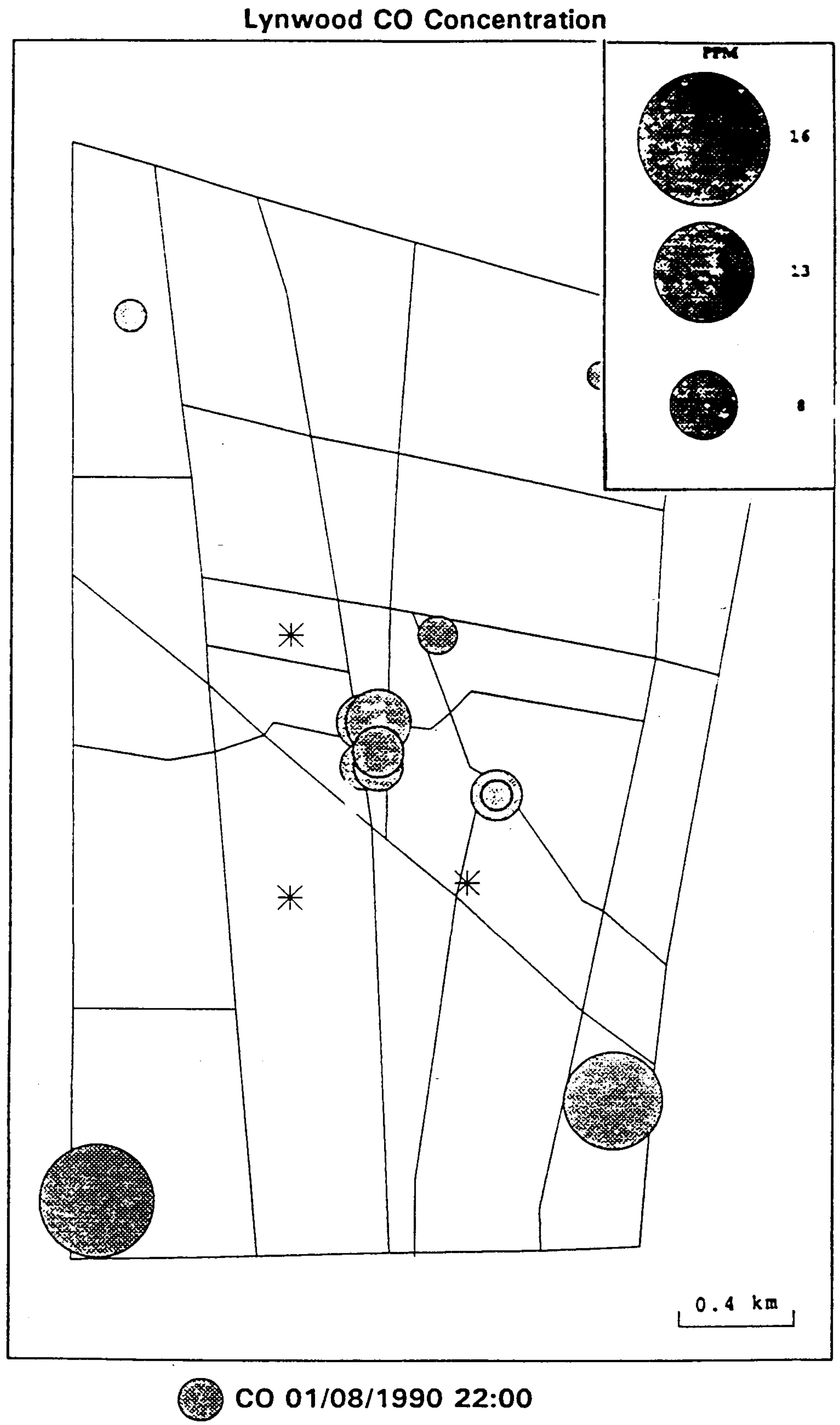


Figure 4e. Evening/nighttime CO monitoring station readings 1/9/90, 0000, immediate vicinity. (Adapted from AeroVironment, 1991.)

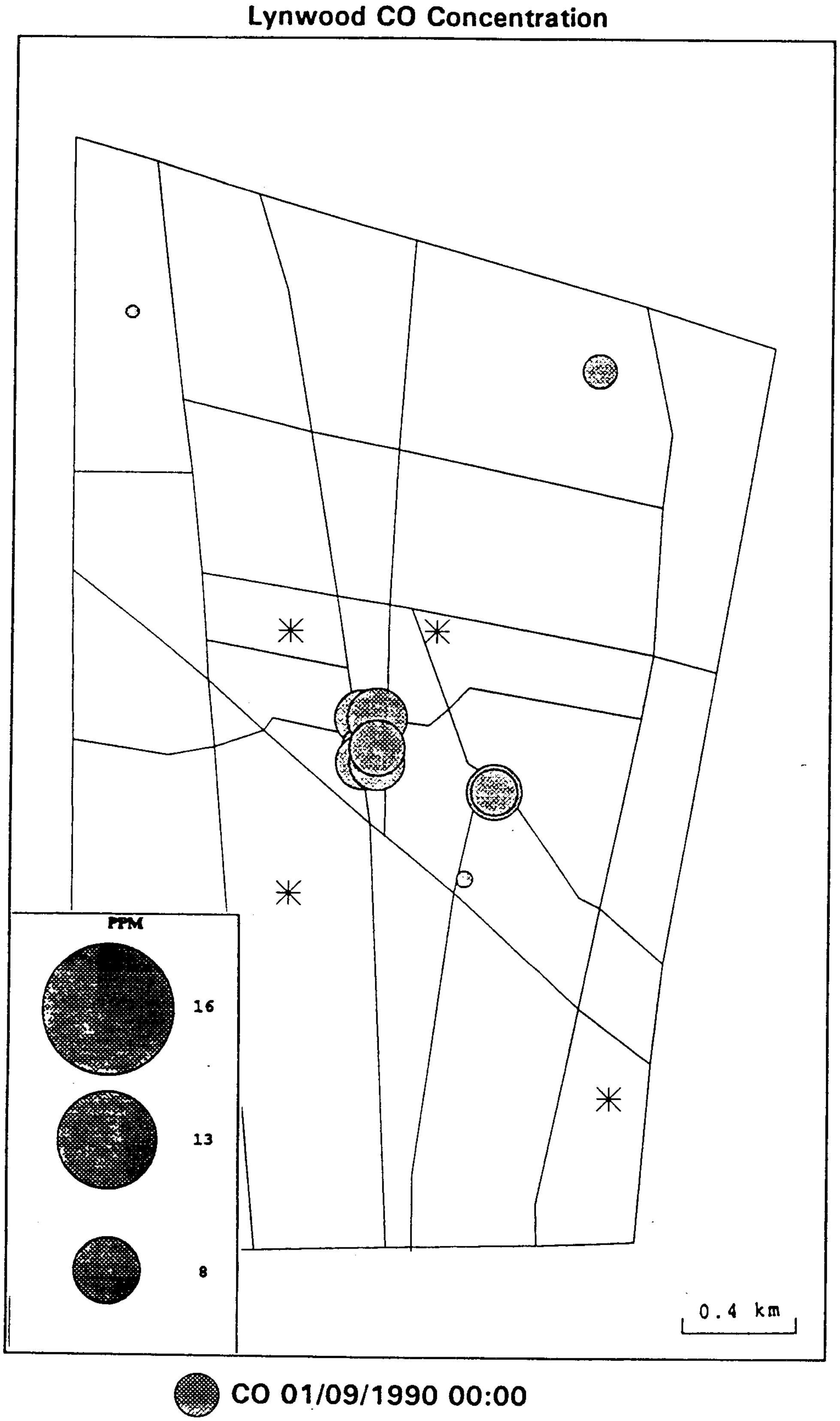


Figure 4f. Early morning CO monitoring station readings 1/9/90, 0300, immediate vicinity. (Adapted from AeroVironment, 1991.)

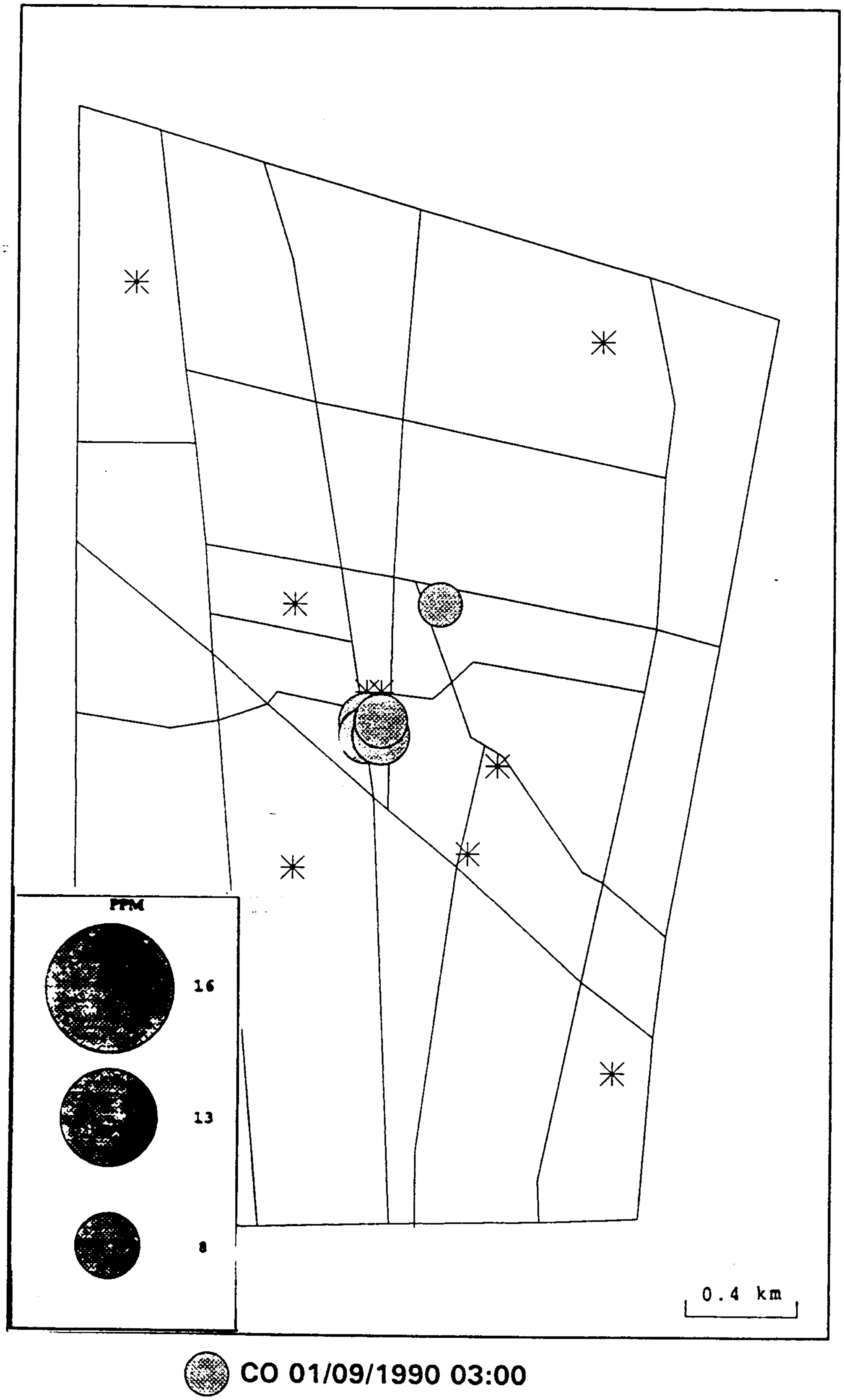


Figure 4g. Early morning CO monitoring station readings 1/9/90, 0400, immediate vicinity. (Adapted from AeroVironment, 1991.)

Lynwood CO Concentration

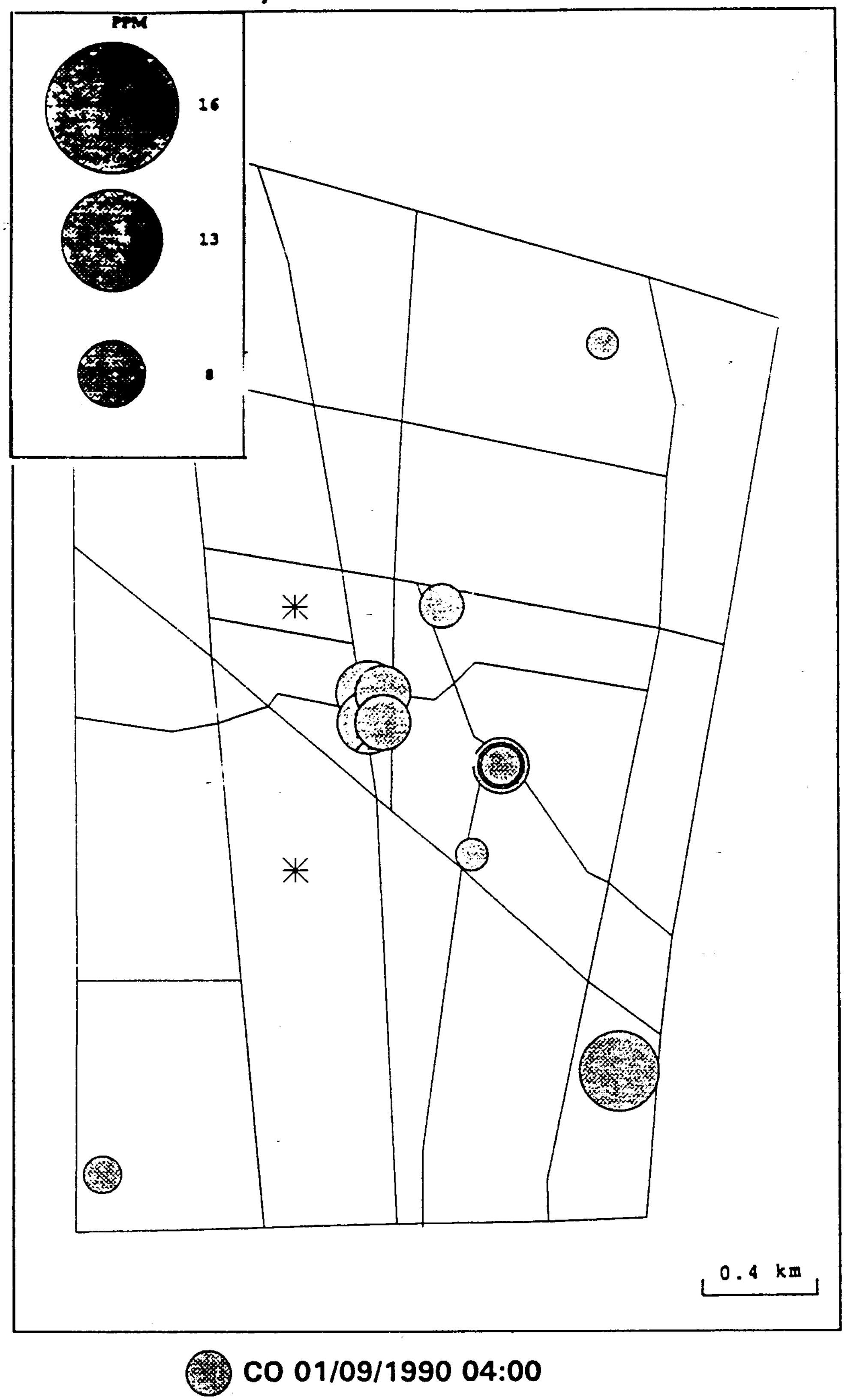


Figure 4h. Early morning CO monitoring station readings 1/9/90, 0500, immediate vicinity. (Adapted from AeroVironment, 1991.)

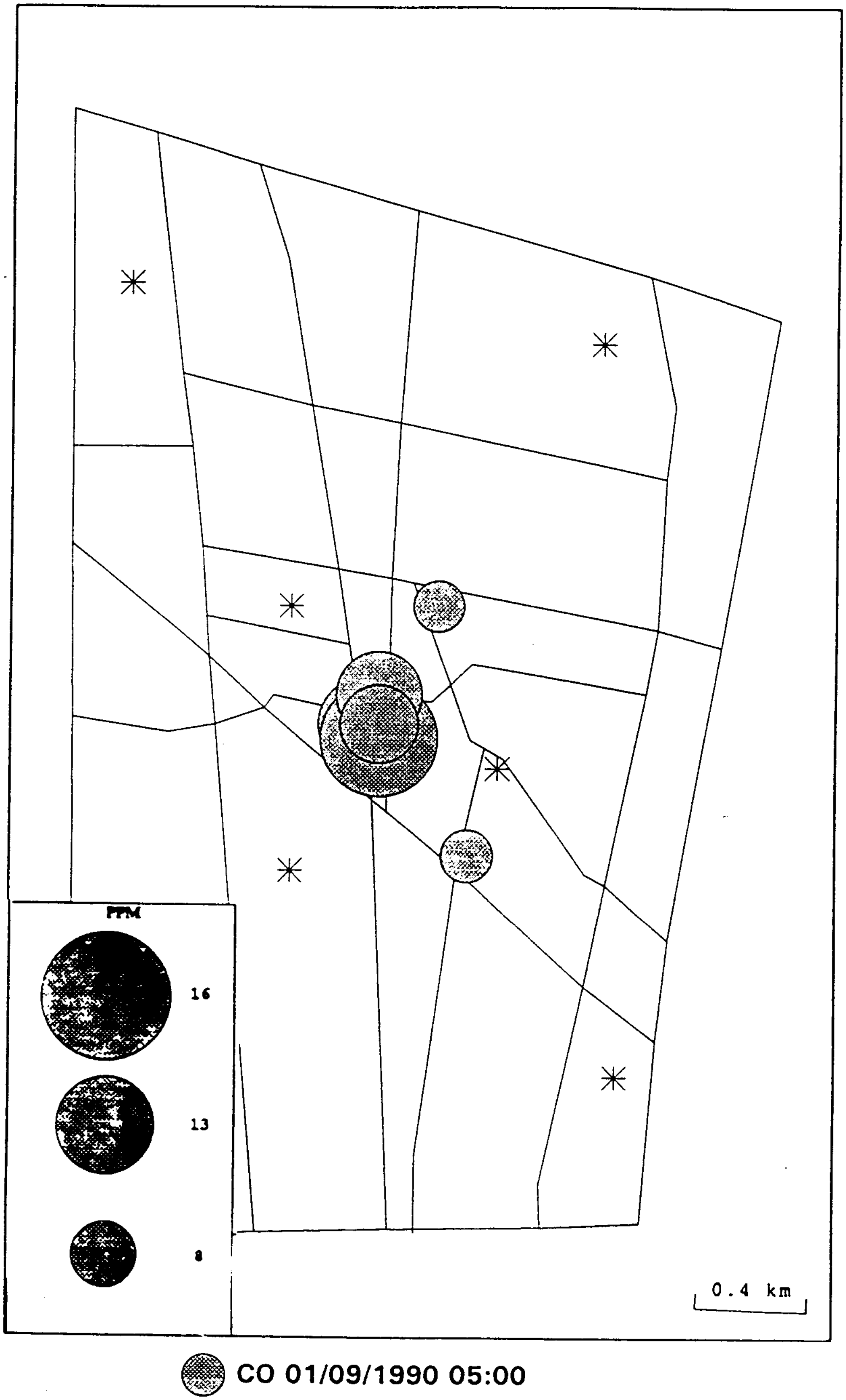


Figure 4i. Early morning CO monitoring station readings 1/9/90, 0600, immediate vicinity. (adapted from AeroVironment, 1991)

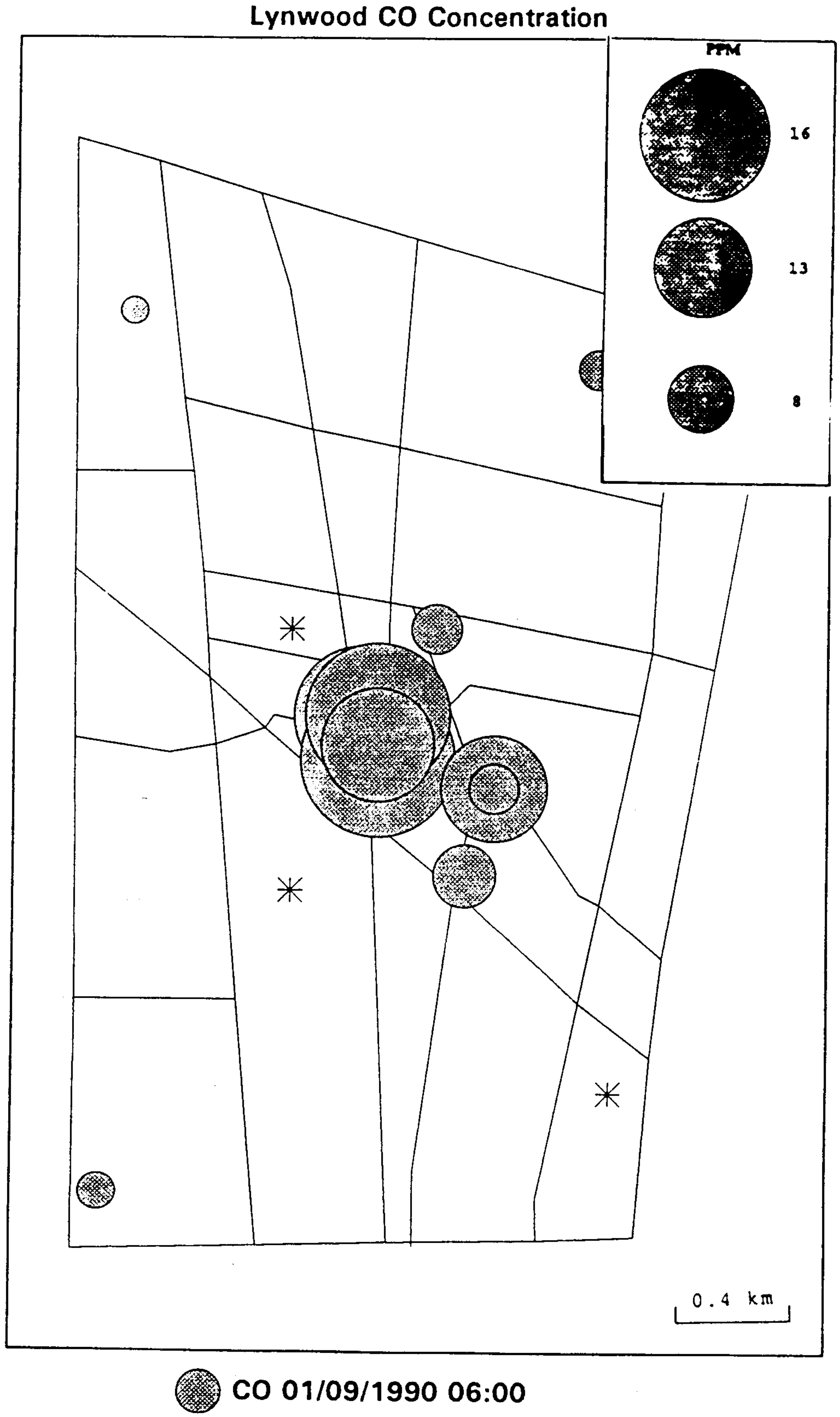


Figure 4j. Early morning CO monitoring station readings 1/9/90, 0800, immediate vicinity. (Adapted from AeroVironment, 1991.)

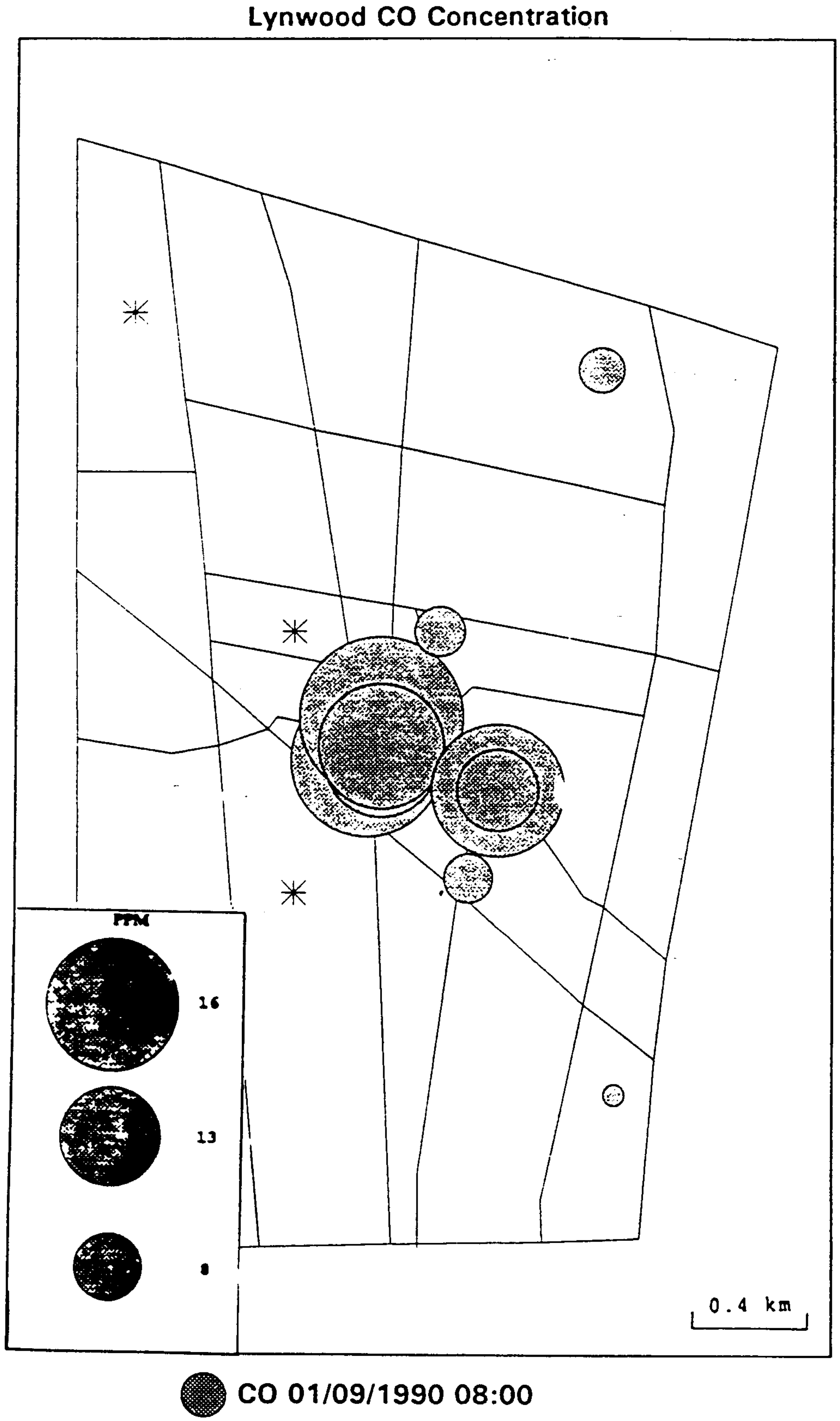


Figure 4k. Early evening/nighttime CO monitoring station readings 1/9/90, 1800, SoCAB. (Adapted from AeroVironment, 1991.)

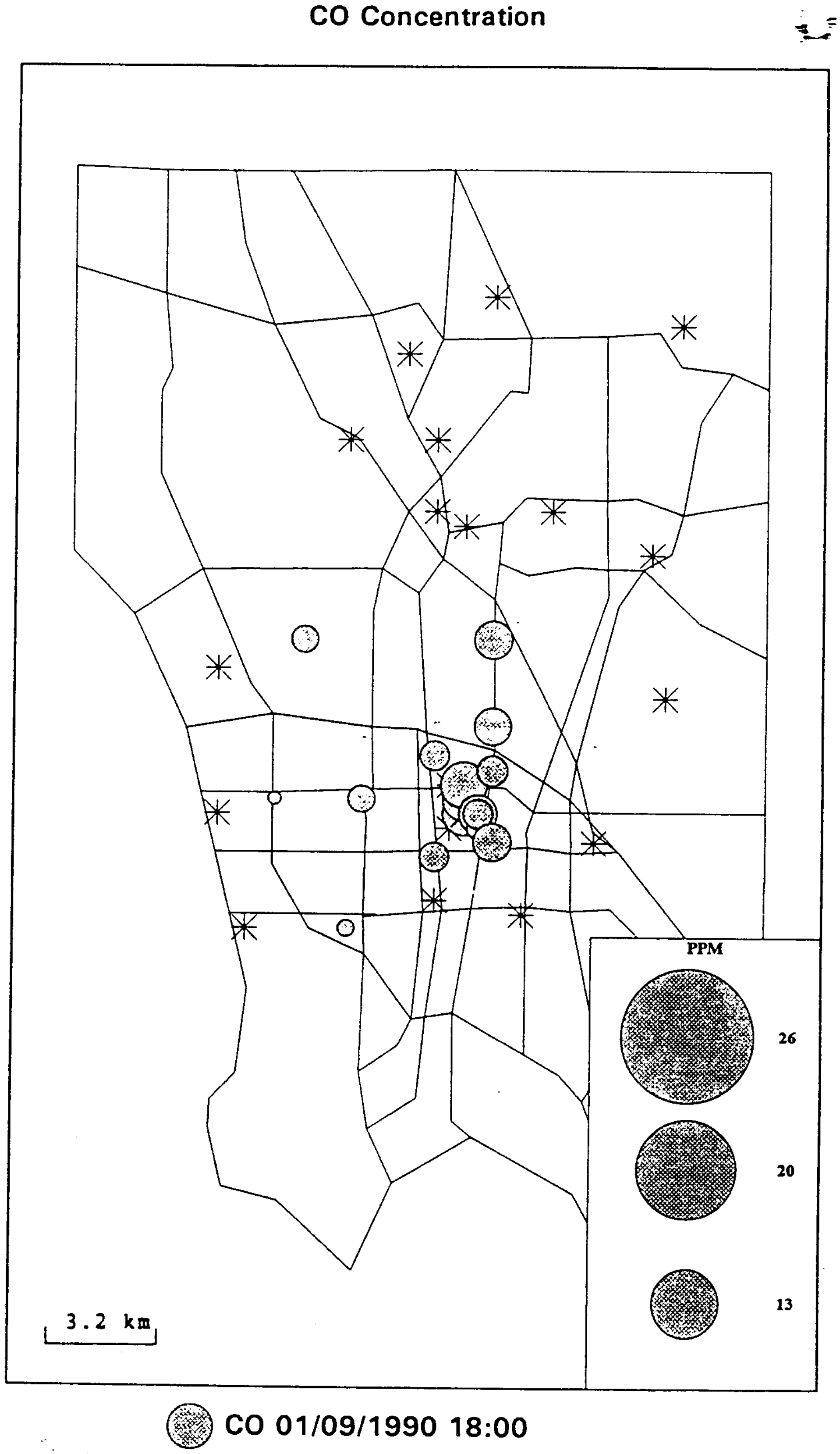


Figure 41. Early evening/nighttime CO monitoring station readings 1/9/90, 2000, SoCAB. (adapted from AeroVironment, 1991.)

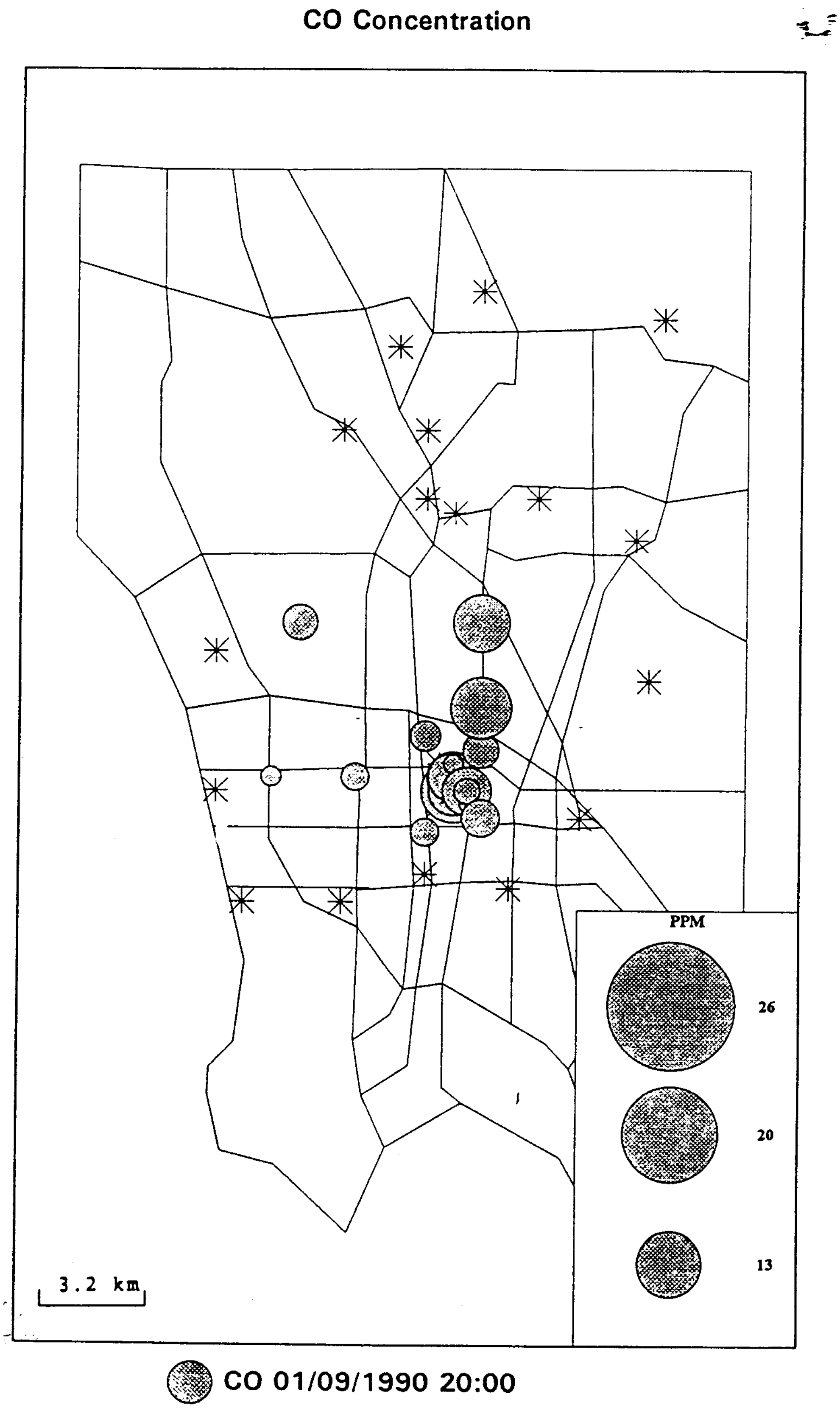


Figure 4m. Early evening/nighttime CO monitoring station readings 1/9/90, 2200, SoCAB. (Adapted from AeroVironment, 1991.)

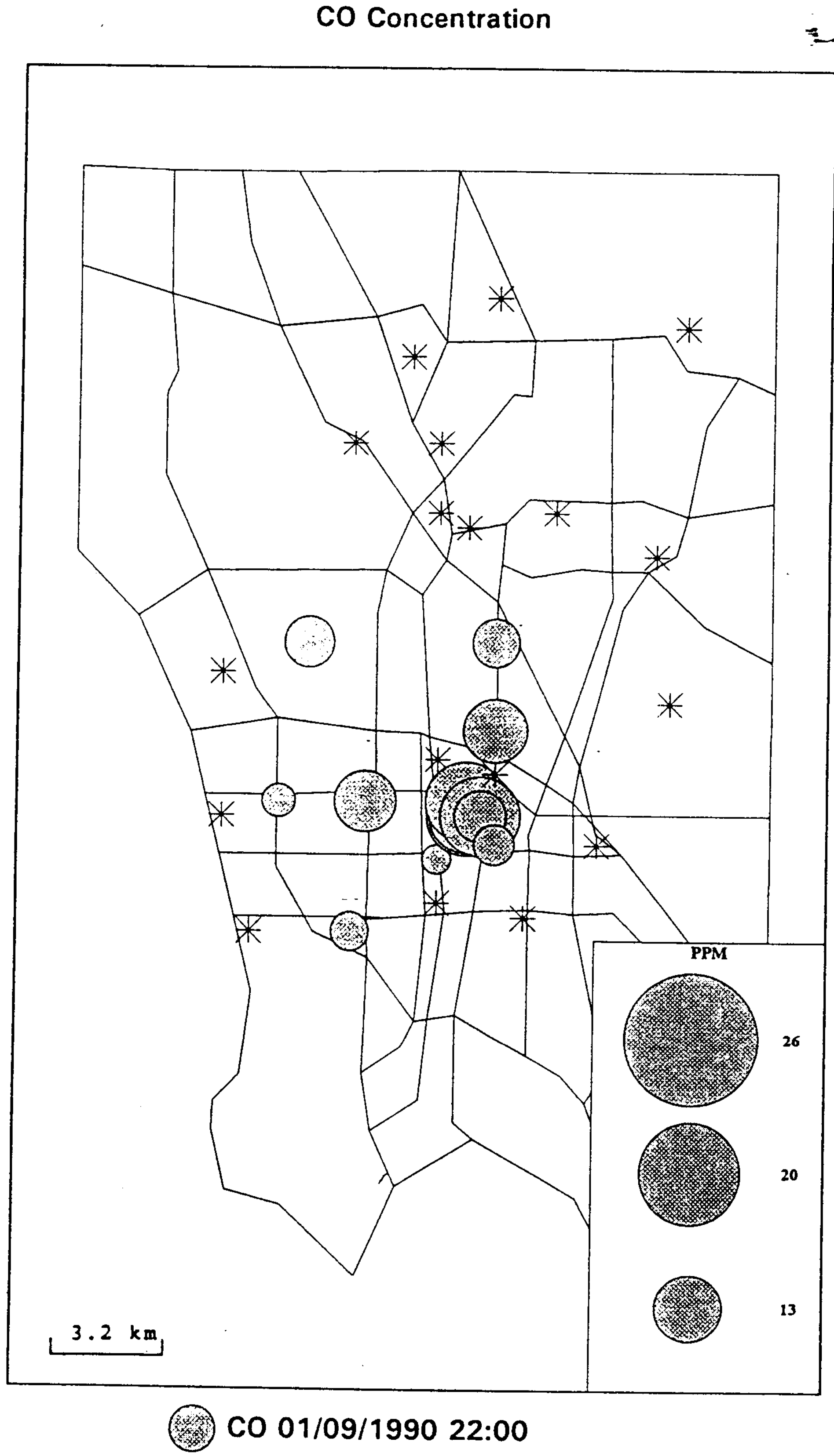
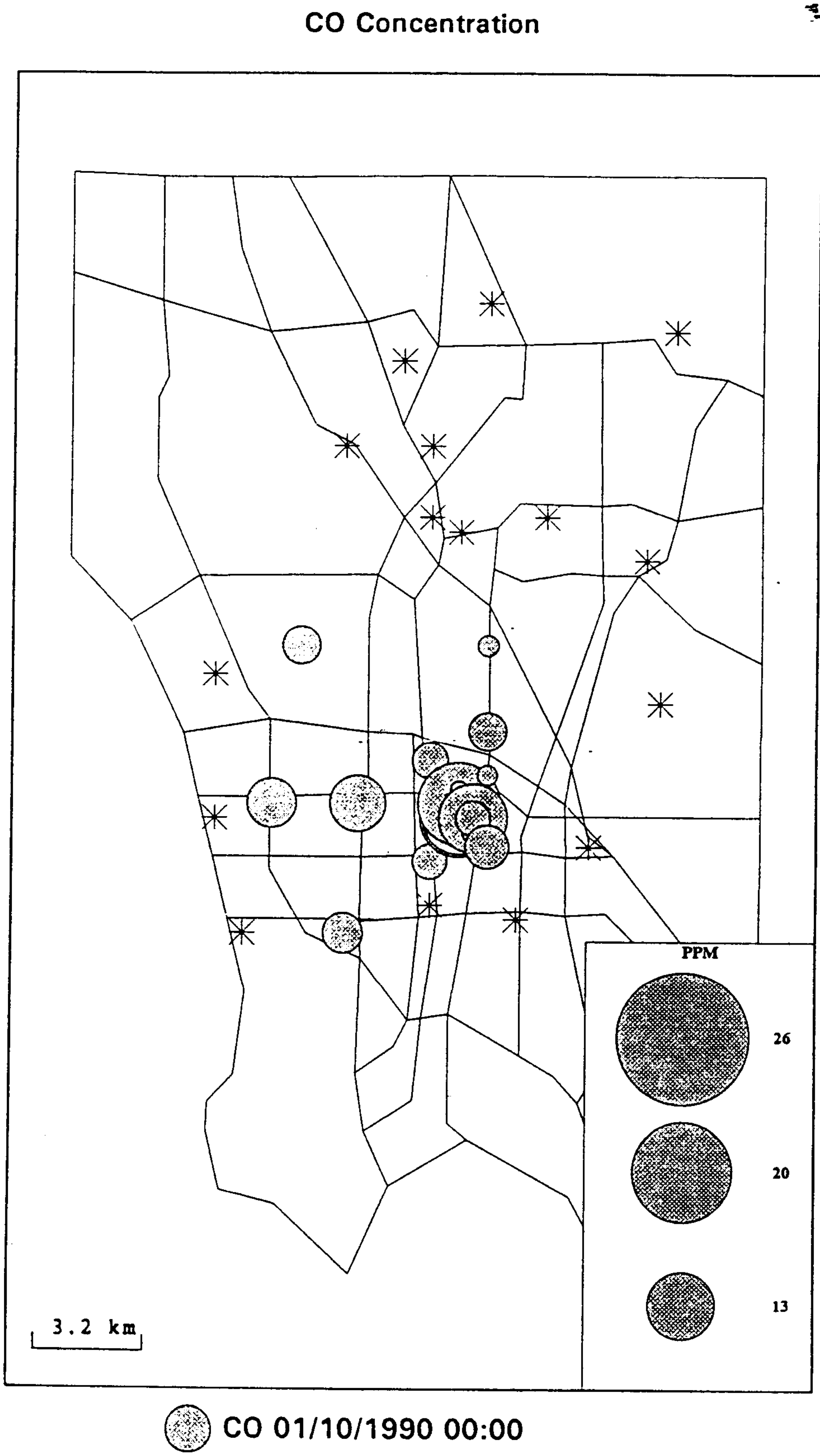


Figure 4n. Early evening/nighttime CO monitoring station readings 1/10/90, 0000, SoCAB. (Adapted from AeroVironment, 1991)



which would tend to reinforce the northerly nocturnal landbreeze, however the amount of this reinforcement would be limited by the small magnitude of slope and would lead to low wind speeds in the vicinity of LYNN when external forcing is weak. The areal extent of small to moderate slope is greater in the vicinity of LYNN than any other site." The significance of that is that nocturnal drainage winds are weaker in Lynwood than many other parts of the SoCAB.

Using the DWM results, it was possible to compute backward trajectories of air transported to LYNN and other SCAQMD sites during the intensive periods. During the two episodes in question, the evening/nighttime air mass over LYNN appeared to have originated from almost due west (Figure 5a, on p. 33, on December 19 and Figures 5b and 5c, on pages 34-35, on January 9) during the more severe nighttime episodes. The trajectories pass near the vicinity of large emission sources, e.g., Los Angeles International Airport and I-405 in the late afternoon. For a less severe nighttime peak on January 8, 1990, the trajectories arrived from the east immediately before arriving at Lynwood, but they originated over southwest to south-southwest source regions, e.g. refineries, in the early afternoon as illustrated in Figures 6a and b, on pages 36-37.

Also noteworthy from the trajectory analysis is that the winds diminish as the nighttime stable conditions establish themselves. Emissions from the strong source regions about 15 km west that arrive at LYNN at 2000 hours were emitted under unstable conditions (1500 to 1600 hours) and underwent considerably greater dilution. The winds became less than 1 km/hr during the nighttime episodes so that emission sources that led to the build-up after the onset of stable conditions must be within a few kilometers of the LYNN station. Thus the emission regions to the West could have contributed to a generally higher background, perhaps as much as 5 ppm, but this cannot explain the high concentrations at LYNN, even if transport aloft had occurred.

An isotopic ratio study $^{14}C/^{12}C$ in CO was also undertaken. An inverse relationship of that ratio, as CO levels increased was taken as evidence that fossil sources of CO, rather than modern sources of CO, e.g., wood-burning, dominated. A relatively constant amount of 0.75 ppm ^{14}CO was observed whereas the northern hemisphere modern ^{14}CO content of 0.2 ppm has been reported in the literature. Therefore, about 0.55 ppm of ^{14}CO appears to be present in the Los Angeles air. The magnitude of the recent CO content ranged from about seven to 32 percent. An attempt was made to identify the source from the ratio of $^{13}C/^{12}C$, but it was inconclusive.

An attempt was also made by the DRI researchers to use the data from the GM rover vehicles to compute fluxes of CO across vehicle paths in order to find sources. This effort proved not particularly insightful because, "the apparent influence of local

Figure 5a. Backward trajectory 12/19/89 arriving at LYNN 2300 hours. (Adapted from Bowen et al., 1993.)

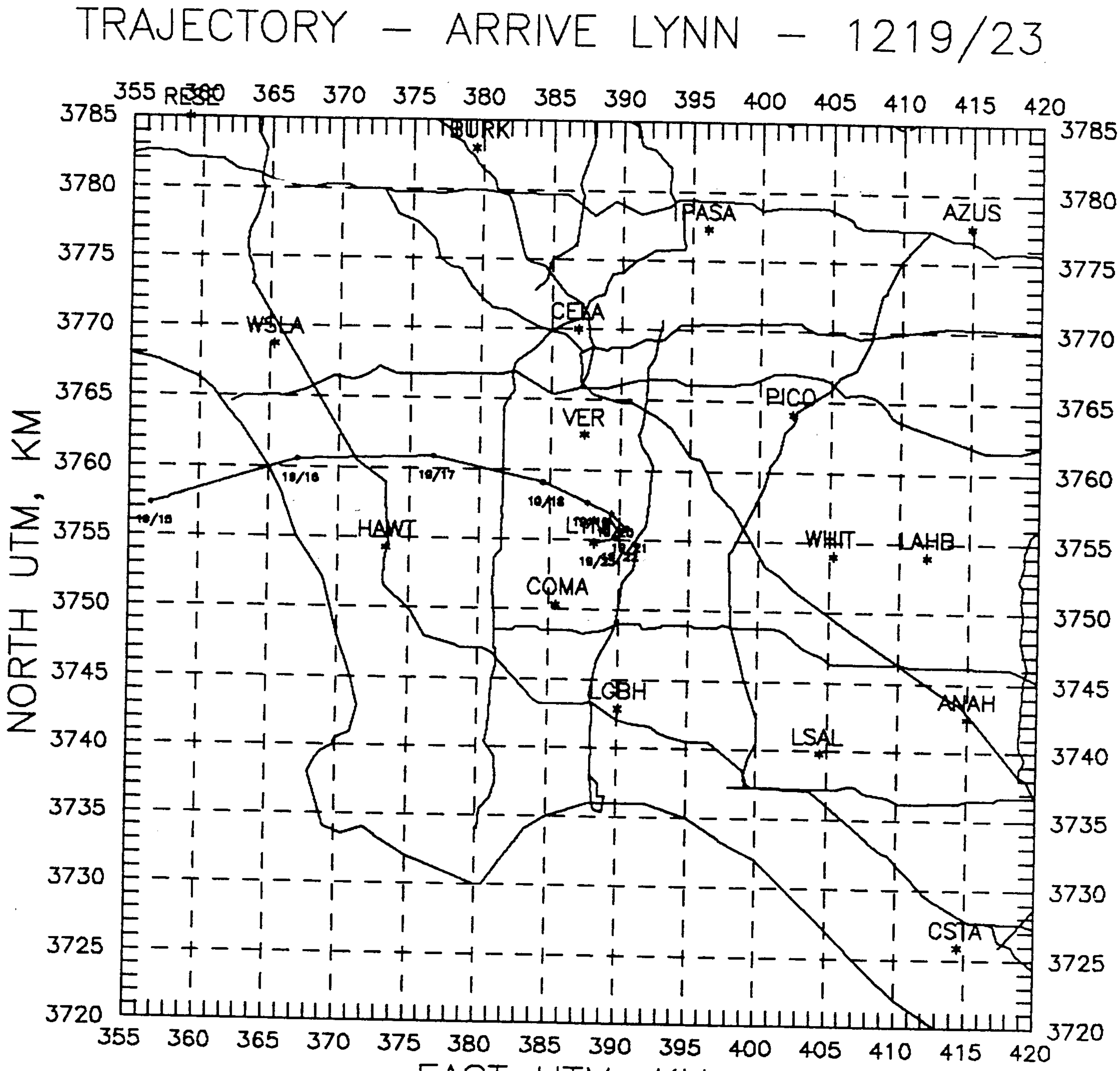


Figure 5b. Backward trajectory 1/9/90 arriving at LYNN 2100 hours. (Adapted from Bowen et al., 1993.)

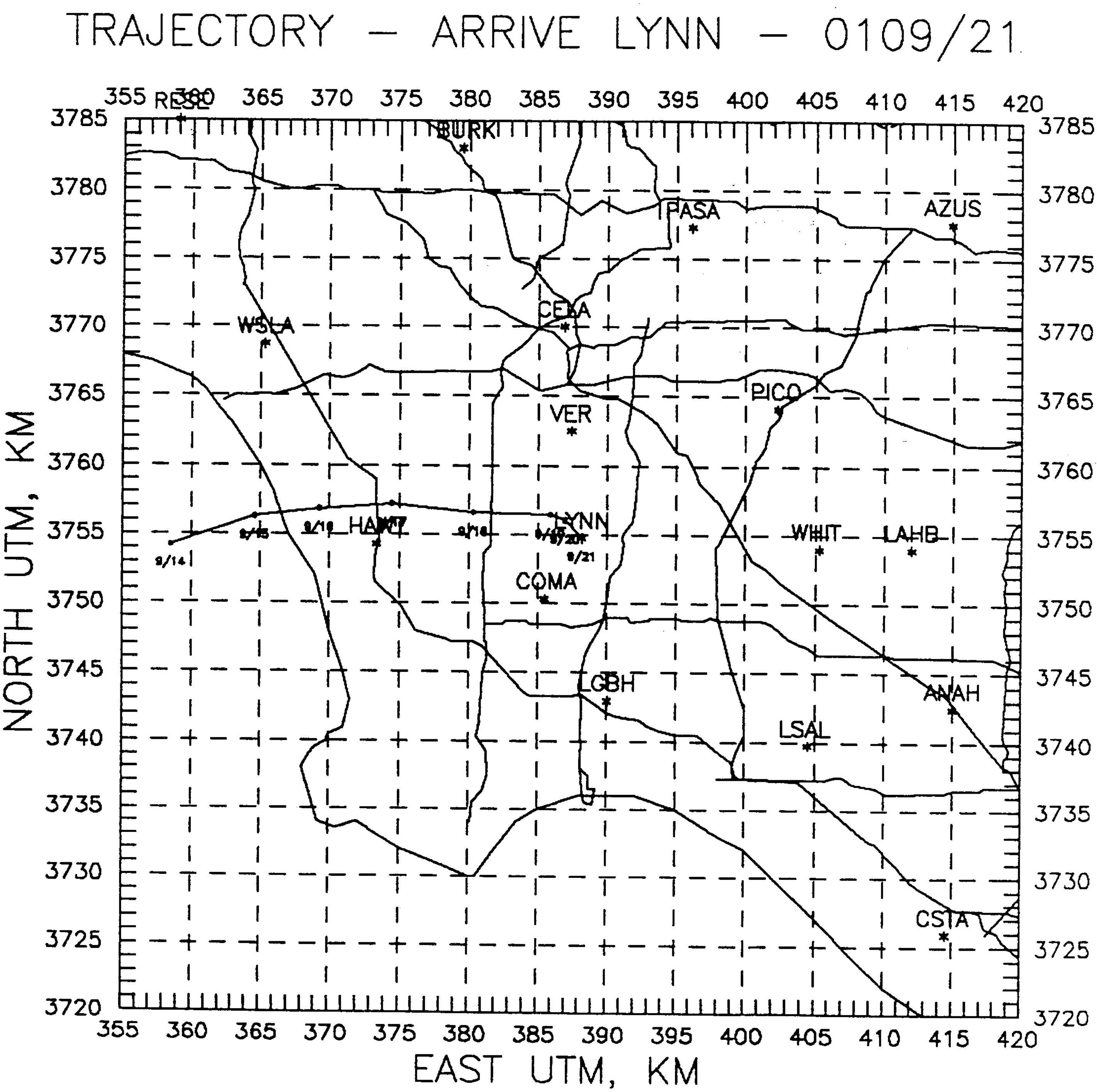


Figure 5c. Backward trajectory 1/9/90 arriving at LYNN 2200 hours. (Adapted from Bowen et al., 1993.)

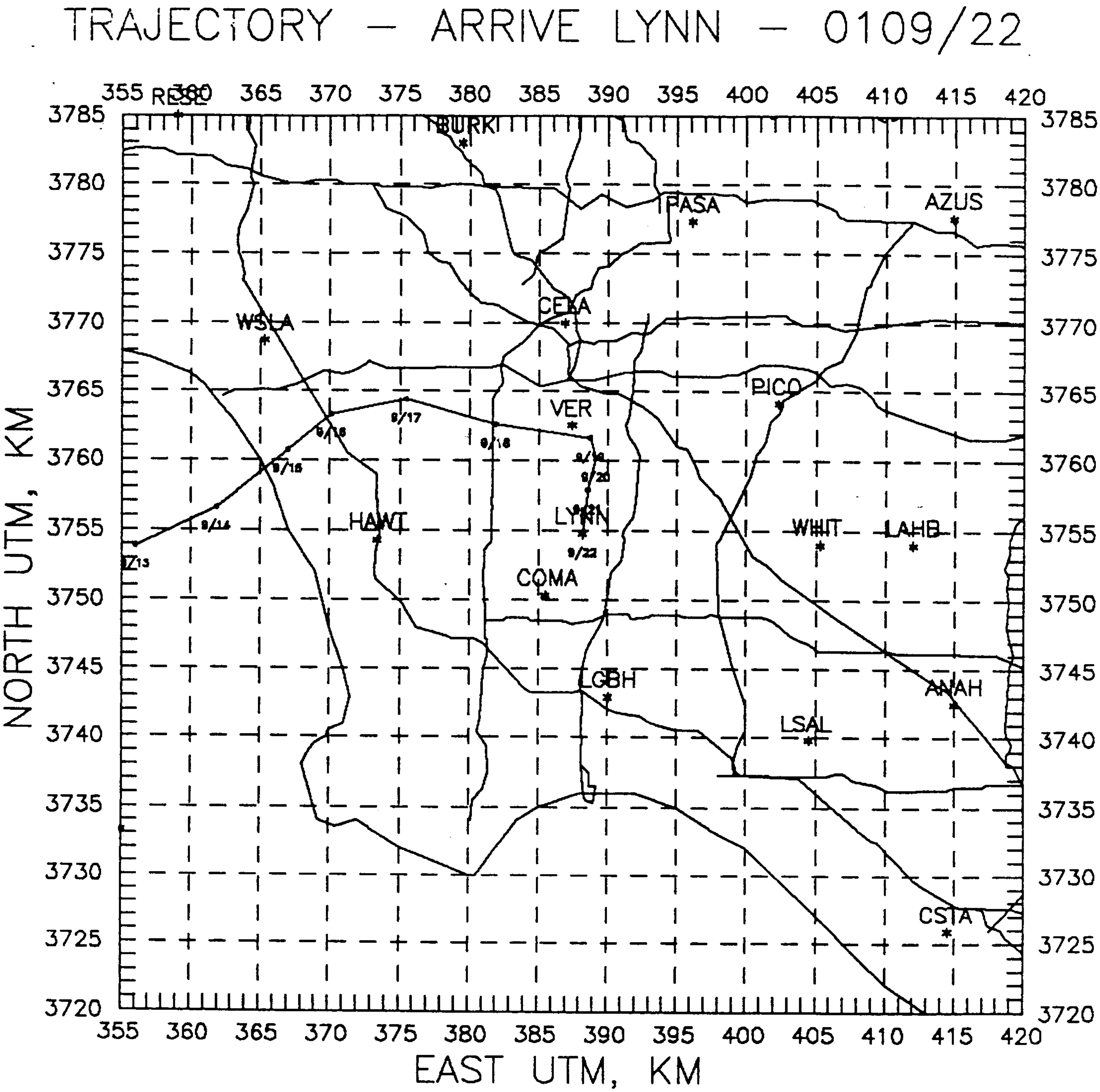


Figure 6a. Backward trajectory 1/8/90 arriving at LYNN 2200 hours. (Adapted from Bowen et al., 1993.)

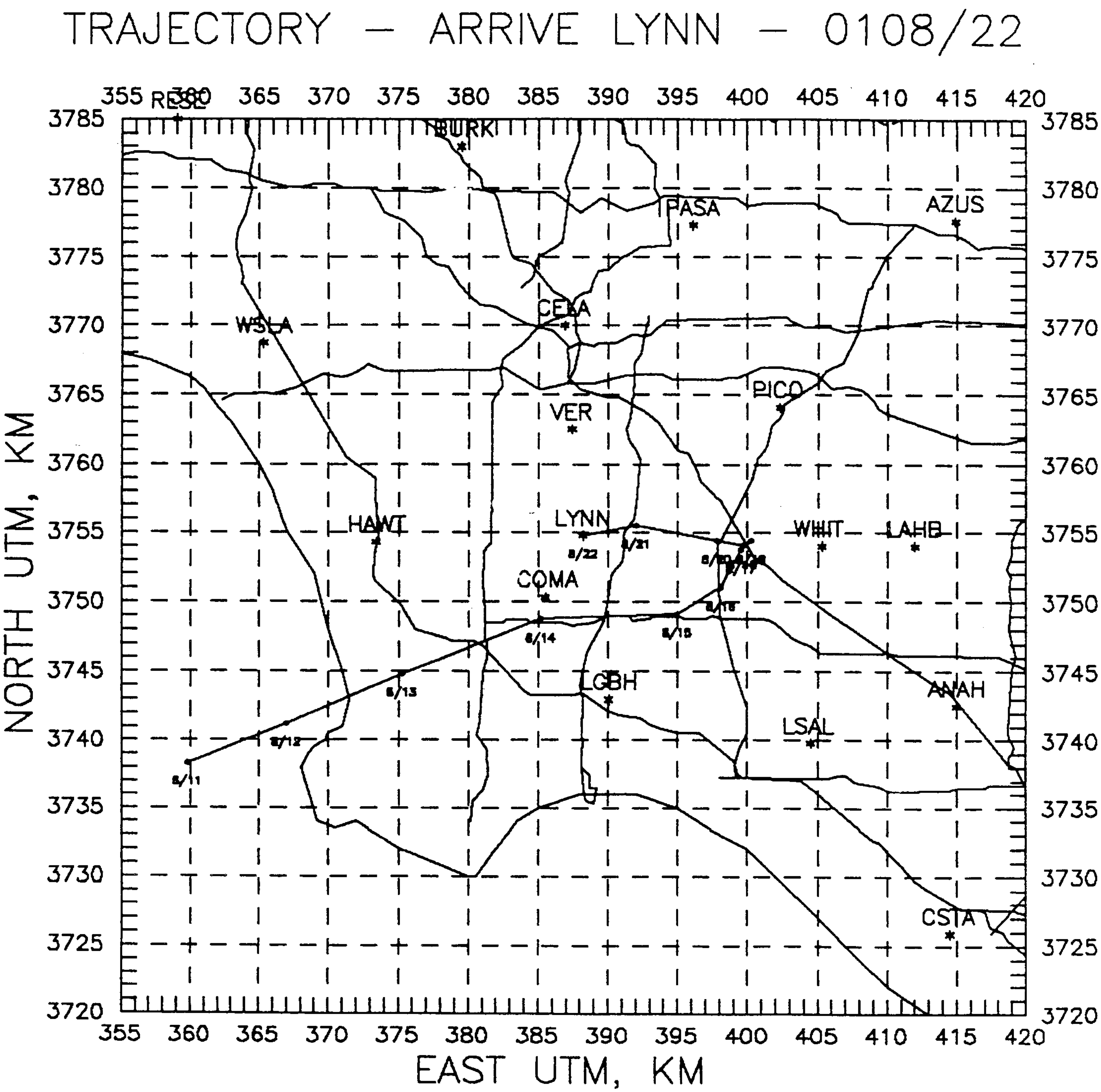
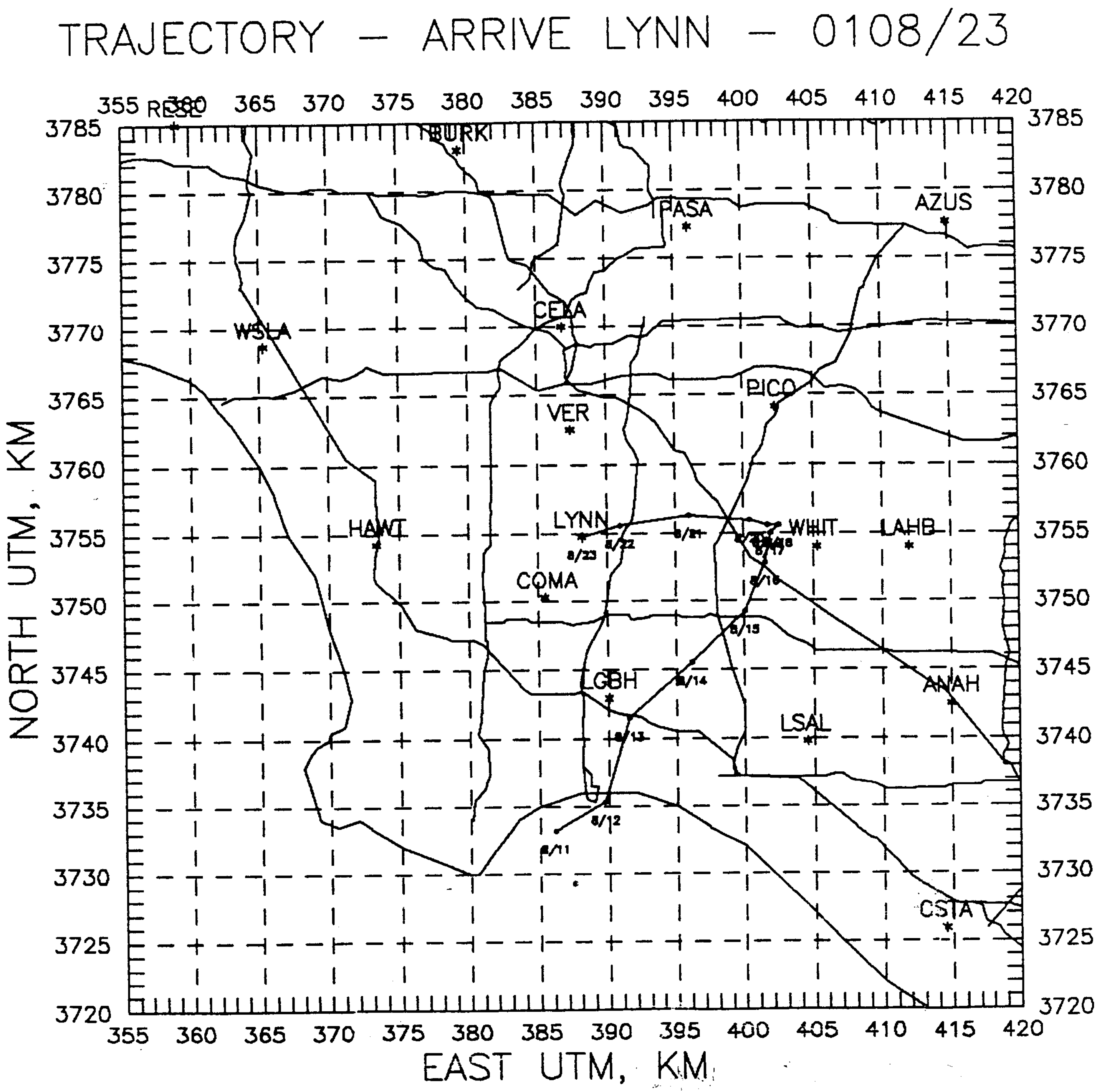


Figure 6b. Backward trajectory 1/8/90 arriving at LYNN 2300 hours. (Adapted from Bowen et al., 1993.)



traffic overwhelmed other sources." Similarly, DRI researchers concluded that the tracer releases were of limited value because of mistimed bag samplers, so that tracers were recorded as being present in some bags before the tracers had been released.

We performed a manual examination of the tracer data contained in Appendix D of the Aerovironment (1991) report in hopes that some information could be gleaned. The perfluoromethylcyclopentane (PMCP) tracer release on the night of December 19th indicated that PMCP released about 10 km northeast of LYNN arrived and departed the vicinity of the LYNN monitor within about a two-hour period. A peak in PMCP concentration appeared to have arrived at sampling stations approximately ten km to the southeast and southwest of LYNN about an hour later. That scenario is reasonably consistent with the measured surface wind speeds, wind directions and the calculated wind field trajectory analyses performed by DRI. It should be noted that the CO concentration declined at the LYNN station by about 50% prior to the time the parcel containing the tracer arrived at LYNN, coinciding with an increase in wind speed just before midnight. No evidence of simultaneous CO transport from the immediate vicinity of the LYNN station to the south is evident from the CO samplers. These data provide further evidence that the CO "hotspot" in the vicinity of the LYNN station is not extensive in area. However, because the tracer release was continuous throughout the period (1700 to 0600 hrs), the interpretation of the trajectory is not definitive and alternate trajectories are possible.

Bowen et al. (1993) applied Empirical Orthogonal Function (EOF) analysis to a limited subset of CO data that had sufficient quality and quantity for model application. The EOF analysis, with "proper interpretation," was used to examine the spatial variation in air quality data and to indicate the location of sources of air pollution. Three spatial patterns were reported to have been found in the data. (See Figures 7a to 7c, on pages 39-40.) "The first EOF explained 65 to 70% of the variability in the CO data and "expressed the fact that CO concentrations at all sites tend to vary together. The second EOF explained 17 to 20% of variability of CO data and represented a major feature of the variability in the data. The fact that the SCAQMD site at Lynwood was associated with coastal sites, while bag sample sites less than 100 meters to the north (HS02 and HS05) were associated with inland sites, indicated that a source existed between the SCAQMD site and the bag sample sites." Bowen et al. noted that a possible source of emissions in the immediate proximity of the LYNN station may be due to operations associated with the U.S. Post Office located between the LYNN site and bag sites. "The source appears to contribute 1 to 3 ppm CO to the concentration at the SCAQMD site. The third EOF explained about 7% of the variability in the CO data and had relatively high values at the Lynwood AQMD site and the two nearby bag sample sites and low values for all the surrounding sites. This pattern is consistent with a source of wider areal extent within 5 km of Lynwood."

Figure 7a. First EOF of CO Data. Values are in ppm difference from the mean. The numbers above the site name are for the two-hour average data; the numbers below are for the one-hour average data; explains 68% of two-hour variance. (Adapted from Bowen et al., 1993.)

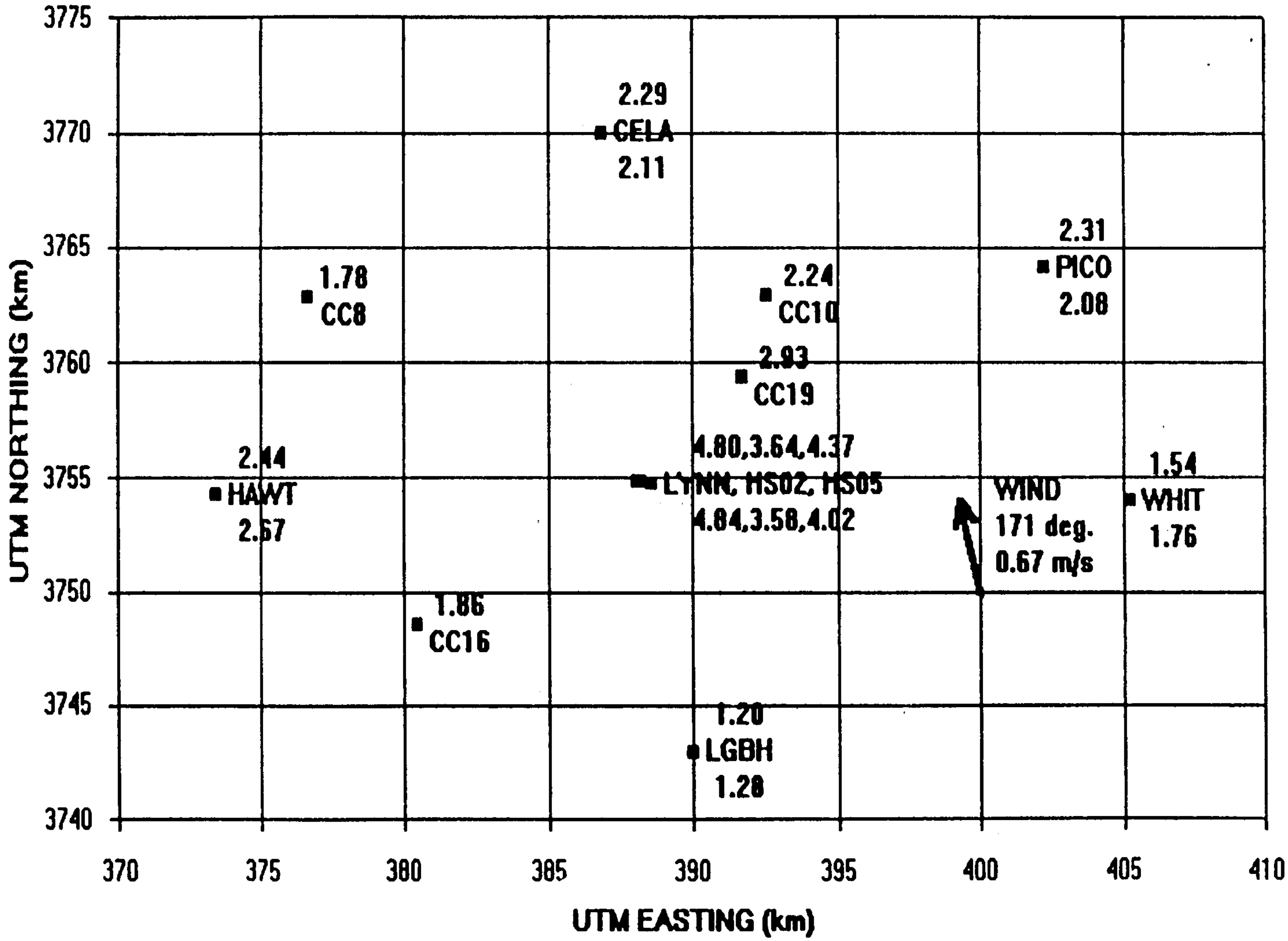


Figure 7b. Second EOF of the CO Data. Values are in ppm difference from the mean. The numbers above the site name are for the two-hour average data; the numbers below are for the one-hour average data; explains 20% or two-hour variance. (Adapted from Bowen et al., 1993.)

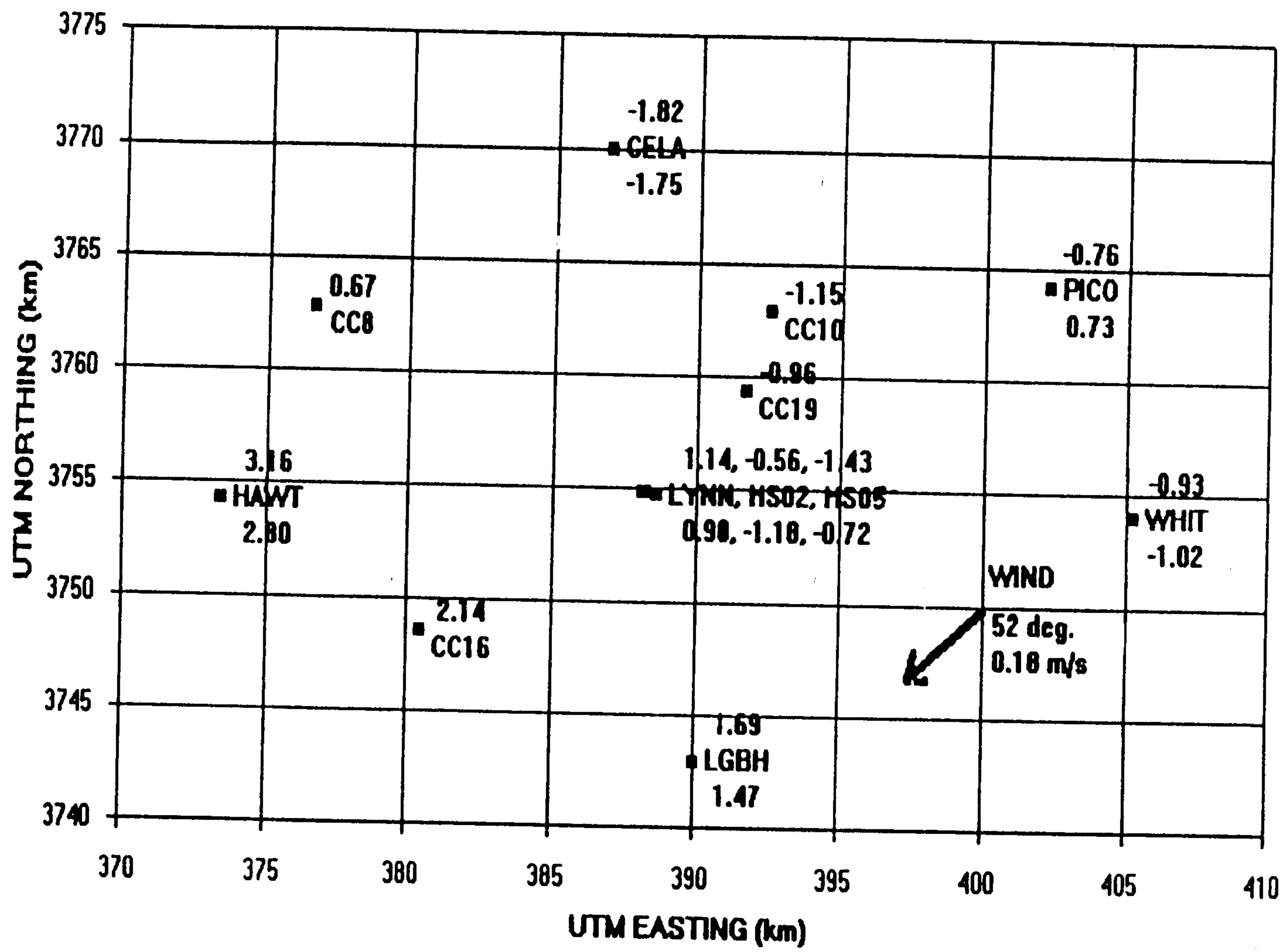
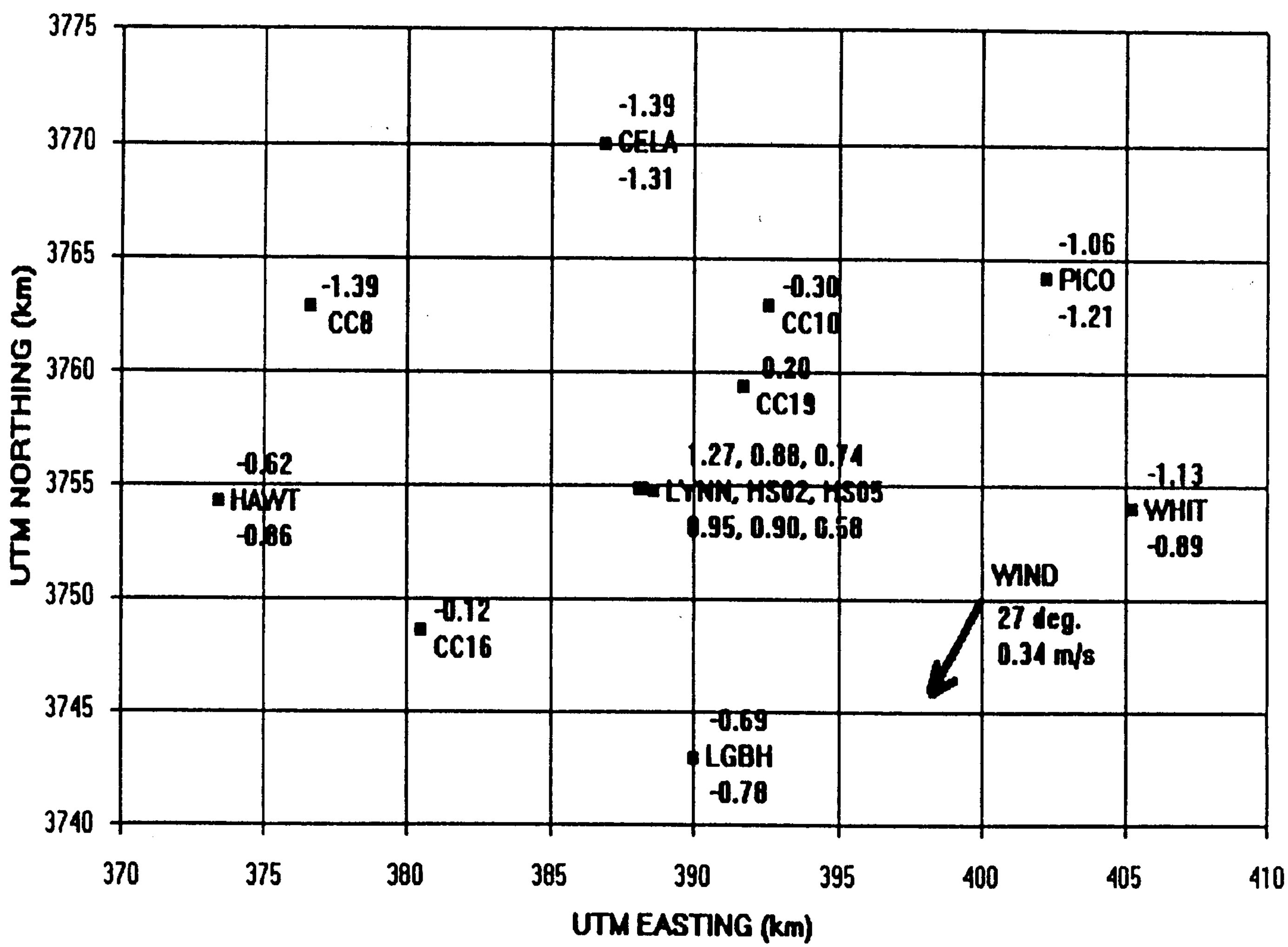


Figure 7c. Third EOF of the CO Data. Values are in ppm difference from the mean. The numbers above the site name are for the two-hour average data; the numbers below are for the one-hour average data; explains 7% of two-hour variance. (Adapted from Bowen et al., 1993.)

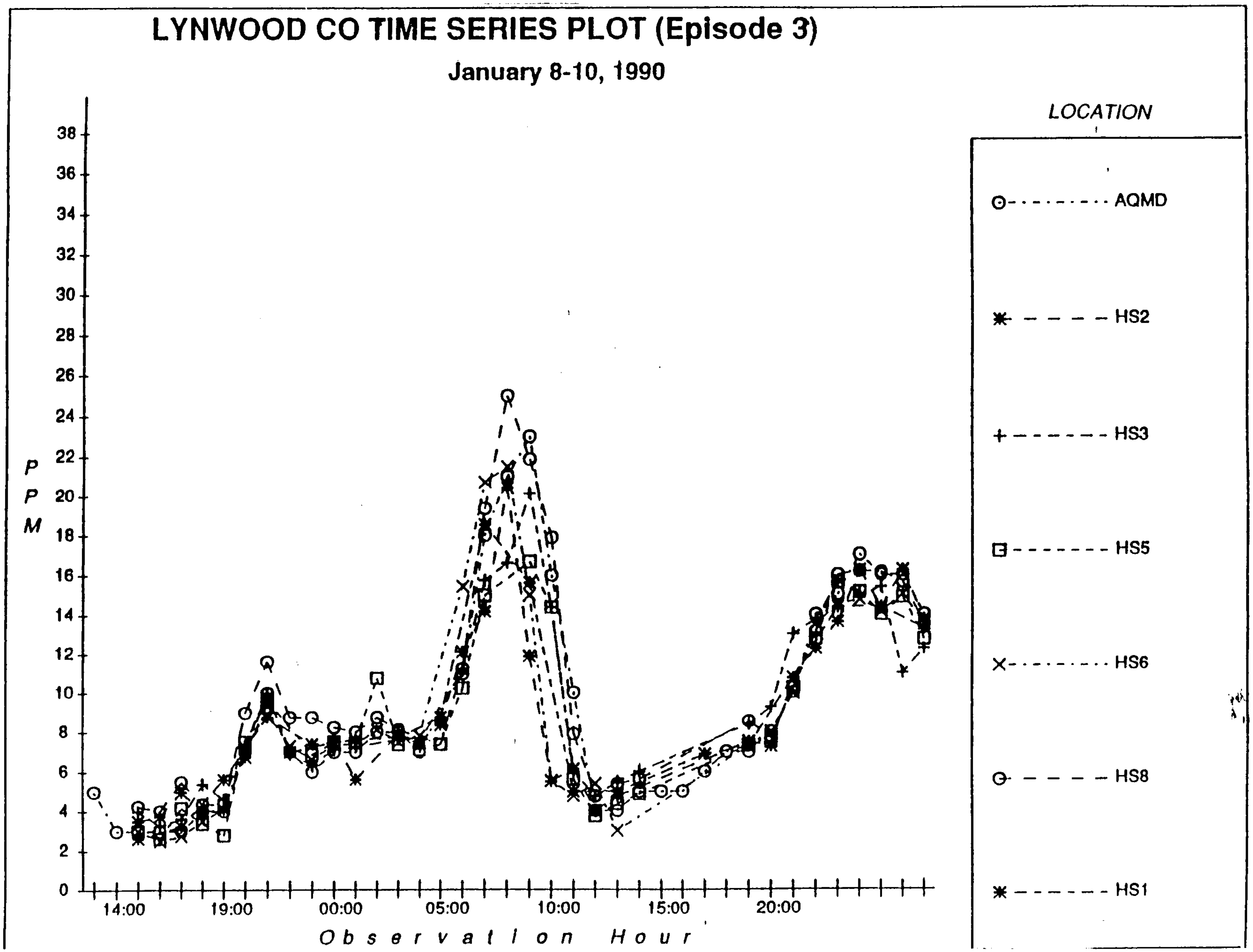


Although the EOF analysis appeared to be a promising approach, a very limited set of data were analyzed in order to achieve a complete data set. Only sites that had a sufficient number of two-hour average concentrations were used. Unfortunately, the need for completeness of the data set for the statistical analysis eliminated the three one-hour bag samplers (HS01, HS08, HS06) that produced the highest single correlations with the LYNN (AQ1) monitor (Bowen et al., 1993a). Two of those stations were operated only during the January episode. One was located near the intersection of Imperial and Long Beach about a block east along Imperial (HS08), and one (HS06) was on Long Beach Blvd. less than one hundred meters south of the LYNN monitor (AQ1). (Refer to Figure 2, on p. 7, for sampler locations.) See Figure 8a, on p. 43, illustrating the variation of concentrations measured at the samplers in the immediate vicinity of the LYNN (AQMD) station. The highest hourly value observed during the study occurred at HS08, about a block and a half northeast of the AQMD monitor. Although wind speeds were low during the episode (less than 1 m/s), average wind direction appeared to be from the north throughout (it is possible the wind vane was stuck). Both HS02 and HS05, in between HS08 and AQMD, appear to have recorded lower values than at HS08, but slightly less than that at AQMD and HS03. The drop off of the peak concentration of CO during the episode related more closely to change in the lapse rate than change in wind speed or traffic from nearby freeway counts. We conclude that it is not possible to draw any firm conclusions from the EOF analysis, but that there is quite clearly an area of at least several hundred meters in diameter about LYNN where CO concentrations are strongly correlated. There is also a possibility that there is a source between the LYNN station and the intersection of Long Beach and Imperial.

Bowen et al. concluded that "the occurrence of high CO concentrations in the Lynwood area are a result of a combination of 5 key factors which are themselves independent: source regions, transport routes, terrain, meteorological conditions, and different sub-periods of CO concentrations. Emissions from local sources within 5 km of LYNN appear to be more important than those transported from larger but more distant sources."

We concur with their assessment, particularly emphasizing the possible importance of local non-vehicular source contributions and indirect sources (parking lots) to the nighttime CO maxima. No evidence could be found for the possible contribution of transport aloft to an elevated background relative to other areas of the basin. However, we note that trajectories arriving at Lynwood during the episodes come from the general vicinity of large sources, so that a generally higher background concentration is a distinct possibility.

Figure 8a. CO monitoring data from stations adjacent to LYNN (AQMD) during the January 8-10th episode. The stations are all within about 200 m of LYNN monitor. (Adapted from AeroVironment, 1991.) The reader is cautioned that two stations, HS8 and AQMD are represented by the same symbol. The highest value at 8:00 a.m. corresponds to HS 8 near Imperial Highway.



Site Visit of the Lynwood AQMD Station

The permanent monitoring station operated by SCAQMD in Lynwood has accumulated CO concentration data for the last 30 consecutive years. The air quality sampling inlets are set on the top of the roof of a leased building, which is located at 11220 Long Beach Boulevard on the east side of the street. On February 12, 1993, a site visit was made to the station, and a drive-by was made again on February 14, 1993.

At the time of the 1989 intensive study, the CO monitor at the station was a Bendix, NDIR type instrument located in a building without temperature control. Calibration of the samplers was automated with an automatic span every night, weekly span and zero check, full calibration every six months and QA audit with separate calibration gases about once a year. A bag sampler (8-hr avg.), collocated with the Lynwood monitor during the January intensive study, showed good agreement. The mean, standard deviation, minimum and maximum for the period from 1200 hours January 8, 1990 to 0300 hours January 10, 1990, (33 hourly bag samples versus 39 hourly averages) were 9.36, 4.44, 3.25 and 20.13 ppm for the bag samples and 9.15, 5.36, 3.0, and 23 ppm for the continuous monitor, respectively (Bowen et al., 1993b). Subsequently the Bendix monitor was replaced with a Dasibi monitor and the building now is temperature-controlled. No differences were noted in the readings after the change over of instruments. We conclude that there is no reason to suspect measurement error in the instrumental data from the Lynwood station.

A glass inlet tube and manifold extended approximately 2 meters above the roof line and plastic tubing (presumably a fluoropolymer) was used to connect the inlet to the monitors. We noted that the roof lines of the post office building to the north and the adjacent building to the south were slightly above the inlet elevation leading to a partially sheltered area at the inlet.

The monitoring station is located in an area of heavy activity. The Imperial Highway/Long Beach Blvd. intersection is about 160 meters north of the station. An U.S. post office (the only post office in Lynwood) is located two doors to the north of the station. The post office loading dock is about 30 meters away to the north and very slightly east. The parking lot itself is quite large, but sparsely filled with vehicles (ten "jeep" type delivery vehicles and 14 small "paneled" van-type vehicles were in the parking lot and one larger delivery van at the loading dock on a Sunday morning). A small postal customer lot is immediately north of the post office building. The windows close at 5:00 p.m., and the post office operations stop at 6 p.m. There are early morning deliveries at about 3:30 a.m. and approximately 5:00 a.m., followed by a third delivery sometime before 6:30 a.m. Two employees typically arrive at about 3:00 a.m. Morning delivery runs do not begin until about 9:00 a.m. During the holiday season the activity increases, but the manager of the post office did not believe that they would increase deliveries by more than about one delivery truck. The post office did not have an after hours lobby area, but drive-by mail boxes were noted at the curbside immediately to the north of the station by about 30 meters. On a Sunday morning, within about a three-minute period, approximately six passenger vehicles stopped to drop off mail. A subsequent phone conversation with postal employees indicated that approximately 400 pieces of mail, principally single items like letter size envelopes, are dropped off between the hours of 6:00 p.m., when the post office closes, and 5:30 a.m. the next morning when the mail boxes are emptied. (These are single observations and may not be representative, though they are suggestive of evening activity levels on weekdays.)

The post office building itself is heated by a gas-fired boiler. From the exterior of the building, there appeared to be a large low stack about the size of a "dumpster" that exhausts just above the roofline of the building. In subsequent phone conversations with postal employees (Hartley and Hawkins, 1993), it was ascertained that the thermostat for the heating system was not on a timer control and would therefore turn on whenever the temperature in the building was below a preset value. The furnace/boiler had a rating of one million British thermal units (Btu)/hr and gas consumption records from November 1992 through January 1993, indicate that the average monthly consumption was twice as large in December (about 400 therms) than either November or January (about 200 therms) monthly consumption levels. We assume that changes of this magnitude reflect changes in furnace use for heating purposes.

From the roof vantage, it was clear that there are fast food restaurants immediately across the street to the west in the shopping plaza (Taco Bell) at the intersection of Imperial and Long Beach a MacDonald's (southeast corner), and at El Pollo Loco outlet (northeast corner), and there are a few service stations (northwest and southwest corners), as well. Within one block there are also a drive-thru ATM machine at the Security-Pacific Bank, as well as a drive-up teller window and within two blocks to the northeast is a Bank of America with similar facilities. A Viva supermarket (hours until 10 p.m.) that used to be in the shopping plaza, during the 1989-90 study, has been replaced by a Food-4-Less and additional stores, e.g., a Thrifty store. The shopping center also has an extensive parking lot, and about 60 meters south of the Taco Bell, there is a Video Max outlet. These businesses all attract evening activity, and although several of them are new and were not present at the time of the 1989 intensive study, we believe they replaced older facilities of a similar nature.

On the east side of the station across a narrow alley (within 20 meters) are some older residential apartments. The roof vents of these single-story apartments are below the probe inlet height of the monitoring station. On the south side of the station there are also some businesses, such as a florist. About one block away, there are several auto service type activities; the largest appears to be a body re-work/fiberglass/paint shop with what appears to be an incinerator or kiln stack on one of the buildings.

The USEPA defines several criteria for different categories of monitoring station that are to be included in a State and Local Air Monitoring Stations (SLAMS) network in 40 CFR Part 58, Appendix D. A 'microscale' station "defines the concentrations in air volumes associated with areal dimensions ranging from several meters to up to about 100 meters," whereas a 'middle scale' station is one that "defines the concentration typical of areas up to several city blocks in size with dimensions ranging from about 100 meters to 0.5 kilometer," and a 'neighborhood scale' station "defines concentration within some extended area of a city that has relatively uniform land use with dimensions in the 0.5 km to 4.0 kilometer range." The SCAQMD's Lynwood station does not fit the definition of a "neighborhood" scale station and is much closer to the definitions of microscale or middle scale. The potential for sources of emission (roof vents, mail drops, boiler emissions) within 30 meters of the inlet of the monitoring station to impact readings, particularly during evening and early morning hours is substantial; nevertheless, direct evidence for such impacts is circumstantial. For example, sharp changes of CO of the order of two to five ppm over periods as short as five minutes are evident in the continuous CO analyzer recorder traces (see Figure 8b, p. 47), e.g., nighttime of January 9th to 10th, 1990. In the early morning hours (0530 hours) on the 10th, changes as large as 10 ppm occurred over periods less than ten minutes. Furthermore during the afternoon hours on the 10th (Figure 8b continued) from 1600 to 1800 hrs, the repetitive "spikes" that appear take noise are not really noise, but are actually regular in frequency. We interpret the signal to be the result of "platoons" of vehicles passing the monitoring station during a period when the demand-type traffic signal at the intersection of Long Beach and Imperial Highway was saturated. The rapid temporal variation of the CO concentrations suggests that local sources, possibly the intersection in the early morning, are contributing to the observed concentrations.

San Jose and Santa Clara (SJSC) Studies

From about 1978 through 1986, the BAAQMD conducted studies of nighttime CO maxima. The majority of these studies occurred in the region between the South San Francisco Bay area and San Jose. Figures 9a and 9b, on pages 49 and 50, illustrate the locations of sampling sites during two periods of study. In addition to having lamp post bag samplers and permanent monitoring stations, mobile sampling was also conducted while driving through various areas with a portable continuous analyzer. Furthermore, BAAQMD attempted to determine whether residential wood-burning could account for some of the observations by conducting an isotopic

Figure 8b. Recorder tracings for a 22-hr period from 0900 hrs 12/9/89 to 0700 hrs 12/10/89. The vertical concentration scale is twice the actual ppm. An automatic daily zero/span check was performed from 0400 to 0500 on 12/10/89.

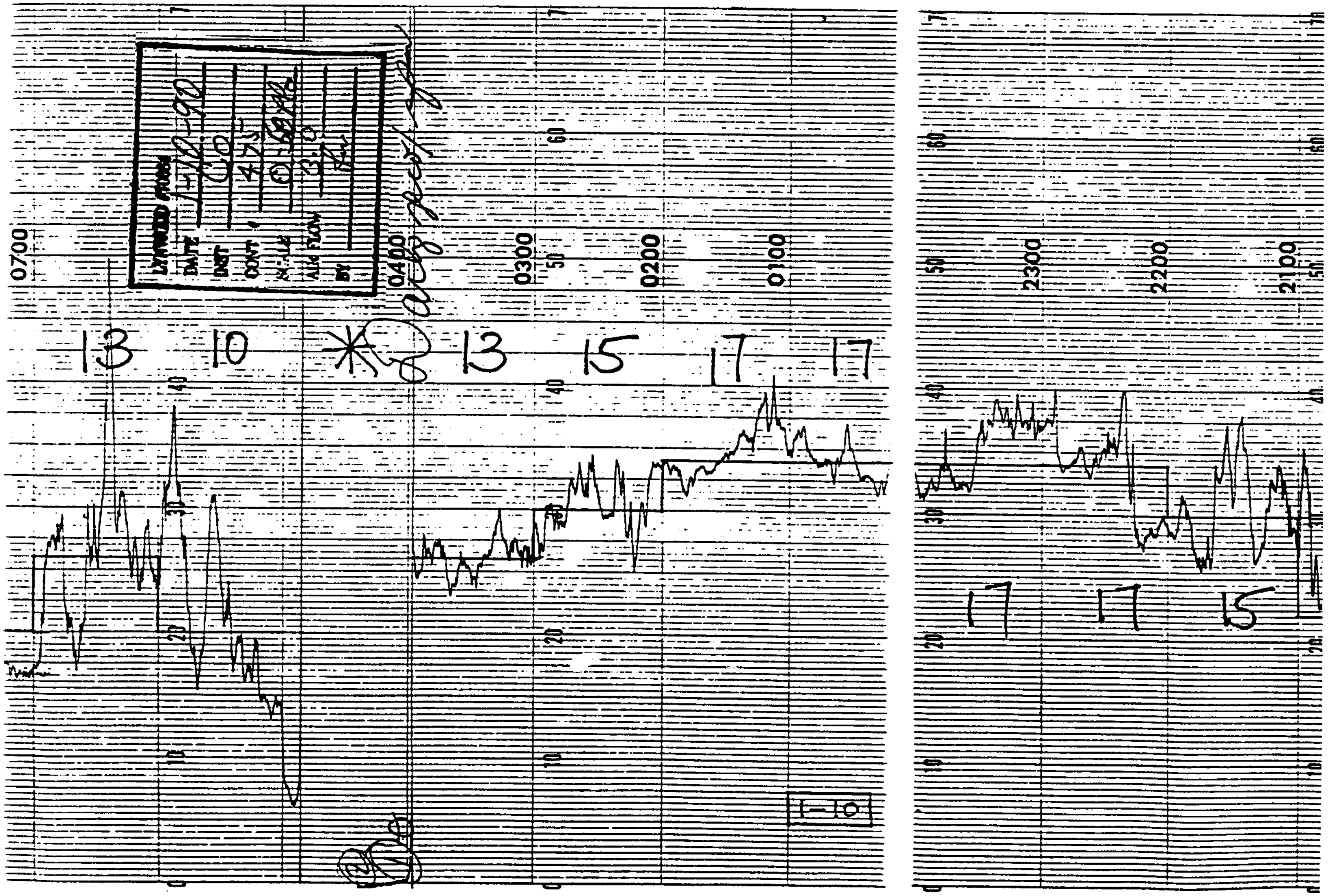


Figure 8b. (con't) Recorder tradings for a 22-hr period from 0900 hrs 12/9/89 to 0700 hrs 12/10/89. The vertical concentration scale is twice the actual ppm. An automatic daily zero/span check was performed from 0400 to 0500 on 12/10/89.

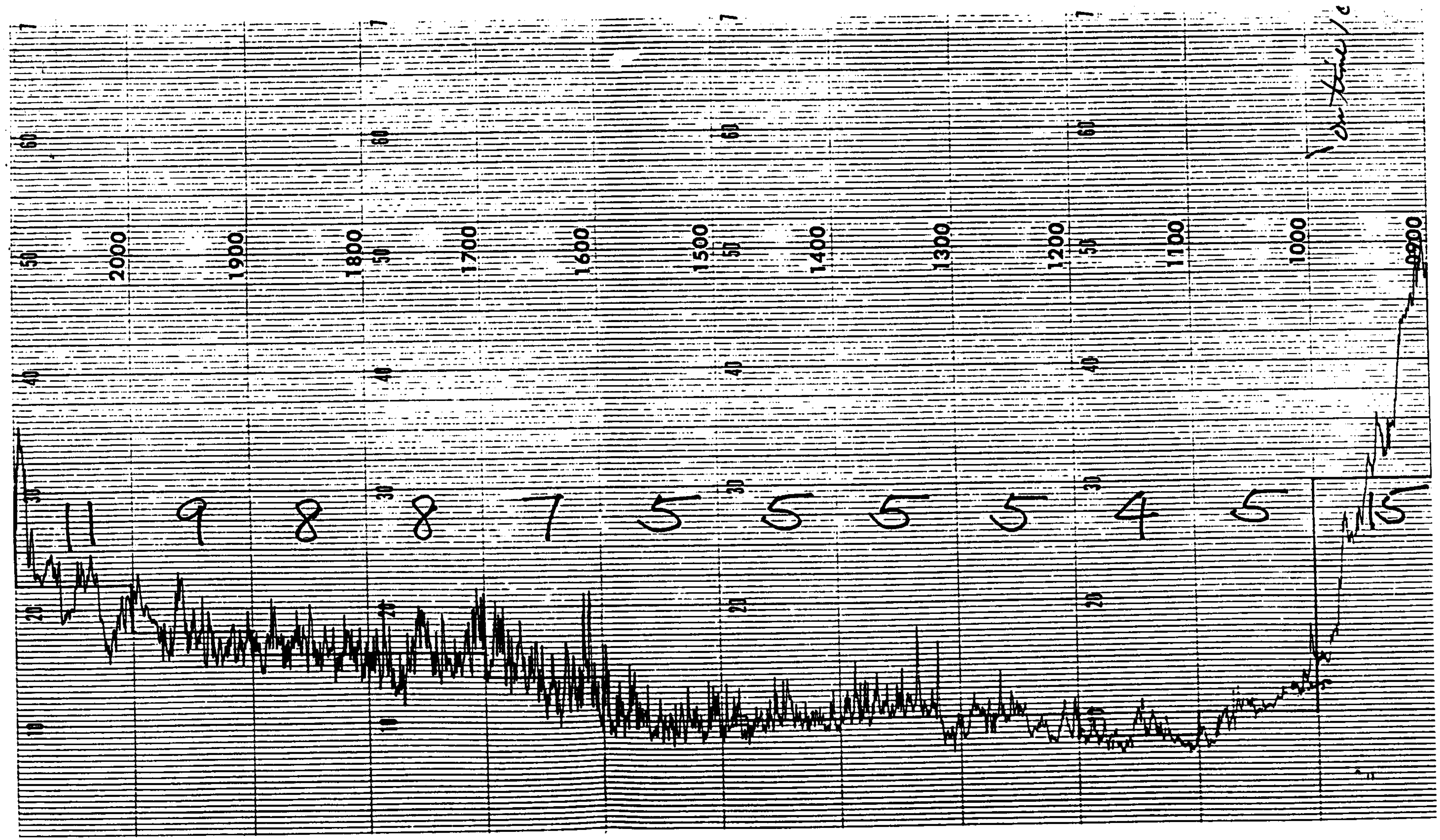


Figure 9a. Map of monitoring sites in Santa Clara County, California. Numbers within circles are BAAQMD sites. Adjacent numbers are highest measured 8-hr CO concentrations between 18 November 1983 and 14 February 1984. Numbers near the black squares at the bottom of the map are highest 8-hr CO concentrations from Caltrans monitors from the same period. (Adapted from Duker et al., 1984.)

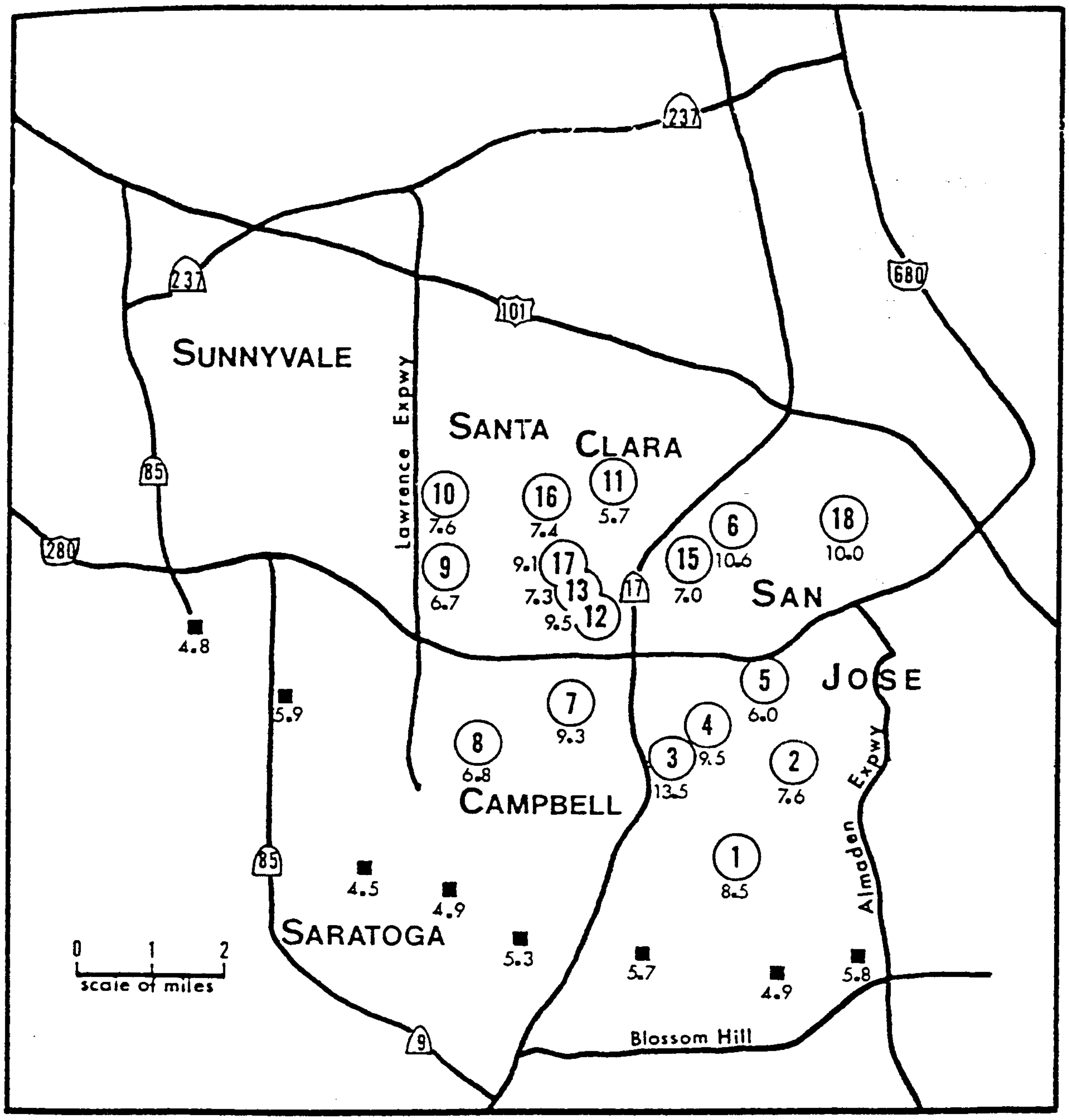
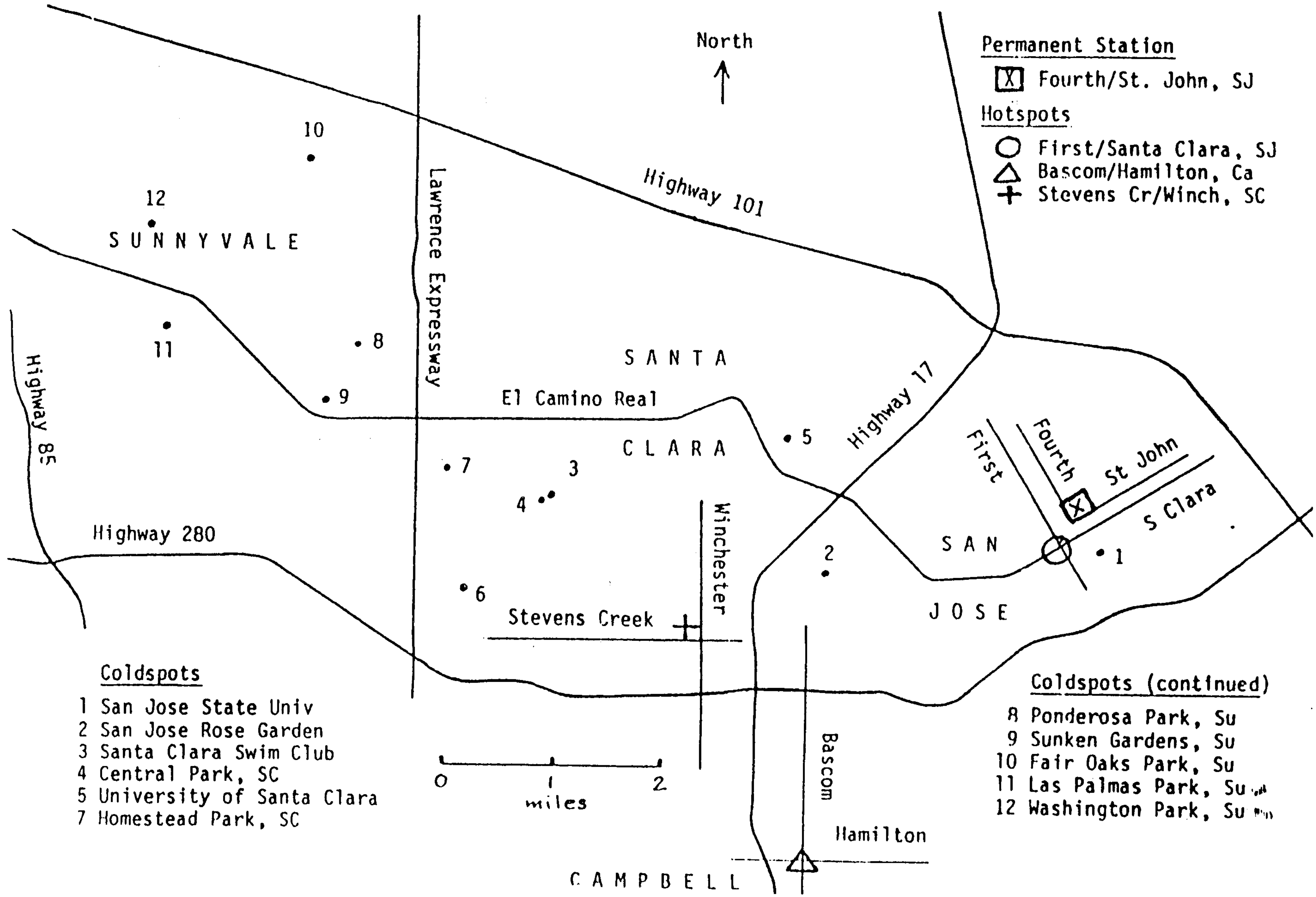


Figure 9b. Locations for hotspot and coldspot monitoring in the San Jose area. (Adapted from Perardi et al., 1984.)



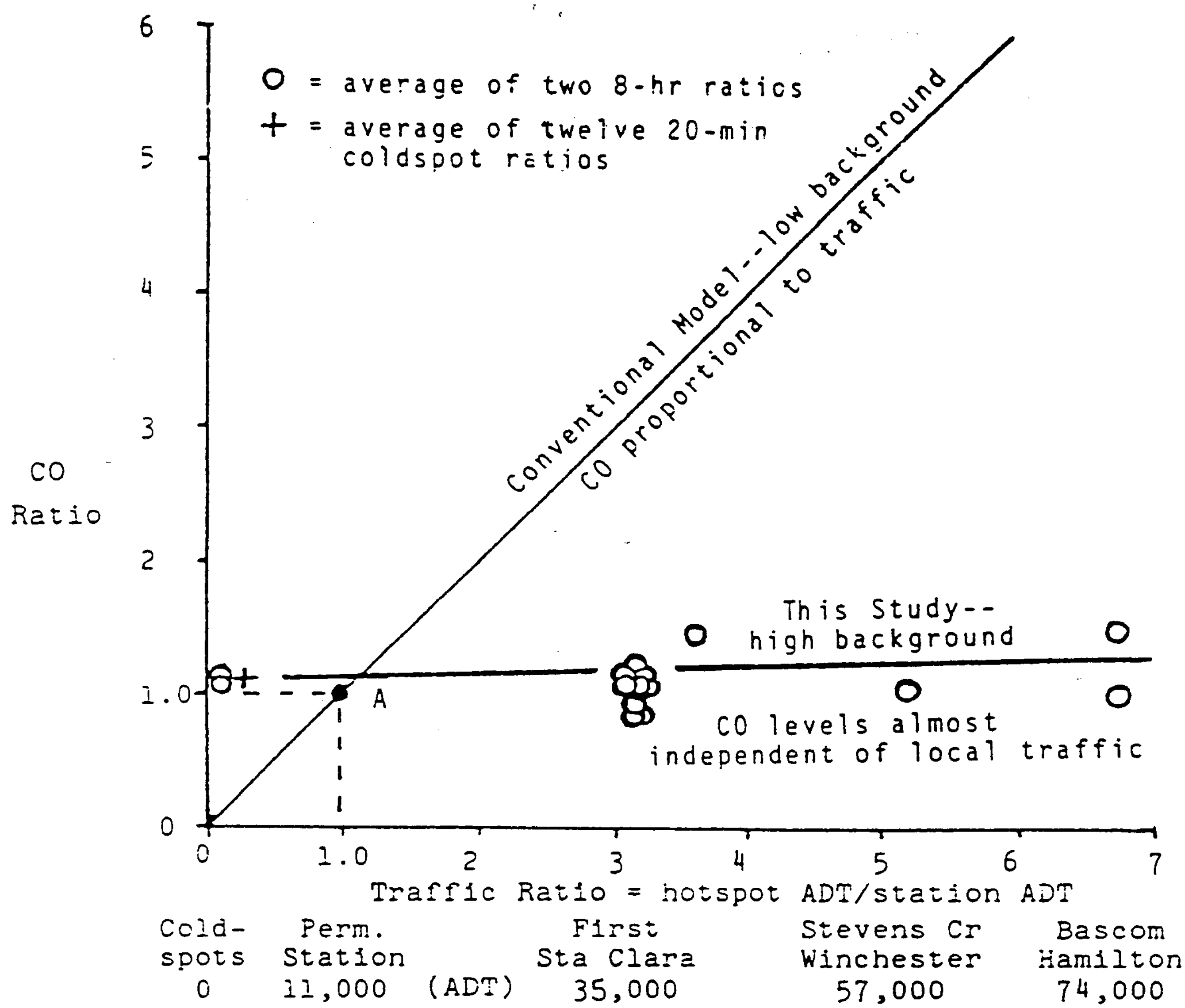
study of ^{14}CO. Because of funding limitations, the studies tended to be somewhat sporadic and were conducted when personnel and equipment were available. With diminishing severity of the CO episodes, the studies were eventually discontinued without having reached definitive conclusions. Nevertheless, valuable insights were gained regarding the areal extent of the "CO cloud" phenomenon and the possible contributions of non-vehicular sources.

Carbon monoxide levels were found to be much higher than previously thought in residential neighborhoods on stable winter nights. The spatial extent of the "CO cloud" was found to occupy as much as 43 square miles on stagnant nights, i.e., the area enclosed within the estimated boundaries of the 9 ppm contour (Duker et al. 1984). Within that area, the decrease of CO level from "hotspots," i.e., areas of high traffic density, to "coldspots," i.e., residential areas or parks removed from high density traffic areas, was only about 30%. Furthermore, when CO was plotted as a function of traffic density, CO concentration appeared to be almost independent of traffic volume during these periods as illustrated in Figure 10, on p. 52 (Perardi et al., 1984). A special sampler for measurement of ^{14}CO was developed. The ^{14}CO measurements (modern carbon assumed to be the major source of additional ^{14}CO) further indicated that residential wood-fired combustion was a significant source of CO (Levaggi, 1989).

The ^{14}CO was found in all samples, and the content ranged from 0.5 to 1.6 ppm. The fraction of ^{14}CO was found to decrease as the total CO concentration increased (inverse relationship also observed in the Lynwood intensive study), and the authors indicated that the observation was consistent with a relatively constant contribution of ^{14}CO from residential wood combustion, on the order of 1 ppm during the episodes. In the Palo Alto area, the content of ^{14}C ranged from 11.5 to 25% of the total CO and from 5.0 to 56.5% in the San Jose/Santa Clara area. Contributions of other fossil fuel sources to heating, e.g., natural gas combustion, could not be evaluated.

The results of the SJSC study reinforce the general conclusion that meteorological conditions are very important during CO episodes. They also strongly suggest that additional sources of local CO can become significant during stagnant, low mixing depth periods. We note that the temperature gradient in the SJSC area and at LYNN are comparable, maximum dT/dz of about +0.15 °C/m (Umeda, 1993) and wind speeds diminish below the measurement threshold of typical anemometers for periods of up to four hours at a time.

Figure 10. Ratio of hotspot maxima to permanent station readings as a function of local traffic volumes. (Adapted from Perardi et al., 1984.)



Sacramento Metropolitan (SAC) Study

A study of CO was conducted by Systems Applications International (Ireson and Shepard, 1992) for SMAQMD during the fall and winter of 1990. Sacramento County provides an interesting contrast to both Lynwood and SJ/SC in that the temperature gradient is even more strongly stable for long periods of time, up to 0.5 $^{o}C/m$ for periods up to eight hours, if the temperature sensor readings were accurate. The areal extent of sources is also less dense leading to relatively small emission sources between some monitors.

The objectives of the study are given below:

"Identification of "background" CO concentrations in different areas of Sacramento County;

Assessment of the adequacy of the existing routine ambient monitoring network;

Determination of the causes of high concentration events, and assessment of the implications for the long-term trends in air quality; and

Assessment of the potential of individual development projects (e.g., high-rise office buildings) and associated traffic increases to cause localized high concentration events."

The routine monitoring networks of Sacramento Metropolitan and Yolo-Solano AQMD were supplemented with additional CO monitors. No traffic count data were available, but a centrally located meteorological station was established, and the data from the study were analyzed in a variety of ways. We will focus upon the forward trajectory analyses, recognizing that the trajectories were computed from wind data from a single meteorological station at a time, i.e., the METS data (or from the Stonemead data plotted as if originating at the METS site).

Most striking is the observation that peak concentrations of CO in downtown Sacramento that occurred at 2000 hours can be observed arriving at about 2300 hours at Sacramento Metropolitan Airport (SMA). Figures 11a and 11b, on pages 54 and 55, illustrate the time sequence of events at the 13th and T, Broderick and SMA monitors and the transport path. Although the trajectory analysis (see Figure 11b) predicts arrival of the air mass over downtown Sacramento at about one-hour earlier, the rise at Broderick and SMA are clearly defined. Both of these locations have a lower density of emission sources and the trajectory of the air mass passes over large expanses of agricultural land (see Figure 12). The only major source located in-between downtown and the airport is Interstate 5, and because these data were obtained on Thanksgiving weekend (Saturday night), traffic along I-5 was not a

Figure 11a. Hourly average CO concentrations in Sacramento County November 24-25th, 1990. (Adapted from Ireson and Shepard, 1992.)

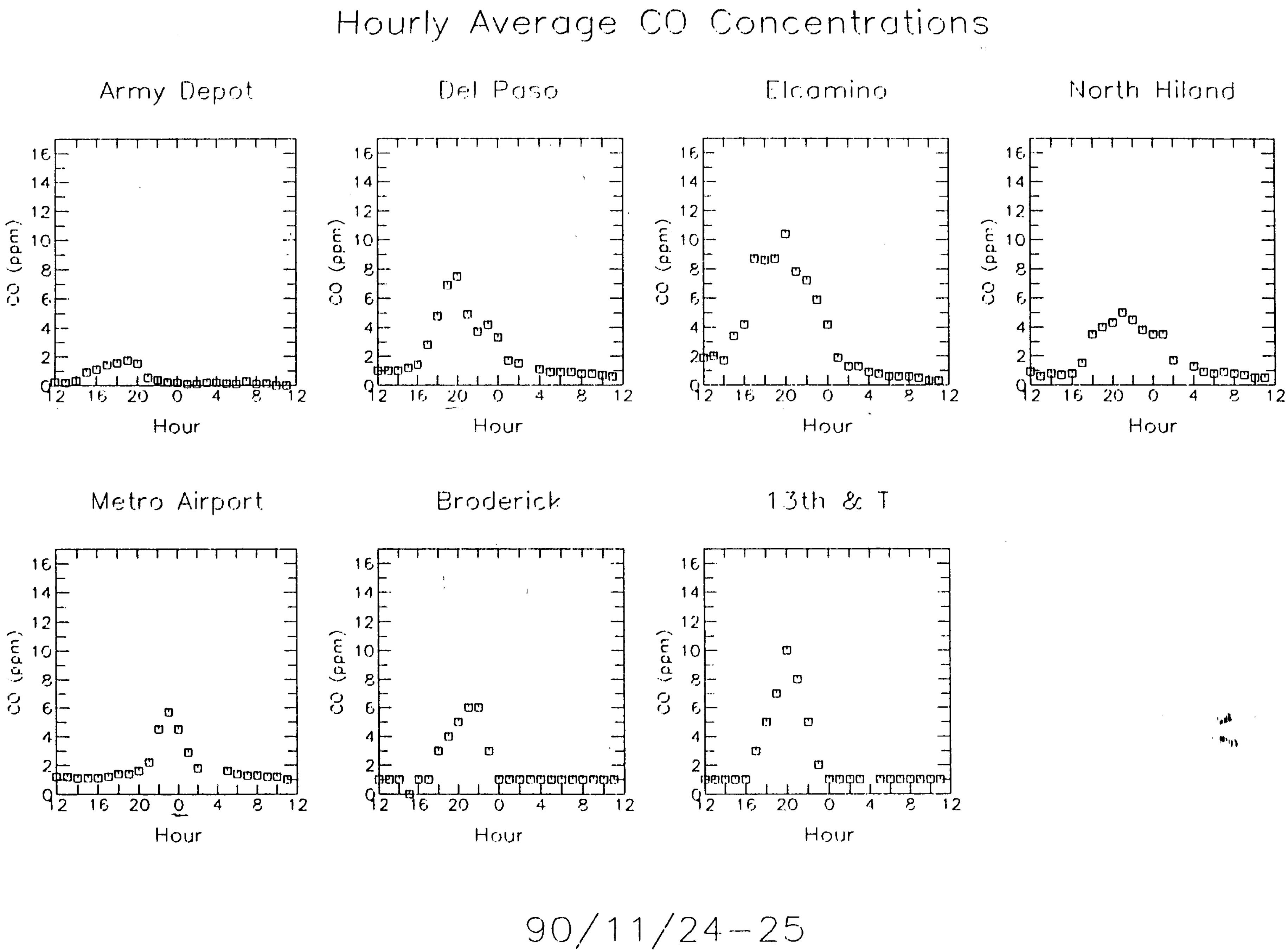


Figure 11b. Forward wind trajectory starting from downtown Sacramento at 1800 hours. (Adapted from Ireson and Shepard, 1992.)

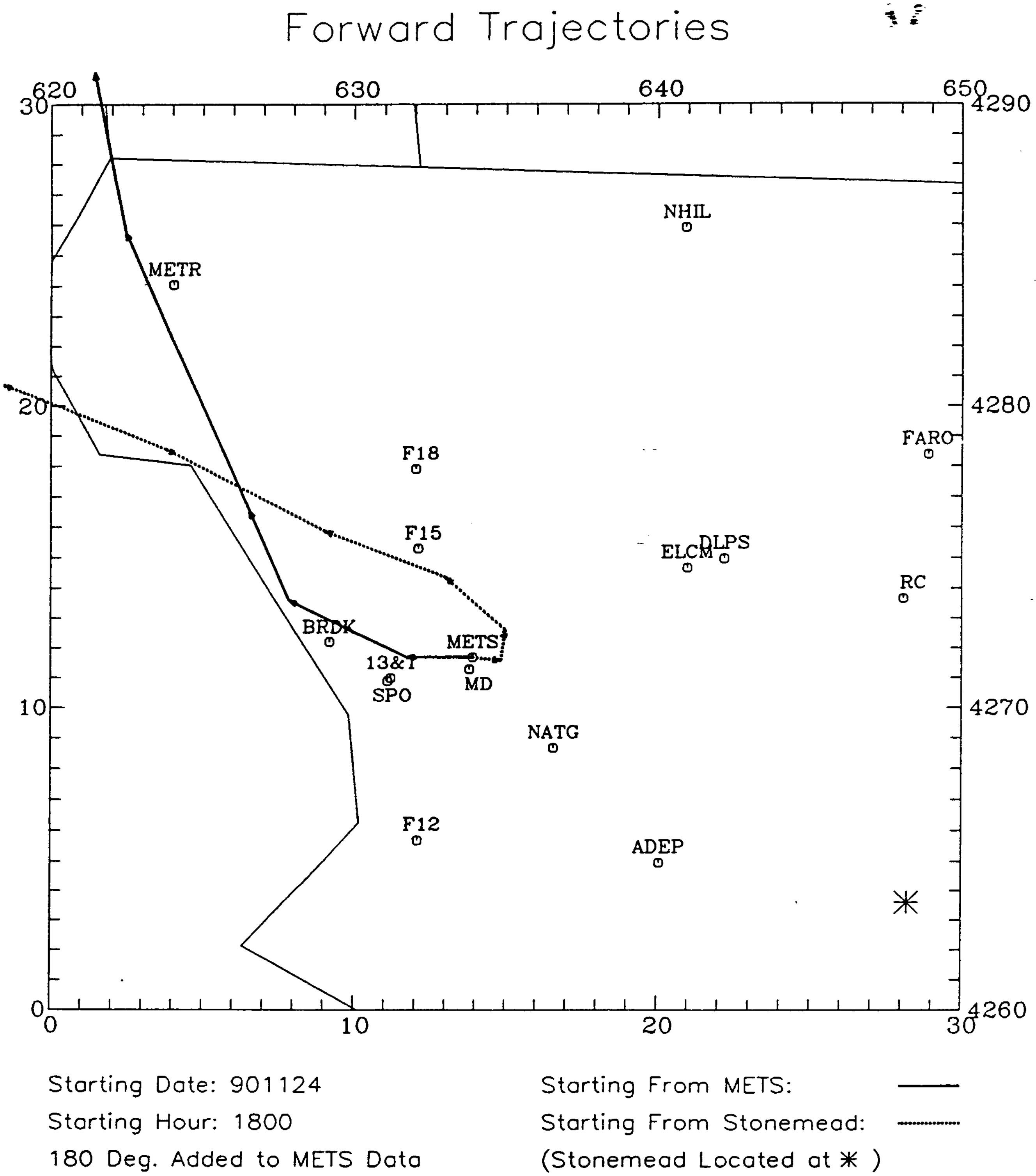
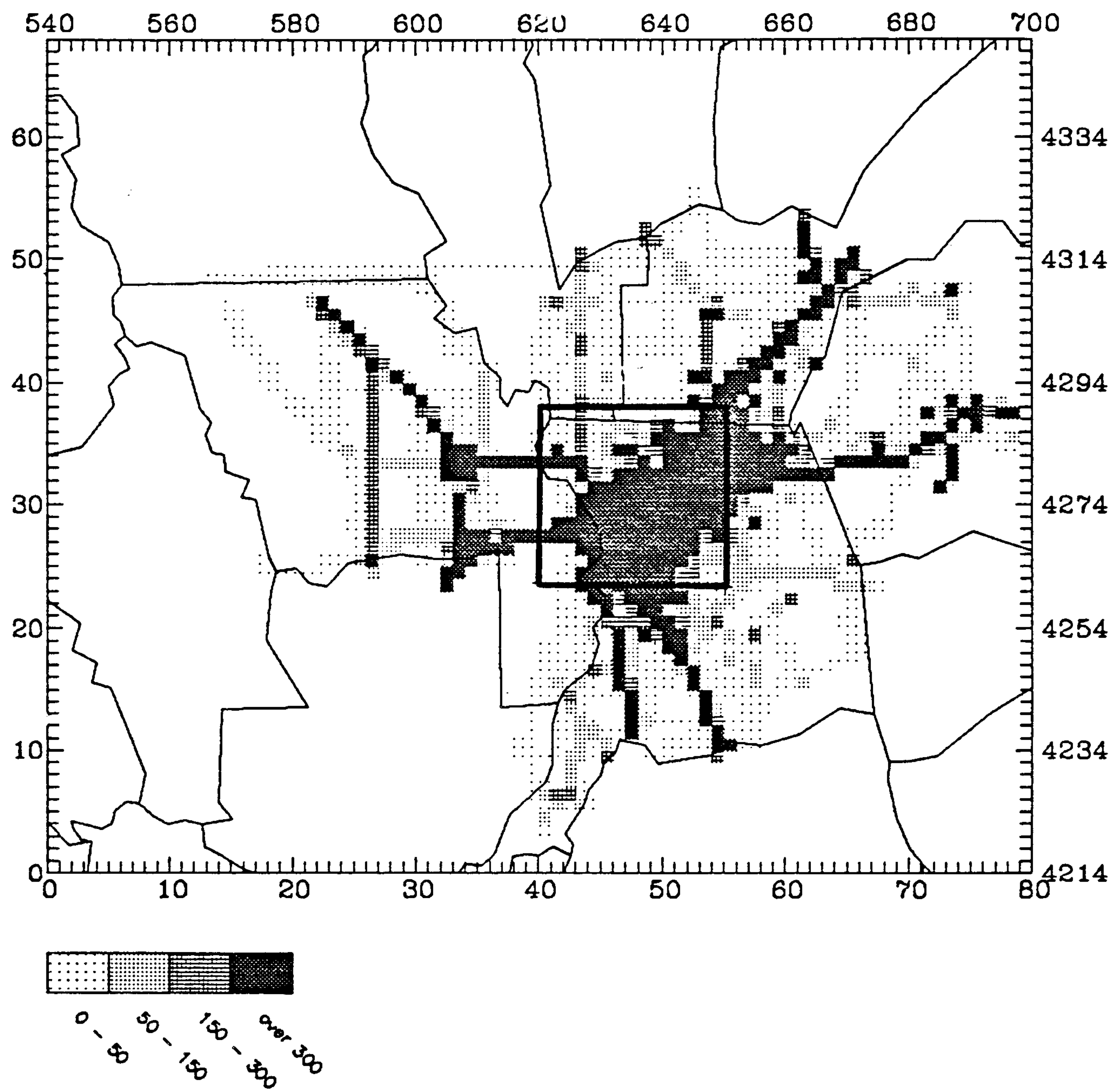


Figure 12. Daily carbon monoxide emission density (kg/day/2 km grid cell). (Adapted from Ireson and Shepard, 1992.)



significant factor.

Similar trajectories were observed on other dates with the same sequence of events. These analyses indicate that if the inversion is sufficiently strong, vertical diffusion is limited even with a moderate wind speed (2.5 m/s for the last hour), and transport occurs along the surface. The reduction of CO concentration in the plume observed at the airport may not be a reflection of dilution within the plume by mixing as much as it is the result of meandering of the wind.

Another observation worthy of note were the data from two stations in close proximity, El Camino/Watt and the Del Paso monitors. The El Camino station was noted to be a microscale station and clearly exhibited an increase in CO (1600 hours) that occurred earlier than that at Del Paso (1700 hours) and that was associated with local traffic. On other days, a double or broadened peak is observed at the El Camino monitor, indicative of a second build-up in CO after strongly stable conditions set in (about 2000 hours) even though traffic had probably diminished. Peak readings at the El Camino site were typically 30 to 40% greater than at Del Paso.

Commonalities and Differences Among Sites

Several features are common among the various sites. The highest CO episodes occurred under stable, low wind speed, radiation inversion and winter night conditions. The morning peaks were associated with high traffic counts expected during morning rush hours. Evening peaks did not match with the evening traffic peaks, with the peak nighttime CO lagging up to several hours. We believe that there is a build-up of CO into a relatively small volume because of low wind speed, and a limited mixing depth accounts for this behavior. The build-up also can be augmented by widespread commercial/residential combustion and indirect sources.

The region around Lynwood affected by high CO concentration, appeared to be more localized than in the case of San Jose/Santa Clara. The data for Lynwood were the most complete, and it is evident that both wind speed and stability are more conducive to CO build-up than in nearby communities. On the other hand, large geographic areas of SJSC appeared to experience relatively more uniform concentrations during the nighttime. The presence of residential wood combustion was also evident in the SJSC case, up to 25% in the Palo Alto area and from as little as 5% to as much as 50% in some locations in San Jose. Although the absolute concentration of ^{14}CO was lower in SoCAB air, it was non-negligible ranging from seven to 32% of the CO during the periods studied. In both cases, the contributions of residential, commercial and industrial gas consumption were not quantified. Given that temperatures are lower and stabilities are greater in Sacramento, it would not be too surprising, if residential space heating proved to be an even more significant fraction of the observed CO during episode conditions.

The mixing depth at Sacramento was limited by the extremely strong surface-based inversion. Vertical mixing appears to have been almost totally suppressed and buoyancy-driven vertical motion appears to have been confined to a much thinner region. Horizontal transport by the mean wind had a much smaller effect on reducing concentrations, and the pollutant mass was evident after having been transported distances of 10 km.

Sources of CO Emission

At the onset of this study, the exact source(s) for the higher concentrations observed at Lynwood relative to other SCAQMD stations was unknown. The 1989 intensive study clearly demonstrated that nighttime CO peaks occurred well after traffic counts had peaked. Subsequent analysis of the monitoring data by DRI suggested that some local source(s) in the immediate vicinity of the monitoring station might be responsible for at least a portion of the CO measured at the Lynwood station. For these reasons, it was decided to re-examine the relative significance of CO sources in the area. An order-of-magnitude analysis was performed in order to determine the relative significance of sources or if some source(s) may have been overlooked.

Carbon monoxide is formed as an intermediate product during the combustion of carbonaceous fuels such as gasoline, diesel, natural gas and wood. Under fuel-lean conditions, its major route of oxidation to carbon dioxide is by the hydroxyl radical (OH) (Flagan and Seinfeld, 1988). Oxidation of CO in the atmosphere is also mediated by photochemically generated OH radicals (Seinfeld, 1986). Because the formation of OH radical is highly temperature dependent and slows dramatically below about 750 °C (Chang, 1991), it is common to have small residual amounts of CO in combustion gases, e.g., as a result of the expansion of a piston or opening of an exhaust valve during the running of an engine, the quenching of a flame against the surface of a utensil during cooking, or from an improperly adjusted gas burner in a furnace. In the absence of sufficient oxygen, CO is a stable product of fuel-rich combustion.

Conventional wisdom would suggest that mobile sources contribute to the majority of CO emissions in urban areas. However, CO emissions from stationary sources may be significant in certain areas and circumstances. Because of the episodic occurrence of high ambient CO concentrations in Lynwood, we suspected that there may be some unique CO sources as well as meteorological conditions that are conducive to the high CO levels observed there. We identified major CO sources and quantified CO emissions from those sources. A summary is presented in this section and the details of the estimation procedure are given in Appendix C.

Summary of CO Emissions Possibly Impacting Lynwood

There is no doubt that motor vehicles are the major source of CO emissions in Lynwood just as in the rest of the SoCAB. The baseline emissions from on-road mobile sources is about 5000 tons per day (tpd) in the SoCAB in comparison to total area-wide emissions of about 200 tpd (SCAQMD, 1992). A crude calculation of emissions from 3.2 km (two mile) long segments of major roadways surrounding or running through the Lynwood area is given in Table 1. An estimate of the local street traffic contribution and the indirect source emissions, e.g., parking lots, was not possible within the scope of this effort, but would increase on-road vehicular emissions.

Table 1. CO Sources In and Around Lynwood (grams per day)

Mobile sources		
	Major Roadways Near Lynwood[a]	
	Approximate Total	9,200,000
Stationary sources		
	Natural Gas Combustion[b]	
	Approximate Total	600,000
	Refineries[c]	
	Approximate Total	14,000,000
	Airports[d]	
	Approximate Total	28,000,000
	Other Major Sources[e]	
	Approximate Total	6,900,000

[a] Contributions from 2-mile segments of Imperial Highway, Long Beach Boulevard, Highway 42, Highway 91, Freeway 110, Freeway 710.

[b] CO Emissions from NG combustion in Lynwood (average of December and January) from residential, commercial, and industrial categories using Gas Research Institute emission factors.

[c] CO Emissions from refineries within 16 km (SCAQMD, 1991).

[d] CO Emissions from airports within 16 km (SCAQMD, 1991). CO emissions from LA International Airport include both aircraft and airport stationary facilities.

[e] CO Emissions from other major stationary sources (So. Cal. Edison Plants, LADWP Plants, Douglas Aircraft, Trumbull Asphalt, Hughes Aircraft, Proctor & Gamble, Douglas Aircraft, Harbor General Hospital, GATX Tank Storage) around Lynwood (SCAQMD, 1991).

It is possible that stationary CO sources result in an elevated background CO concentration in Lynwood relative to the South Coast Basin as a whole. The analysis by DRI of trajectories arriving in Lynwood during the nighttime CO episodes typically originated from the West or South in the mid- to late afternoon. If subsidence of air occurred in Lynwood during episode conditions, it was hypothesized that emissions from large sources might be transported aloft and contribute to a higher background in Lynwood. Thus the magnitude of stationary sources of emissions was examined and is also summarized in Table 1. We emphasize that no evidence for subsidence or transport aloft could be found to support the hypothesis.

The EOF analysis conducted by DRI was not definitive, but it suggested that local sources, in the immediate vicinity of the station, may have contributed as much as 3 ppm to the total CO concentration. Distributed local emissions from gas-fired appliances were hypothesized to be a potentially significant source of CO. The concern was based on observations made at the Lynwood monitoring station of roof vents from gas-fired equipment in close proximity to the inlet. The estimate was performed to gain insight into the possible magnitude of CO emissions from gas-fired equipment, normally thought to be insignificant. Coupled with very low mixing depth and ventilation over periods of several hours, i.e., the early evening to nighttime and early morning hours, NG sources might also account for some portion of the nighttime CO maximum observed at Lynwood.

A "back-of-the-envelope" calculation of the potential emissions from the boiler at the U.S. Post Office indicates that using an assumed emission factor for an "in-use" commercial boiler could give rise to concentrations of CO from about one-tenth to several ppm under favorable wind conditions and a limited plume rise/building wake effect. We conclude that the possibility of local source impacts on the Lynwood monitor warrants further investigation.

Analysis of Buoyancy Effects

One puzzling facet of CO episodes is that they do not occur more frequently in the immediate vicinity of large emission sources, e.g., areas of high traffic volumes associated with major intersections or freeway interchanges. We believe that part of the explanation for this observation is the influence of the meteorological conditions associated with episodes, i.e., calm conditions accompanied by a highly stable atmosphere. In fact, conservation-of-energy arguments can be made to illustrate that when wind speed diminishes towards zero, heat releases from emission source areas will generate their own buoyancy-induced wind. In this section, a "back-of-the-envelope" energy conservation computation is used along with a "puff-model" to illustrate the potential problems with conducting microscale modeling with existing air pollution models.

Figure 13, on p. 63, illustrates the predicted average rise in temperature of the air associated with a crosswind velocity component of 0.1 meter/second (m/s) across varying numbers of lanes of traffic. Several simplifying assumptions were made in performing this computation; however, the purpose of the illustration is to highlight the phenomenon, not the exact temperature increase. The numbers on the curves correspond to the assumed fuel efficiency of the vehicle (kilometers per liter of fuel), and the symbols correspond to different assumptions about the traffic density per lane (cars passing a fixed point per second - 0.5/s = 1800/hr). All of the heat from the fuel is assumed to result in the heating of air up to a height of 2 m above the roadway. (A more conservative assumption may be that only 60 percent of the heat from the gasoline combustion actually heats the air mass, i.e., the vehicle and roadway masses may still be warming up, and the initial well-mixed mass of air could extend up to approximately 3 m.) A well-mixed region above the roadway of 3m was used in the "puff" trajectory calculations described below.

Clearly, temperature increases of 40 °C across eight traffic lanes are not observed in reality, though temperature increases of about one degree have been documented from a moderately heavy traffic (5462 vehicles/hr over four lanes) simulation (Chock, 1977). The reason that very large temperature increases would never be observed is that a buoyancy-induced airflow rising from the surface would occur with a corresponding horizontally-induced flow toward the roadway of greater than 0.1 m/s to replace the rising air mass! The same amount of buoyant rise would not be expected for isolated vehicles because the surrounding air would mix into the plume more rapidly, diluting the air mass and limiting its rise.

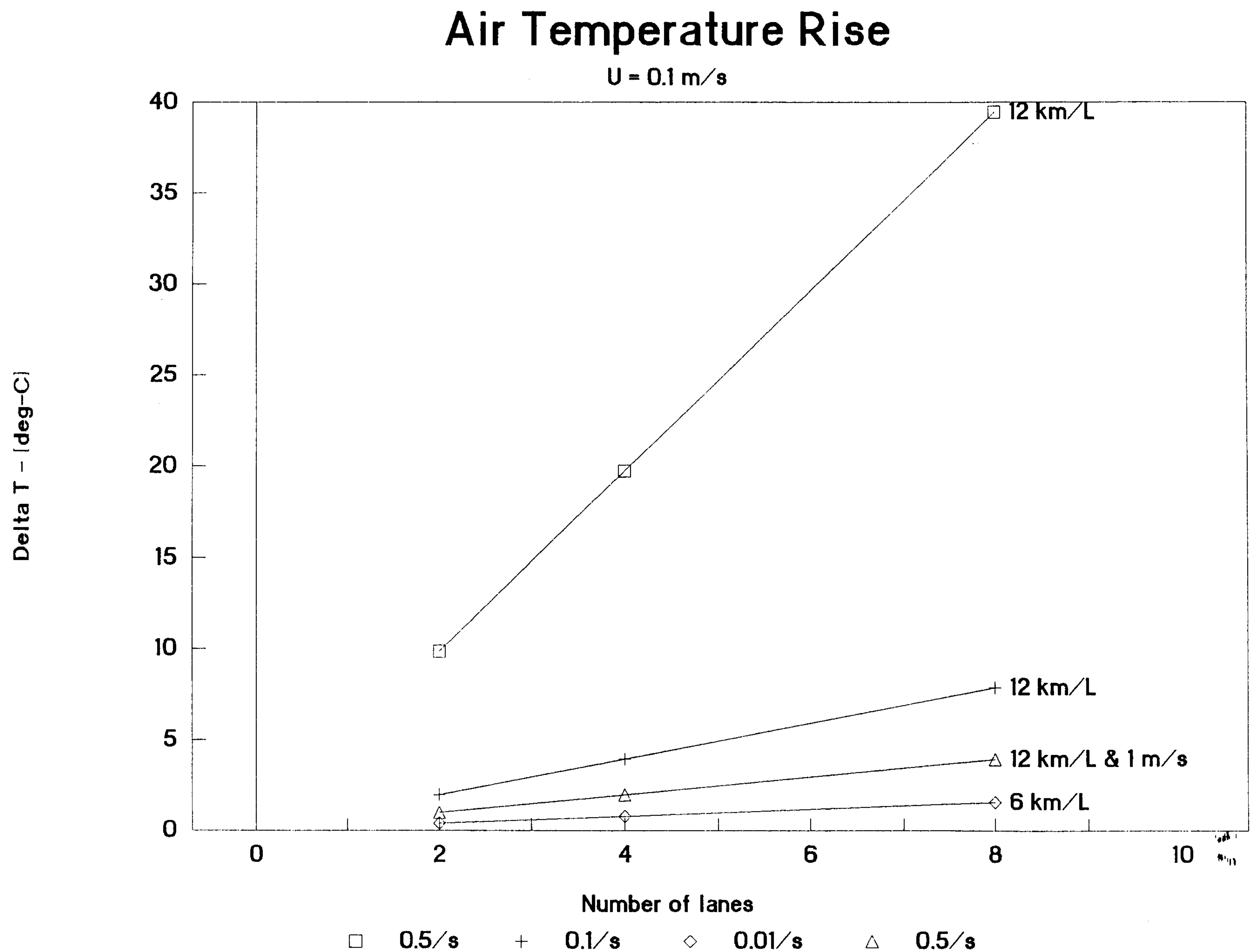


Figure 13. Temperature rise across an eight-lane roadway assuming 0.1 m/s cross-wind component and varying traffic density.

A model was prepared to predict the trajectory of a puff of buoyant air released into a "free" atmosphere following the method given by (Shieh, 1978). The equations of continuity, momentum and heat were numerically integrated. The results shown in figures 14a through 14e correspond to an assumed initial temperature difference with the surrounding air, delT,[2] a mean crosswind wind speed component, u, (m/s) and a lapse rate corresponding to that observed at Lynwood (0.17 °C/m). In addition, an equal vertical and horizontal diffusivity of 0.01 m^2/s (Berman and Rankin, 1979) has been assumed (along with an air entrainment coefficient of 0.14). These values are probably too low for use close to the roadway because of the mechanical turbulence in the immediate vicinity; however, the computations are for illustrative purposes only. The heavy lines correspond to the centerline of the "puff," and the lighter solid line corresponds to the "width" of the puff. These crude calculations indicate that, conceivably, under conditions of moderate traffic density and essentially calm and stable conditions (u less than or equal to 0.25 m/s), noticeable "lifting" of the plume to the 10 m or greater elevation is possible at distances as small as 10 to 20 m in the downwind direction. Buoyancy may be a key factor that explains why higher concentrations of CO are not measured in the vicinity of higher density emission sources during episode conditions.

A preliminary attempt was made to see if evidence of "plume rise" was present in data obtained during studies of CO from freeways in Los Angeles (Bemis et al., 1977). Unfortunately, the data were obtained from a site (San Diego Freeway Site #6) that was later determined to be above grade, complicating the interpretation. Figure 15, on p. 68, illustrates the physical configuration of sensors at the test site. The CO concentration data shown in the plot in Figure 16, on p. 69, correspond to 15 minute bag sample averages and have the "upwind" CO concentration (see probe #6 in Figure 15) subtracted from them. The wind speed was the average of many observations over the hour that the bag samples were drawn. The averaged data (not taking into account wind angle) were grouped into categories of $0 < u < 1$ mph, $1 < u < 2$ mph and $u > 2$ mph; these categories show that CO concentration above the median normally decreased with height when a crosswind component was present. Nevertheless, data obtained from the site under low wind speed and stable conditions (two cases) illustrate that CO concentrations at the 44 ft sampler were comparable to or higher than at the 4 ft level. In these two cases (marked anomalous), the data were drawn on February 14, 1975, at the 0600 and 0700 hours, under conditions when the hourly wind average was less than 1 mph, and the crosswind component was shallow (22 and 36 degrees, respectively).

---

[2] Total traffic volume assumed as 3160 vehicles/hr over eight-lanes corresponding to evening/nighttime hour traffic levels, 15 mpg fuel economy, 60% heat released to air, initial mixing height 3 m, initial puff dimensions $s_x = s_y = 3.5$ m, $s_z = 1.5$ m.

Figure 14a. Puff model trajectory calculation illustrating buoyant rise phenomenon for an eight-lane roadway with initial del T = 22.4 °C, crossroad mean wind component u = 0.05 m/s. The heavy solid line is the puff centerline and lighter solid line is the puff's s_z.

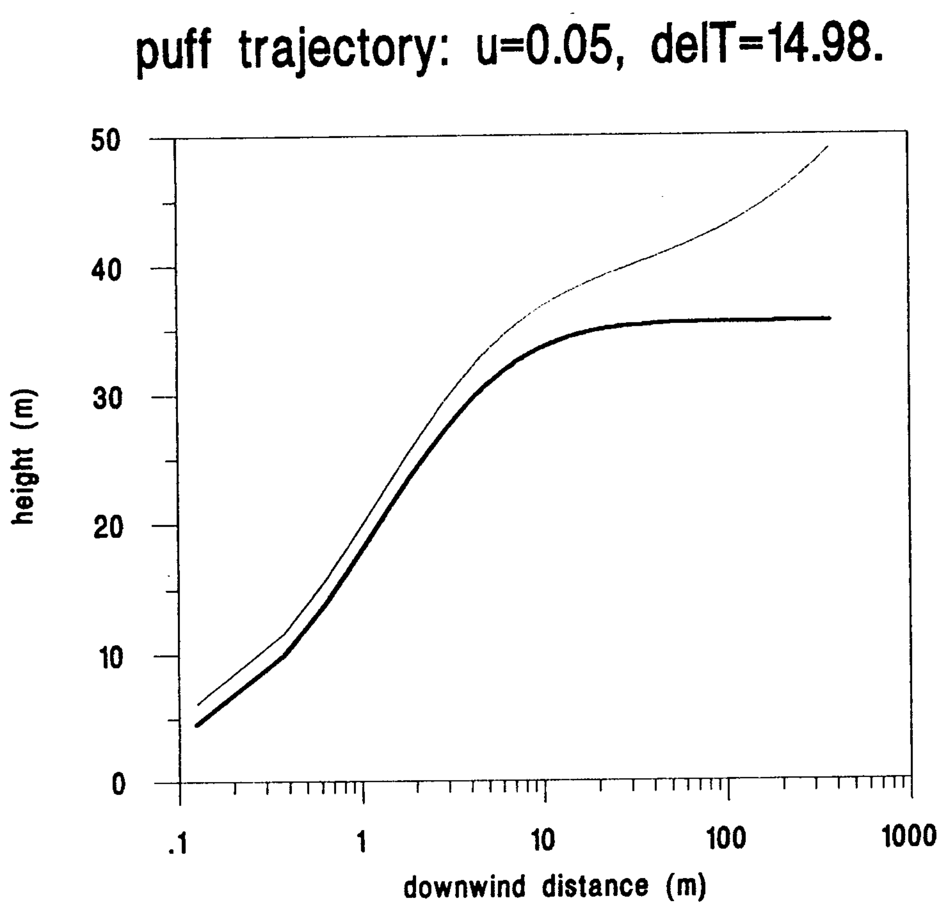


Figure 14b. Puff model trajectory calculation illustrating buoyant rise phenomenon for an eight lane roadway with initial del T = 11.2 °C, crossroad mean wind component u = 0.1 m/s. The heavy solid line is the puff centerline and lighter solid line is the puff's s_z.

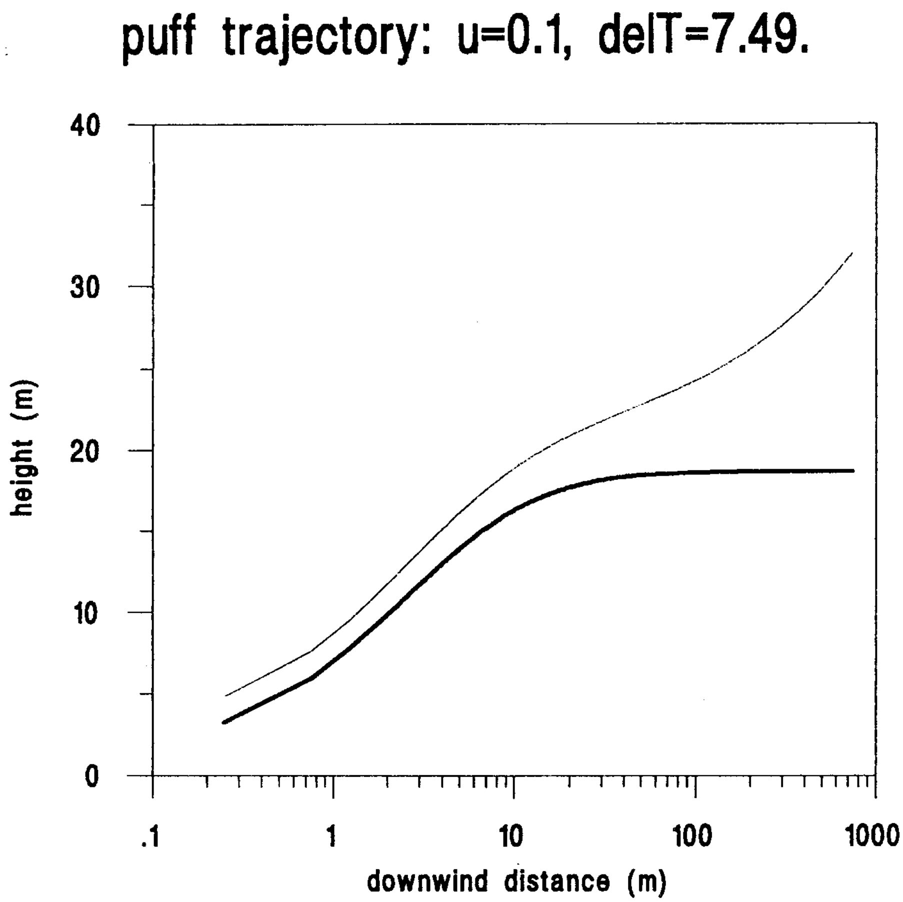


Figure 14c. Puff model trajectory calculation illustrating buoyant rise phenomenon for an eight-lane roadway with initial del T = 4.4 °C, crossroad mean wind component u = 0.25 m/s. The heavy solid line is the puff centerline and lighter solid line is the puff's s_z.

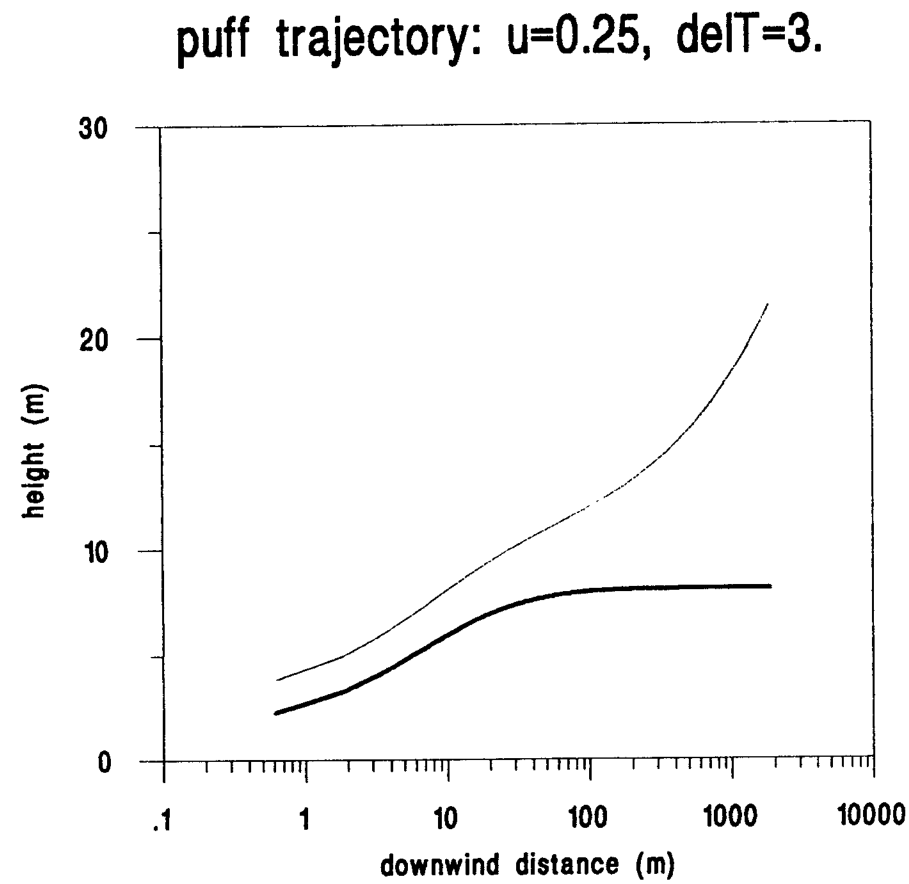


Figure 14d. Puff model trajectory calculation illustrating buoyant rise phenomenon for an eight-lane roadway with initial del T = 2.2 °C, crossroad mean wind component u = 0.5 m/s. The heavy solid line is the puff centerline and lighter solid line is the puff's s_z.

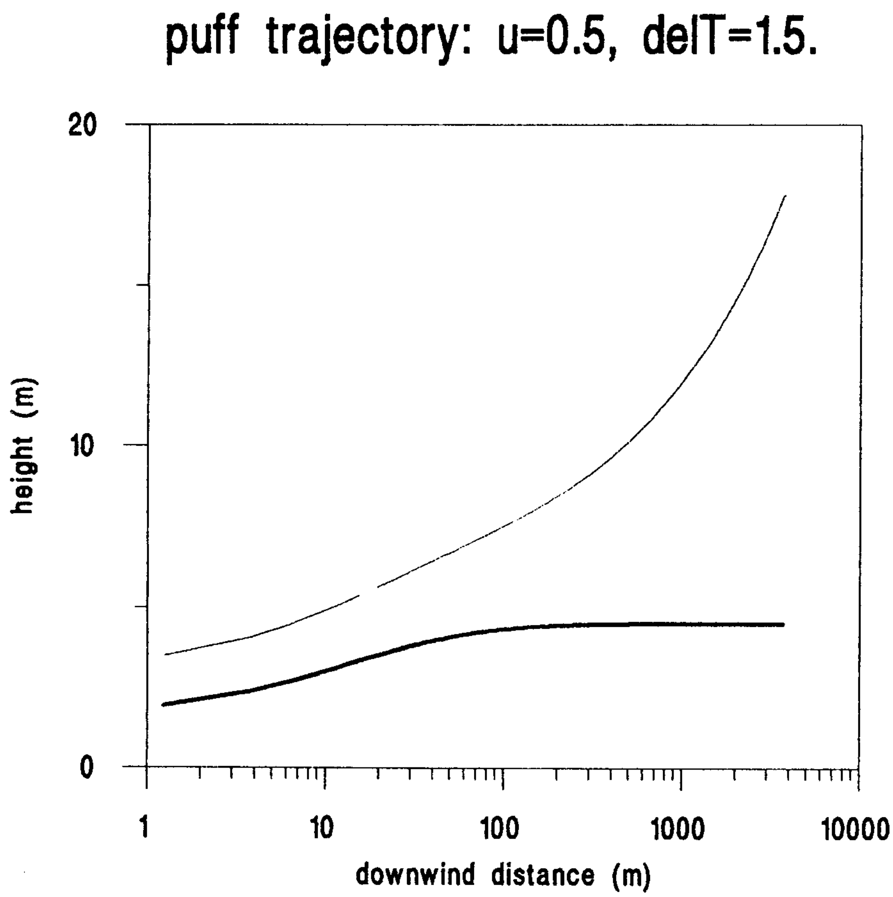


Figure 14e. Puff model trajectory calculation illustrating buoyant rise phenomenon for an eight-lane roadway with initial del T = 1.1 °C, crossroad mean wind component u = 1.0 m/s. The heavy solid line is the puff centerline and lighter solid line is the puff's s_z.

Figure 14e

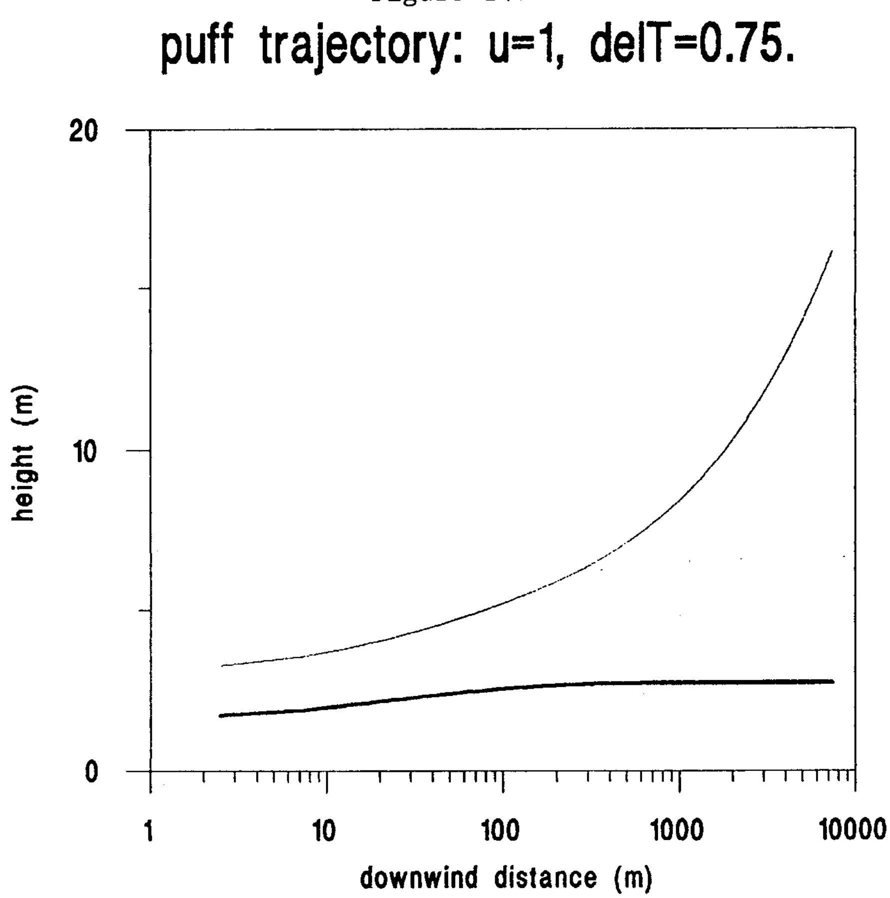
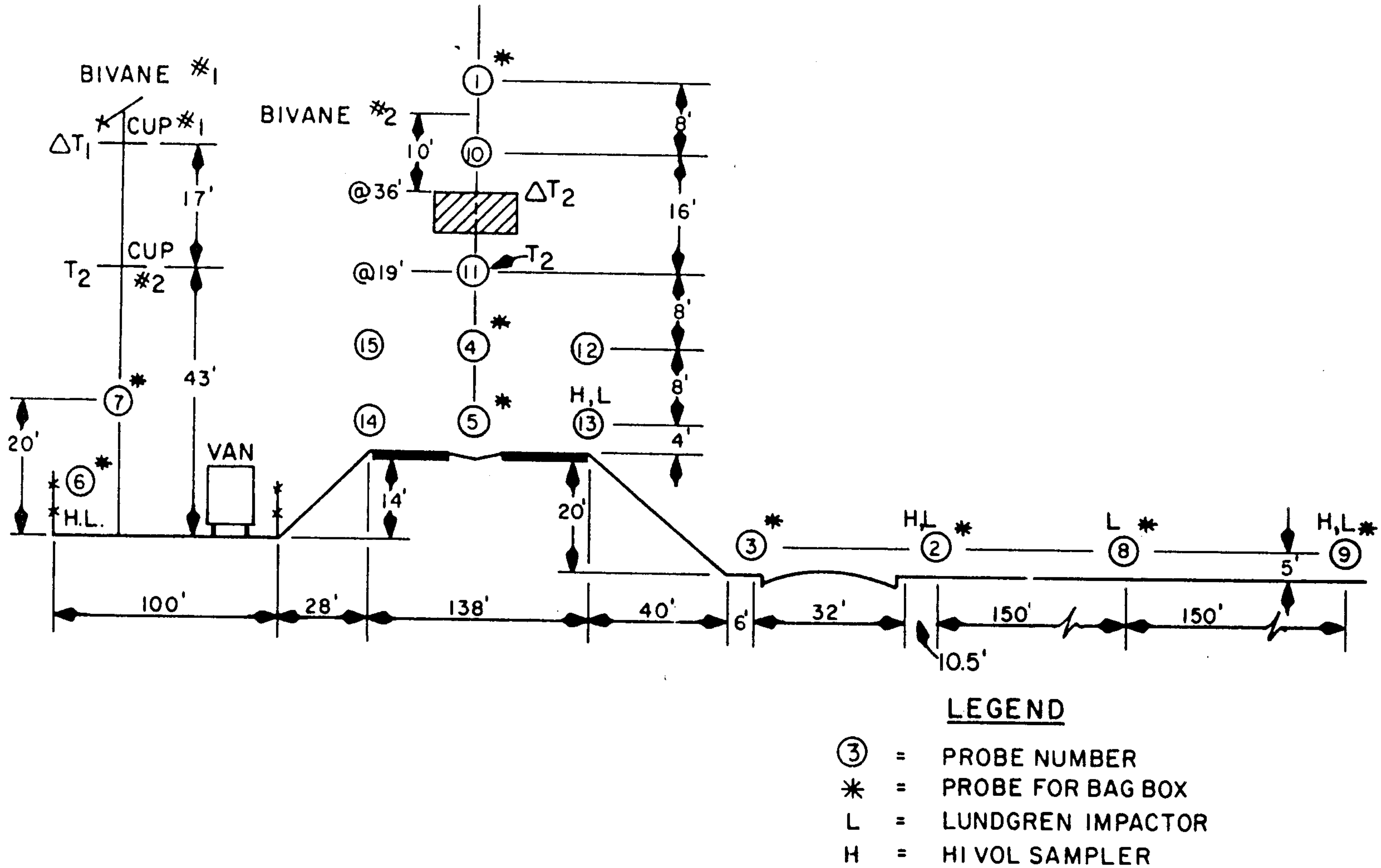


Figure 15. Sensor array at San Diego Freeway Site 6 adapted from Bemis et al. (1977).



PROBE LOCATIONS, SITE 6, SAN DIEGO FWY. AT 134TH STREET (1974-75)

(NOT TO SCALE)

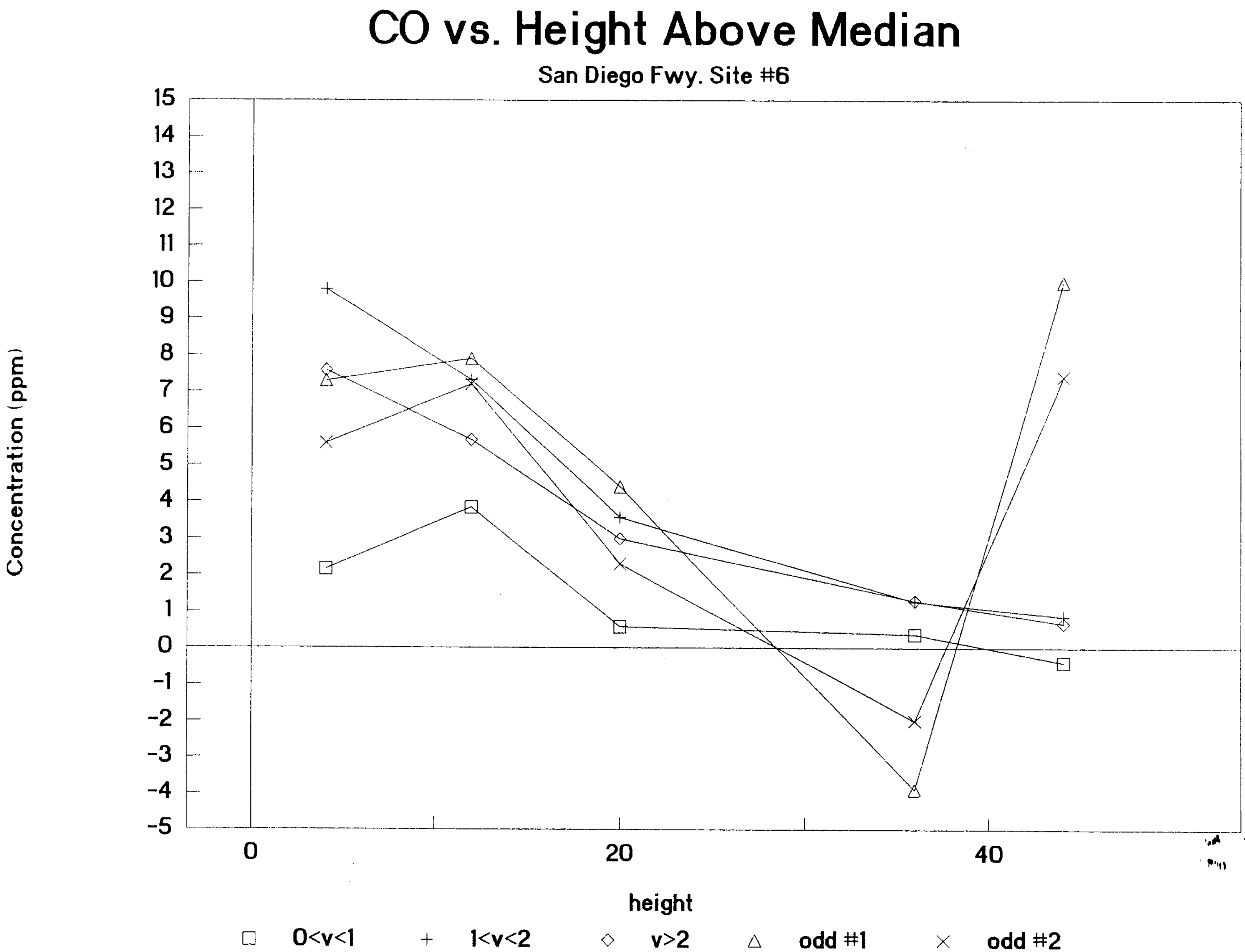


Figure 16. CO concentration above the median at Site 6 during stable atmospheric conditions for three wind speed categories and two anomalous points exhibiting increased CO concentration at the 44 ft level.

It must be kept in mind that buoyant rise requires some time in order for a plume to reach the 44 ft elevation, and that the crosswind component carries the plume away from the median. The anomalous data may have arisen from a combination of a relatively shallow crosswind component coupled with a low wind speed, so that upwind traffic lanes contributed to the 44 ft observation. There is also a possibility of mis-identification of the bag samples, but in any case, further examination of the existing data sets appears to be warranted.

Existing research on CO modeling has recognized that dispersion due to buoyancy becomes more significant under stable atmospheric conditions as wind speed diminishes (Dabbert, 1976; Chock, 1977), and methods have been suggested (Chock, 1978) or developed (Benson, 1982) that partially account for the phenomenon. Nevertheless, the most commonly used Gaussian dispersion models (CALINE3 or CALINE4) and even the less widely applied numerical grid models have short-comings when the wind speed diminishes below about 0.5 to 1 m/s because most methodologies do not explicitly account for along-wind diffusion or plume rise. For example, even with the "residence time over the roadway" correction for increased initial dispersion utilized in CALINE4, the centerline of the emission remains at the initially assumed height of release (typically within 2 m of the surface for vehicular emissions), consequently concentrations will always be predicted to decrease with downwind distance from the source. These short-comings are important precisely under the conditions that correspond to high CO episodes. Therefore, if microscale modeling is to be used for conformity analyses, further research and model development are warranted.

Predictions Based on Total Persistence Factor

Another method of modeling CO concentrations utilizes the concept of "persistence factors" to take short-term microscale predictions, i.e., 1-hr averages, and adjust them to longer periods of time, i.e., 8-hr (Nokes and Benson, 1985; Cooper, 1989; Cooper, 1992; SCAG, 1992). The approach is highly appealing because it is apparently simple to apply and is based partially upon historical observations. However, the persistence factor approach is statistical in nature, and it is important that its statistical nature and the underlying physics in its formulation be understood. The guidance provided in the SCAG (1992) recommends use of a persistence factor (PF) that incorporates persistence of both meteorological conditions and emissions, and that is based upon the nearest permanent monitoring station. Alternatively a proponent is permitted to use site-specific monitoring data, if two or more complete seasons of monitoring data are available. A simplified discussion of persistence factors and the possible implications of using the nearest permanent monitoring station are discussed below.

For a conservative pollutant like CO and a near surface release, e.g., vehicles, the atmospheric concentrations should depend most strongly upon: 1) emissions distribution (spatial); 2) wind speed; 3) wind trajectory (history of the air parcel); and 4) mixing depth, all of which vary with time. (Note that under low wind, episodic conditions, wind trajectory may not be as important a factor as the emission sources in the immediate vicinity.) A Total Persistence Factor (TPF) can be formed as a ratio between observed maximum 1-hr and observed maximum 8-hr concentrations (for the same continuous 8-hr period) over some record of hourly observations.[3]

$$TPF = C_{max,\ 8\text{-}hr}/C_{max,\ 1\text{-}hr}$$

Ideally, the TPF captures the joint probability that emissions (e.g., traffic counts) and adverse meteorological conditions (e.g., wind speed, direction and mixing depth) "persisted" to result in the 8-hr maximum observation. The TPF calculated from observations can be conceptualized as reflecting a probability that a modeled 1-hr maximum concentration will result in an 8-hr maximum observation. Note that a TPF defined in this way inherently assumes that both the temporal distributions of

[3] The SCAG (1992) guidance states, "The persistence factor should be based on values obtained using the 10-highest non-overlapping 8-hour concentrations obtained from the latest three CO seasons of monitoring data. The ratio of the 8-hour concentration to the highest 1-hour concentation in each of the non-overlapping 8-hour periods is determined, and the average of the 10 values is used as the persistence factor."

emissions and meteorological conditions are the same at the modeled site as at the monitoring station.

As a first approximation, the variation of emissions with time can be considered to be statistically independent of changes in the meteorological conditions. Then, a TPF can be considered to be composed of the product of two independent factors, one that represents the Emissions Persistence (EPF) and one that captures the Meteorological Persistence (MPF).

$$TPF = EPF * MPF$$

However, statistical independence between emissions and meterological conditions may not always hold. For example, cold starts and residential heating will be temperature dependent as can be cold, clear-night, radiation inversions, so that treatment of the distributions, as if they were statistically independent, is only an approximation. Furthermore, the EPF can be thought of consisting of time-varying statistical distributions from each source category, e.g., vehicles and stationary combustion, which should be combined in some way prior to multiplication with the MPF. In the vast majority of cases, the dominant contribution of emissions is from vehicular sources, but as we have seen earlier, under the nighttime episode conditions, it is possible that stationary sources are not negligible. Also, because one is typically interested in exceedances of the ambient standard, one is also interested in the probability of extreme events in the joint distributions. The uncertainties become larger in those cases.

The bimodal nature and lack of correlation of CO peak concentrations with traffic counts in the evening/nighttime period also suggests that emission patterns and possibly even meteorological conditions leading to nighttime exceedances differ from those that occur during the early morning. Therefore, application of a single persistence factor to 1-hr maximum "worst case" concentration predictions can be inappropriate as far as the underlying physical situation is concerned; i.e., the conditions that led to the observed "worst case" morning peak may have been independent of the conditions that led to the "worst case" evening peak.

An example of the nature of the problem is given by the early morning CO maximum observed at the Lynwood station on January 9th (see Figure 4a, on p. 18). It was preceded by a very small evening peak on the 9th and was dispersed before the nighttime peak on the 10th. The vehicular persistence factor for the morning peak was probably high while the meteorological factor was low. For the evening/nighttime peak on the 10th, the reverse was likely true; i.e., the traffic persistence was low while the meteorological persistence was high. A nighttime peak is probably broader, extending over a larger number of hours, with a smaller ratio of the peak-to-mean concentration; whereas, the morning peak may be quite sharp, and it may have a higher peak-to-mean ratio. If the morning traffic peak is modeled and an evening peak TPF is applied, an unrealistically conservative value would result. We note that the persistence factor approach is probabilistic in nature, and it is not at all clear that the probability distributions from one time period to another are consistent.

The observed differences in meteorology between communities, as geographically close as Vernon and Lynwood, suggest that meteorological persistence factors may be spatially dependent and may possibly differ on scales as short as a few kilometers; it is almost a certainty that EPF varies spatially. Thus, we also note that TPF can vary with geographical region (Nokes and Benson, 1985); hence, the SCAG guidance to use the nearest monitoring station is well-advised.

Utilization of the nearest monitoring station poses a problem if the monitoring station does not fit the description of a neighborhood scale station and particularly, if the project has a predicted impact on the monitoring station. In the latter case, the station cannot serve as a "background" station, since a double counting of the impact of the proposed emission source would have occurred. On the other hand, if a monitoring station does fit the criteria of a neighborhood station, then there is no guarantee that the observed TPF provides a correct representation of a project's EPF but only the combined EPF of dominant emission sources in the area in general! To the extent that the project's EPF and the area's EPF are correlated, a reasonable prediction may result. We point out these shortcomings of the TPF method, recognizing that in striving for a simple methodology for predicting impacts, compromises have been made that increase the uncertainty in the predictions.

In order to develop a sufficient base of observations for meaningful statistical inferences, it is necessary to examine several years of meteorology. However, the longer the database, the more likely it is the emissions distribution, that gave rise to the observed CO concentrations, will have changed. The current SCAG protocol suggests a balanced length of meteorological record of three years, and that the average of the ten highest 8-hr to 1-hr, non-overlapping periods be used to compute a TPF. An EPA default value of 0.7 should be used, if at least two years of qualified data are unavailable. Cooper's analysis of the use of persistence factors (1992) indicates that choice of the modeled "worst-case" condition has a strong influence on the TPF. Based on the results of Cooper (1989, 1992), who found values closer to 0.55 to 0.6 for the "worst-case" methodology he applied,[4] the latter value seems unnecessarily conservative (high) for some

---

[4] The typical guidance provided by the different agencies use a 1 m/s wind speed and class D stability in cases of roughness, corresponding to urbanized areas.

areas. At the same time, the study by Nokes and Benson (1985) illustrated that persistence factors greater than 0.7 also occur.

From the above discussion, it should be clear that when site-specific data are available, they should be utilized. Also, since most air district's monitoring stations have meteorological records of wind speed, direction and temperature (sometimes at more than one height), as well as the CO monitor data, it does not seem necessary or desirable to resort to a persistence factor approach, but rather it is more desirable to utilize the actual meteorological record that corresponds to the measured maxima directly. The Gaussian model can be applied for successive 1-hr calculations assuming actual, rather than "worst case" meteorology, e.g., for the ten highest measured 8-hr averages over some period of time. Because the impacts from near surface releases diminish with distance, the greatest impacts are close to the source, where the Gaussian assumptions of steady-state are more nearly met on an hour-by-hour basis. Unfortunately, if the CO exceedance in fact corresponds to a period of calm, then the existing Gaussian models cannot be applied, though with some model development, a Gaussian puff model might give results as accurately as a grid-type model.

We recommend that if the persistence factor approach is pursued, a study be performed to determine: 1) whether the choice of modeled "worst case" condition (1 m/s wind speed, neutral stability) is appropriate for predicting the episode conditions and 2) whether a separation of the evening/nighttime and early morning peaks is necessary in developing the persistence factor, i.e., a specific project may have a greater impact during one time period than another, and the total persistence factors for the two periods may differ from one another. In addition, if a specific project changes the existing emission source distribution in such a way as to significantly impact the concentration at the monitoring site used to calculate the total persistence factor (as determined by model calculation), we suggest that both the existing project and the new project be modeled, so the TPF may be applied to the modeled difference between them, and the corrected difference can be added to the "background" in order to determine the impact. We believe that by taking this approach, the factors that influence changes in emission distributions and the double counting of background CO will be minimized, resulting in a closer measure of meteorological persistence.

Monitoring for Background CO

The objectives of a particular monitoring program should be clear before deciding upon placement of a monitor(s) or even whether monitoring is warranted. If the goal is to determine the spatially averaged concentrations for a region ranging from one to several kilometers in linear dimension for a period of several hours (i.e., a site suitable for "background") then a monitor should be located sufficiently far away from any single source that can significantly alter the concentration at the monitor (i.e., over a period of several hours). As a practical matter, monitors should be protected against tampering; these monitors will commonly require power, must be accessible to service personnel, provide validated data and should be cost-effective.

The SCAQMD has indicated that the UAM estimates of the 8-hr CO averages were in good agreement with all monitoring stations in the SoCAB, except for the Lynwood monitor (Mitsutomi, 1993); nevertheless, even in the Lynwood case, the modeled value of 18.5 ppm corresponded to the measured value of 21.8 ppm (December 7, 1989), i.e. within approximately 15 percent. For reasons explained in the review of the Lynwood study, local indirect emissions may have influenced the readings of the Lynwood monitor. Given the good performance of the UAM model, there is no apparent need to conduct site specific monitoring of background for purposes of determining project conformity in those areas where the UAM model capability exists. What is required is a good meteorological network to provide the information necessary to drive the wind field and the mixing depths used in UAM.

If a modeling approach is unacceptable as an alternative to monitoring, then selection of the background monitoring station should strictly adhere to the EPA criteria for a neighborhood scale station. Several air districts utilize their existing monitoring network with supplemental special studies and meteorological experience to prepare concentration contours (isopleth diagrams). These serve as the basis for determination of "background" for CO impact analyses. The isopleths are generally selected as representative of "worst case" observations, and all of the stations employed may or may not meet the neighborhood station siting criteria. For that reason, we recommend that larger districts with staff expertise to run the UAM model and that have collected an emissions inventory for photochemical modeling purposes, eventually convert to using a Diagnostic Wind field Model (DWM) and UAM to determine CO background. Supplemental meteorological studies may be needed to refine the estimation of mixing depth and to provide more accurate wind field input to the DWM.

Discussion

The data and their analyses from the various studies clearly indicate that meteorological conditions dominate the occurrence of 8-hr CO episodes. The observed CO concentrations do not correlate with the rate of vehicular emissions during the evening/nighttime episodes, but they may reflect an integral of vehicular emissions from on road and indirect sources over a period corresponding to calm stable conditions, coupled with non-negligible emissions of CO from other widely distributed combustion sources, such as residential NG usage. In the case of the Lynwood monitor, there is a possibility that localized sources, e.g., the presence of a boiler at the Post Office or activity at the mailboxes, have influenced its readings. However, the entire area (several kilometers in diameter) may also experience a relatively elevated background as a result of significant stationary emission sources that surround Lynwood, particularly to the West and South.

The early morning peak at Lynwood is more closely correlated with emission rates from vehicular sources, than the nighttime peak, but both peaks may be augmented by non-vehicular contributions. The CO "hotspot" phenomenon in Lynwood appears to occupy a smaller geographic area (roughly about 0.5 km in diameter) than in San Jose/Santa Clara; however, the meteorological conditions that lead to CO episodes are not limited to one geographical area of the State. In the case of extremely stable atmospheres, even with low wind speed (i.e., greater than 1 m/s), transport of a CO "plume" over distances of 10 kilometers occurs, e.g., in Sacramento.

Prediction of the impacts from CO over 8-hr periods cannot be accurately performed with the existing microscale dispersion models commonly used for vehicular sources, e.g., CALINE 3 or 4. One reason for this is that the continuous Gaussian models were not designed for wind speeds below about 0.5 to 1 m/s. Secondly, buoyant sources of CO are not accurately handled in current models for episode meteorology. Although use of a grid-type model, e.g., UAM, is theoretically possible, the grid would have to be made much finer, perhaps as little as 5 to 10 m on a side and 2 to 5 m in the vertical. Parameterization of diffusivity and inclusion of buoyancy effects must still be introduced, and enhanced accuracy would require good characterization of mixing depth. The resolution of the emissions inventory must be correspondingly fine in order to apply it to local microscale impacts, such as those that occur at the Lynwood monitor, and collection of these data would be highly labor intensive and impractical. We believe that further research concerning the parameterization of the appropriate horizontal diffusivities used in the model should be undertaken for conditions typical of the episodes. Therefore, we believe that the use of UAM or other small scale 3-D grid models is not a practical solution for improving the prediction of microscale level impacts at this time. Use of a particle-in-cell (PIC) hybrid model may be possible, but the computational resources required to model an intersection or on-ramp would have to be examined.

Use of UAM to predict "background" CO levels applicable to areas of 1 or 2 km grid squares seems feasible; however, it would be helpful to attain higher resolution of mixing depths near the surface since they appear to be critical to the "episode" condition. Nevertheless, SCAQMD has had reasonable success at predicting observed CO concentrations for 8-hr periods using UAM at stations other than Lynwood (Mitsutomi, 1993), and even the differences at Lynwood were relatively small. The reason that UAM can be used over 8-hr averaging periods for neighborhood-scale modeling is that the model averages and effectively "diffuses" emissions over an entire grid square, so that even in calm situations, concentrations do not build up at any single spot. Buoyancy effects may need to be accounted for in the model for some sources as well (e.g., a refinery flare in the same grid cell) though the mixing depths are probably more critical, and at distances of several kilometers, the influence of single elevated sources is probably negligible because under stable conditions the plume cannot diffuse downward. The use of the UAM model for defining "background" concentrations for microscale studies, in place of site-specific monitoring, may be more cost-effective and just as accurate since, in that case, a consistent inventory would be applied to any additional microscale modeling. The UAM model accuracy can be strengthened with improved meteorological information, i.e., wind speed, direction and mixing depth.

A more cost-effective and methodologically consistent alternative for attainment planning purposes is to manage 8-hr exceedances by comparing estimated project emissions with estimated current emissions (i.e., from an emissions grid size corresponding to the current CO inventory, typically about 1 km). There is so much uncertainty with regard to actual on-road emissions, on top of the meteorological uncertainties associated with microscale modeling under episode conditions, that use of dispersion models to predict relative changes for the 8-hr standard is not warranted. Thus, if the estimated emissions produced total emissions in a given grid square, say equal to or less than the existing situation, and also basinwide, it might be allowed to proceed. The rationale for this approach is that the errors in the emission models are most likely systematic, hence a reduction in the emission model will likely reflect an actual reduction in spite of the uncertainty in the absolute prediction.

In order to ensure that a local exceedance of the 1-hr standard had not occurred, a 1-hr "worst case" model run could be made (under the current model guideline). We believe that a continuous Gaussian model under the current "worst case" scenario provides a conservative overestimate. Even the necessity of that modeling effort could be avoided, if it could be shown that the temporal emissions rate were less than or equal to the existing emissions. In essence, modeling effort improvements would be focused on accuracy of emissions modeling rather than dispersion modeling, a situation of value to photo-chemical modeling efforts as well.

Conclusions

Emissions corresponding to the night time peak and exceedance of the 8-hr standard at the Lynwood site do not appear to be attributable to local on-road motor vehicle sources alone. An elevated background concentration relative to other stations is probable at the Lynwood station because of the geographic distribution of sources surrounding it. Furthermore, the possible impact of natural gas combustion cannot be dismissed at this point. Although no direct evidence could be found for the importance of off-road sources, several bits of circumstantial evidence were discovered: 1) a statistical analysis (EOF) of the data from the Lynwood intensive study in 1989-90, conducted by DRI, suggests a local source of CO between the intersection and the monitor; 2) a site visit to the area indicated that many commercial enterprises in the area lead to potential vehicular sources of CO (from about 10 to 11 p.m. at night) that are located in the vicinity of the monitoring station, e.g., increased emission due to cold starts; 3) the recorder trace of the LYNN CO monitor displayed small (two to five ppm) transients throughout much of the nighttime period; 4) source inventories suggest that there are major sources surrounding the community of Lynwood that could lead to a higher background than at other stations because of transport; 5) demographic data suggest that the age and density of residences exceeds that of LA County in general and emission factors for NG suggest that its contribution, while small, may not be entirely negligible during the evening/nighttime CO episodes; 6) the distribution of vehicle ages in LYNN was shown to have a larger mean, so that cold-start emissions may also be higher, as well as the running emissions; and 7) studies of isotopic composition of CO indicate the existence of non-fossil fuel sources.

Both the Lynwood intensive study and studies by BAAQMD in the San Jose/Santa Clara area show ^{14}CO of about 0.5 to 1 ppm above what would be expected from vehicular sources or global background were present in the air. The source of the ^{14}CO could not be determined; but the range of ^{14}CO percentage varied from as high as 50% down to 5% site specific locations during episode conditions. In both studies, it was noted that an inverse relationship of ^{14}CO with total CO concentration was observed, indicative that ^{14}CO from other sources was only a small fraction of the total.

Based upon observations made during the site visit, the Lynwood station is concluded to not be representative of a "neighborhood scale" monitoring station, but to more closely approximate a "middle scale" station by the EPA definition. Several indirect sources that are the result of commercial activity that extends into the nighttime period are located near the monitor. The probe inlet location is in relatively close proximity to nearby space heating emissions sources and to vehicular idling and acceleration emissions from mailboxes located at the post office. A "back-of-the-envelope" calculation of possible CO emissions from the post office also indicated that boiler CO emissions possibly could account for up to several ppm of CO, comparable to the magnitude of transient CO changes observed in the LYNN CO recorder traces.

The early morning peaks during the 1989 Lynwood intensive study would have led to an exceedance of the 8-hr standard at the Lynwood site and appear to be correlated primarily with vehicular sources, i.e. morning traffic, though there is circumstantial evidence that the rise in CO levels may begin (4:00 a.m.) before on-road traffic increases.

In cases of extremely stable conditions, mixing is limited so strongly that horizontal transport was apparent in the Sacramento study, e.g., CO from the downtown Sacramento area appeared to be transported to the Sacramento Metro Airport, and give rise to a measurable peak even under conditions of moderate wind speed. However, long-range transport alone is unlikely to lead to an 8-hr exceedance.

A review of the meteorological conditions during the period in which CO can be expected to lead to 8-hr exceedances in Lynwood as well as other air basins, (San Jose/Santa Clara and Sacramento) indicate that project-specific microscale studies are not appropriate because of current modeling methodologies. Conditions leading to CO exceedances correspond to very light or non-measurable wind speed (by conventional instrumentation) and extremely stable inversions that cannot be handled accurately with the continuous Gaussian plume models currently applied. The more sophisticated 3-D grid models require too much input data to be practical on a microscale so that they do not offer an improvement over the Gaussian methodology at this time. Buoyancy effects are predicted to become important as wind speed diminishes, especially below about 1.0 m/s. Energy conservation and momentum conservation suggest that the "plume rise" phenomena can become significant for multi-lane heavily trafficked corridors so that both the Gaussian and grid-type models may need to take it into account.

Application of the concept of "persistence" is useful as an initial estimate relating one-hr "neighborhood scale" CO concentration predictions to 8-hr time periods because CO can be treated as a conservative pollutant. But, because the TPF may vary both temporally and spatially, use of a single value may not provide a good estimate of impacts. Unless the monitor used to determine the TPF is significantly impacted by a specific project, there is no guarantee that the EPF is taken into account properly. If the monitor is sited close enough to the project to be influenced by its emissions, then it no longer can be considered a neighborhood scale monitor and representative of the area. Therefore, the simplification that the method would provide is lost. The persistence factor method, if it is to be applied, also needs further study to determine if significant differences arise from nighttime and early morning regimes.

Use of the UAM model for determination of "background" would be more cost-effective than site-specific monitoring for CO. However, UAM predictions are sensitive to mixing depth under episode conditions, and the accuracy of UAM predictions would be improved with better near surface temperature profile data to determine mixing heights to be used. Additional tethersonde studies or a larger number of vertical temperature measurements at existing permanent monitoring stations would be desirable.

At this time, a CO management methodology based upon reduction of total estimated CO emissions within units of one to several kilometers on a side (corresponding to normal air district emission inventories) would appear to be appropriate for determining the impacts of transportation-related emission sources over periods corresponding to the 8-hr ambient air quality standard. Efforts should be focused on improving the accuracy of the emissions estimates.

Recommendations

Project specific microscale studies for the 8-hr averaging period are not recommended. As an alternative, comparison of existing and future project emission estimates could be undertaken at a grid scale of 1 or 2 kilometers in order to determine whether CO emissions would increase, remain the same or improve. The continuous emission Gaussian models used for "hot-spot" analyses are inaccurate under episode conditions, and the uncertainties in the emissions inventory preclude use of more sophisticated grid models. Use of an emissions inventory approach at least provides a consistent error so that relative changes can be examined. If the microscale modeling approach is to have a strong scientific foundation, a new set of tools must be developed. Such tools may need to address the possible importance of buoyancy effects during periods of low wind speed.

Further effort to determine whether buoyancy phenomena are important under CO episode conditions are warranted. We recommend that a more sophisticated 2-D computational modeling effort, one that does not entail parameterization of entrainment, be undertaken to determine whether the "puff" plume rise method applied in this study has given reasonable results. The numerical solution of the full Navier-Stokes equation is computationally feasible and could be compared to data from other freeway sites obtained by Caltrans in the mid-70s.

Use of a "grid" model, UAM, in conjunction with a diagnostic wind field model, to predict "background" concentrations over 8-hr periods provides a reasonable estimate of actual concentrations. We recommend that the approach be pursued further by other districts, and a study be undertaken to validate the method by comparing it with historic data from neighborhood scale stations. Such a methodology would be more consistent with estimates currently used for attainment planning purposes. Better resolution of mixing depth is desirable, and it is recommended that a program to obtain near surface vertical temperature profiles be undertaken.

Development of a statistical method for determining the representativeness of siting of a given monitoring station should be attempted. A specific monitoring station may appear to satisfy the neighborhood scale siting criteria, but it may be unduly influenced by local conditions. In principle, conservation of the mass of CO requires that mixing depth, wind speed, emission source strength and transport (trajectory) of CO to a monitoring station dominate the determination of the measured concentrations. During periods corresponding to exceedances of the 8-hr standard, transport is typically limited to distances of a few kilometers (low wind speeds); sources more distant have undergone significant dilution, suggesting that each monitoring station is primarily influenced by nearby sources, i.e., within several kilometers. A regression analysis should be capable of explaining most of the variance in the data. If mixing depth, wind speed (these could be measured or modeled) and emission source strength can be computed, it should be possible to undertake a statistical analysis (hourly during the periods leading to exceedances) to examine outliers in the relation for existing monitoring stations. New statistical methods have been developed that are capable of finding outliers in data sets, even when the causal variables are unknown. Application of such a technique could provide a means for determining whether a station fits such a model or where the model has weakness, e.g., large underestimate of emissions. Such a study, carried out in collaboration with several of the air districts, is recommended.

Simultaneous measurement of mixing depth (by tethersonde) at several locations during periods of episode meteorology, high stability and low wind should be undertaken (e.g., near a freeway away from other major heat sources, among high rise buildings, a residential area, etc). A standard methodology for integrating such information to produce contours of mixing depth for use with the UAM model would be useful.

Limited studies of space heating as possibly significant CO emission sources, during periods of limited ventilation, should be undertaken (e.g., measurement of CO concentration and exhaust temperature in post office boiler exhaust and roof vents of gas-fired heaters). This need not be an extensive set of source tests; however, these studies may simply confirm whether the emission factors that are currently used for space-heating are underestimating in-use appliance emissions. If there is evidence for gross underestimation, then a program to determine in-use emission factors should be undertaken.

The SCAQMD Lynwood monitor better fits the definition of a "middle scale" than a "neighborhood scale" monitor and should not be used for purposes of determining background at projects located more than about 0.5 km from the station.

Carbon monoxide is produced by the body and has only recently been recognized to have a possible role as a neuro-transmitter (Barinaga, 1993; Verma et al., 1993). There has been no evidence of chronic illness resulting from ambient level CO exposure (USEPA, 1984). It is also one of the best understood of the criteria air pollutants in terms of health effects of sensitive populations. Models of exposure and resulting carboxyhemoglobin levels have been developed so that dose-response relationships are well defined. Given this level of understanding, the selection of receptors for purposes of determining CO exceedances of the NAAQS should be examined (e.g., timing of occurrence of CO exceedances compared to health risk, siting of receptors for exposure and on-road short-term driver exposure compared to pedestrian exposures).

References

Aerovironment Inc., (1991). "Determination of Source Contributions to High Ambient Carbon Monoxide Concentrations and Categorization of Carbon Monoxide Potential," Final Report, #A832-135, California Air Resource Board.

Barinaga, M. (1993). "Carbon Monoxide: Killer to Brain Messenger in One Step," Research news article, *Science*, Vol. 259., p. 309-310.

Barrett, R.E., et al. (1973). "Field Investgation of Emissions from Combustion Equipment for Space Heating." Battelle Columbus Labs, Ohio, EPA R2-084A, EPA 68-02-0251.

Bauman, S.E., E.T. Williams, H.L. Finston, E.F. Ferrand, and J. Sontowski. (1982). "Street level versus rooftop sampling: carbon monoxide and aerosol in New York City." *Atmospheric Environment*. Vol. 16. No. 10. pp. 2489-2496.

Bemis, G.R., A.J. Ranzieri, P.E. Benson, R.R. Peter, K.O. Pinkerman, and B.T. Squires (1977). "Air Pollution and Roadway Location, Design and Operation Project Overview." Caltrans Final Report FHWA-CA-TL-7080-77-25, September.

Benson, F. B., J.J. Henderson, & D.E. Caldwell (1972). "Indoor-outdoor Air Pollution Relationships: Literature Review." U.S. EPA Publ. No. AP-112. pp. 5-20.

Benson, P. (1982). "Modification to the gaussian vertical dispersion parameter, s_z, near roadways." *Atmospheric Environment*, Vol. 16. pp. 1399-1405.

Benson, P. (1989). "CALINE4 - a dispersion model for predicting air pollution concentrations near roadways." State of California Department of Transportation. Report No. FHWA/CA/TL-84/15.

Berman, N.S., and R.L. Rankin (1979). "Eddy diffusivities in stable ground-based inversions." *AICbE Symposium Series 188*. Vol. 75. pp. 191-195.

Bowen, J.L., P.A. Walsh, and R.C. Henry, (1993). "Analysis of Data From Lynwood Carbon Monoxide Study." Draft final report, California Air Resources Board, DRI Document No. 685-2656.D2, Desert Research Institute, Reno, NV.

Bowen et al. (1993a). p. 3-49.

Bowen et al. (1993b). p. 2-3, 2-5.

California Air Resources Board (1991). "Methodology to Calculate Emission Factors for On-Road Motor Vehicles." On-Road Motor Vehicle Emission Inventory Section, Technical Support Division, California Air Resources Board, Sacramento, California, July.

California Department of Transportation (1992). "1991 Traffic Volumes on California State Highways." Division of Traffic Operations, California Department of Transportation, Sacramento, California, June.

Chang, D.P.Y., R.E. Mournighan, adn G.L. Huffman (1991). "An Equilibrium Analysis of Some Chlorinated Hydrocarbons in Stoichiometric to Fuel-rich Post-flame Combustion Environments." *J. Air & Waste Management Assoc.*, Vol. 41, pp.947-955.

Chock, D.P. (1977). "General Motors Sulfate Dispersion Experiment-an overview of the wind, temperature, and concentration fields." *Atmospheric Environment*. Vol. 11. pp. 553-559.

Chock, D.P. (1978). "A simple line-source model for dispersion near roadways." *Atmospheric Environment*. Vol. 12. pp. 823-829.

Cooper, C.D. (1989). "Persistence factors for mobile source (roadway) carbon monoxide modeling." *JAPCA*. Vol. 39. pp. 714-720.

Cooper, C.D. (1992). "Identifying 'Worst Case' Persistence Factors for Carbon Monoxide Modeling Near Intersections in Orlando, Florida." *J. Air. Waste Manage Assoc*. Vol. 42. pp. 1461-1465.

Dabberdt, W.F. (1976). "Temporal dependence of microscale dispersion from roadways." Presented at the 69th Annual Meeting and Exhibition of the Air Pollution Control Association, Portland, OR, June 27-July 1.

Draxler, R.P. (1976). "Determination of atmospheric diffusion parameters." *Atmospheric Environment*. Vol. 10. pp. 99-105.

Duker, D.C., D.A. Levaggi, T. Umeda, R.E. Mandel, and T.E. Perardi (1984). "Measurements of a Carbon Monoxide Cloud in San Jose, California." Paper No. 84-118.4, presented at the 77th Annual Meeting & Exhibition of the Air Pollution Control Association, San Francisco, CA, June 24-29th.

Eskridge, R.E, F.S. Binkowski, J.C.R. Hunt, T.L. Clark, and K.L. Demerjian (1979). "Highway Modeling Part II: Advection and Diffusion of SF_6 Tracer Gas." *J. of Applied Meteorology*. Vol. 18. pp. 401-412.

Eskridge, R.E., and S.T. Rao (1983). "Measurement and prediction of traffic-induced turbulence and velocity fields near roadways." *J. of Climate and Applied Meteorology*. Vol. 22. pp. 1431-1443.

Eskridge, R.E., W.B. Pertersen, and S.T. Rao. 1991. Turbulent diffusion behind vehicles: effect of traffic speed on pollutant concentrations. *J. Air. Waste Manage Assoc*. Vol. 41. pp. 312-317.

Flagan, R.C. and J.H. Seinfeld (1988). Fundamentals of Air Pollution Engineering. Prentice-Hall: Englewood Cliffs, New Jersey, p. 201 ff.

Gas Research Institute (1985). "Characterization of Emission Rates from Indoor Combustion Sources," GRI Report 85/0075, Gas Research Institute, Chicago, Illinois, March.

Godish, T. (1989). Indoor Air Pollution Control. Lewis Publishers: Chelsea, Michigan, p. 26.

Groblicki, P. J. (1990). Presentation at the California Air Resources Board Emission Inventory Workshop. Sacramento, California, August.

Hartley, M. and L. Hawkins, (1993). Personal communication with U.S. Postal Service employees, Lynwood Post Office, Lynwood, CA.

Henry, R.C., and Y.J. Wang (1991). "The relationship between empirical orthogonal functions and sources of air pollution." *Atmospheric Environment*. Vol. 25A. pp.503-509.

Ireson, R.G. and S.B. Shepard (1992). "Spatial and Temporal Carbon Monoxide Concentration Patterns in the Sacramento Area." Report to the Sacramento Area Council of Governments." SYSAPP-92/002, Systems Applications International, San Raphael, CA.

Levaggi, D.A. (1989). "Determining the impact of carbon monoxide emission from residential wood combustion on ambient air quality in Santa Clara county." BAAQMD, Technical Division.

Meyer, B. (1983). Indoor Air Quality. Addison-Wesley Publishing Company: Inc. Reading, Massachusetts, p. 170.

Mitsutomi, S. (1993). SCAQMD, personal communication, February, 12th.

Morton, B.R., S.G. Taylor, F.R.S., and J.S. Turner (1956). "Turbulent gravitational convection from maintained and instantaneous sources." *Proc. R. Soc. A*, Vol. 234. pp. 1-23.

Mott, L. (1993). SCAQMD, personal communication.

Nokes, W.A. and P.E. Benson (1985). "Development of Worst Case Meteorology Criteria." Report No. FHWA/Ca/TL-85/14, California Department of Transportation, Sacramento, CA, November.

Pasquill, F. (1974). Atmospheric Diffusion: The dispersion of windborne material from industrial and other sources. 2nd Edition. John Wiley & Sons: New York, pp. 240-250.

Pasquill, F. and F.B. Smith (1983). Atmospheric Diffusion: study of the dispersion of windborne material from industrial and other sources. John Wiley & Sons: New York, pp. 242-245.

Perardi, T., R.E. DeMandel, D.C. Duker, W. Siu (1984). "Carbon Monoxide: Hotspots, Coldspots and Implications for Attainment Planning." Paper No. 84-118.4, presented at the 77th Annual Meeting & Exhibition of the Air Pollution Control Association, San Francisco, CA, June 24-29th.

Remsberg, E.E., J.J. Buglia, and G.E. Woodbury (1979). "The nocturnal inversion and its effect on the dispersion of carbon monoxide at ground level in Hampton, Virginia." *Atmospheric Environment*. Vol. 13. pp. 443-447.

Seinfeld, J.H. (1986). Atmospheric Chemistry and Physics of Air Pollution. Wiley-Interscience: New York, p. 124 ff.

Sheih, C.M. (1978). "A puff pollutant dispersion model with wind shear and dynamic plume rise." *Atmospheric Environment*. Vol. 12. pp. 1933-1938.

South Coast Air Quality Management District (1991). "Air Quality Management Plan--Appendix III-A: 1987 Emissions Inventory for the South Coast Air Basin for an Average Annual Day." South Coast Air Quality Management District.

South Coast Air Quality Management District (1992). "Final Federal Attainment Plan for Carbon Monoxide." November.

Southern California Association of Governments (1992). "Carbon Monoxide Transportation Project Protocol." December.

Southern California Gas Company (1993). Personal communication with Environment and Safety Division, July.

Stedman, D.H., G.A. Bishop, J.E. Peterseon, and P.L. Guenther (1991). "On Road CO Remote Sensing in the Los Angeles Basin." Draft Final Report #A932-189, California Air Resources Board.

Turner, J.S. (1973). Buoyancy Effects in Fluids. Cambridge University Press: New York.

United States Environmental Protection Agency (1984). "Revised Evaluation of Health Effects Associated with Carbon Monoxide Exposure: An Addendum," EPA-600/8-83-033f, Office of Air and Radiation, Office of Air Quality Planning and Standards, USEPA, Research Triangle Park, North Carolina, August.

United States Environmental Protection Agency (1992). "Compilation of Air Pollutant Emission Factors--Volume I: Stationary Point and Area Sources," AP-42, 4th Edition, Office of Air and Radiation, Office of Air Quality Planning and Standards, USEPA, Research Triangle Park, North Carolina, October.

Verma, A., D.J. Hirsch, E.G. Glatt, G.V. Ronnett and S.H. Snyder. "Carbon Monoxide: A Putative Neural Messenger," *Science*, Vol. 259, p. 381.

Wadden, R.A. & P.A. Scheff (1983). Indoor Air Pollution: characterization, prediction, and control. John Wiley & Sons: New York, p. 2.

APPENDIX A

CO Health Effects

A major factor in the selection of receptor-modeling locations and monitoring stations should be a realistic potential for adverse impacts on human health. This appendix has been prepared to summarize the nature of the health concerns of CO at ambient outdoor air concentrations and is intended to provide guidance to assist with the selection of receptor locations.

The current health effects basis of the National Ambient Air Quality Standard (NAAQS) for CO is protection of the portion of the population that experiences certain cardiovascular effects such as aggravation of angina (USEPA, 1984, 1991). Table A-1, excerpted from the recent criteria document (1991), illustrates the key health effects from exposure to CO at ambient levels. The group viewed as the most sensitive at-risk group for CO exposure effects, chronic angina patients, was determined based on evidence of aggravation of angina occurring in patients at carboxyhemoglobin (COHb) levels of 2.9 to 4.5% of COHb (USEPA, 1984).[1] The Clean Air Scientific Advisory Committee (CASAC) concurred with the USEPA's judgment on this matter in 1984, and the conclusions have not changed with the more recent review completed at the end of 1991. Decrements in maximal exercise performance of healthy individuals exposed to one hour peak ambient CO levels producing ≥ 2.3% COHb have also been observed (USEPA, 1991), however, "The decrements in performance that have been described at the lowest levels (≤ 3% COHb) are in the range of reproducibility of the exercise stress test and may not be alarming to some physicians."

The review of the NAAQS for CO (USEPA, 1984) recognized the possibility of effects below 2.9% COHb and provided a "margin-of-safety." The most recent studies (Allred et al., 1989a, 1989b, 1991; Kleinman et al., 1989) confirm that significant changes in two experimental endpoints, time to onset of angina and time to change in the "ST segment" of electrocardiograms after exposure to CO and beginning an exercise program, occur in the range of CoHb 1.5 to 3.0% above baseline (Kleinman et al., 1989) in one study and at 2% above baseline (Allred et al., 1991) in the other study corresponding to a total COHb of approximately ≥ 3.0%. Uncertainty remains about the accuracy of the measurement method for COHb at the low concentrations of CO used in these studies and the criteria document recommended further examination of the measurement method. Nevertheless, if the measured COHb levels are accurate, then a revision of the current federal 1-hr standard (35 ppm_v) seems unlikely.

---

[1] The percentage of COHb reflects that portion of the oxygen carrying capacity of the blood that is occupied by carbon monoxide and is therefore unavailable for oxygen transport. Aggravation of angina is considered to represent an adverse health effect.

TABLE A-1 KEY HEALTH EFFECTS OF EXPOSURE TO CARBON MONOXIDE

Target Organ	Health Effect(s)[a]	Sensitive Population[b]
Heart	Reduced exercise duration due to increased chest pain (angina) with peak ambient exposure (3-6% COHb)[c]	Individuals with ischemic heart disease
Heart/ Lungs	Reduced maximal exercise performance with 1-h peak ambient exposures (≥ 2.3% COHb)	Healthy individuals
Brain	Equivocal effects on visual perception, audition, motor and sensorimotor performance, vigilance, and other measures of neurobehavioral performance with 1-h peak exposures (≥ 5% COHb)	Healthy individuals
	Neurological symptoms can occur ranging from (1) headache, dizziness, weakness, nausea, confusion, disorientation, and visual disturbances to (2) unconsciousness and death with continued exposure to high levels in the workplace or in homes with faulty or unvented combustion appliances (≥ 10% COHb)	Healthy individuals

[a]EPA has set significant harm levels of 50 ppm (8-h average), 75 ppm (4-h average), and 125 ppm (1-h average). Exposure under these conditions could result in COHb levels of 5 to 10% and cause significant health effects.

[b]Fetuses; infants; pregnant women; elderly people; and people with anemia or with a history of cardiac, respiratory, or vascular disease may be particularly sensitive to CO.

[c]Carboxyhemoglobin levels were determined by the optical method (CO-Oximeter).

The question of what constitutes a "reasonable exposure" remains for policymakers. Therefore, it is of interest to examine the levels of ambient CO and the duration over which they must be present in order to elevate COHb levels into the range of approximately 2 to 3%. Note that the COHb level attained for a given CO concentration in air is believed to be an equilibrium process, but that it takes time to achieve the equilibrium from either direction. Figure A-1a and A-1b have been adapted from the USEPA (1984, 1991) documents to illustrate the approach to equilibrium, from an assumed baseline to higher concentrations of COHb, at different activity levels. The predictive (Coburn) equations are, "...widely accepted as the best available modeled estimates of COHb levels likely to result from varying CO concentrations, exposure durations and exercise levels ... proposed alternative approaches yield very similar estimated COHb levels to those projected by Coburn's approach. In addition, actual blood COHb concentrations observed in response to particular external CO exposures situations have been consistent with those projected by Coburn ..." (USEPA, 1984). The reader should note that the modeled equilibrium concentrations depend upon assumptions regarding the individuals and their breathing rates.

An examination of Figure A-1a shows that even with a heavy exercise condition (50 LPM) at 10 ppm_v, COHb levels of 1.5% are reached only after several hours. At resting levels, approximately 8 hours of exposure are required. Given that the nighttime CO maxima in the Lynwood, Sacramento and Santa Clara/San Jose area occur in the range of 2200 to 2400 hrs, it is clear that modeled exceedances of the current 8-hr standard at the edge of a right-of-way does not constitutes a "reasonable likelihood" of exposure at night and would be unlikely even during the daytime hours. Also given the seasonal (late fall/winter - cold, clear night) nature of CO episodes, indoor concentrations of CO at night would not be expected to track outdoor concentrations as closely as at other times of the year because air infiltration rates are expected to be lower during winter nights. Studies of indoor concentrations of CO, in the absence of an indoor source of CO, often indicated lower indoor concentrations than in the ambient air because of the lag time for air to infiltrate the building. On the other hand, in the presence of indoor sources (e.g., cooking, pilot lights, unvented space heaters, smoking, fireplace, etc.) CO levels can become much higher indoors than prevailing outdoor ambient concentrations. There is no generally applicable method available to relate indoor concentrations to outdoor concentrations and the ambient standard is intended to be applied to outdoor exposure.

Alleviation of peak early morning (0700 to 0900 hrs) exceedances of the 8-hr standard appear to be of potentially greater health significance than alleviation of nighttime exceedances. Common experience suggests that more individuals exercise in the early morning than late at night. However, because of the length of

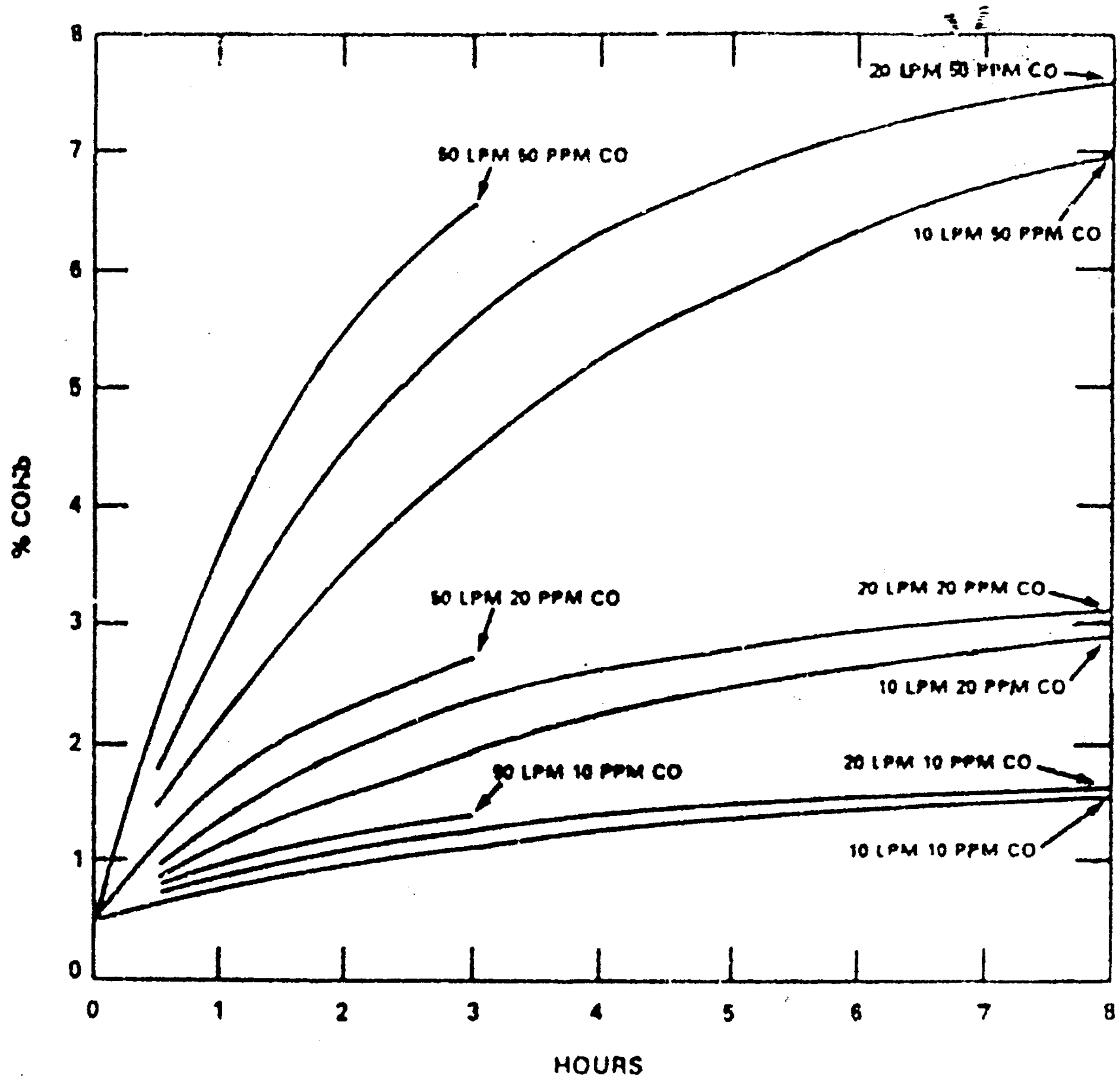


Figure A-1a Blood COHb concentrations predicted by Coburn equations to occur as a function of exposure duration and ambient carbon monoxide concentrations under resting (10 LPM), light exercise (20 LPM), or heavy exercise (50 LPM) conditions. LPM = liters per minute ventilation rate.

Adapted From -
U.S. EPA (1984).

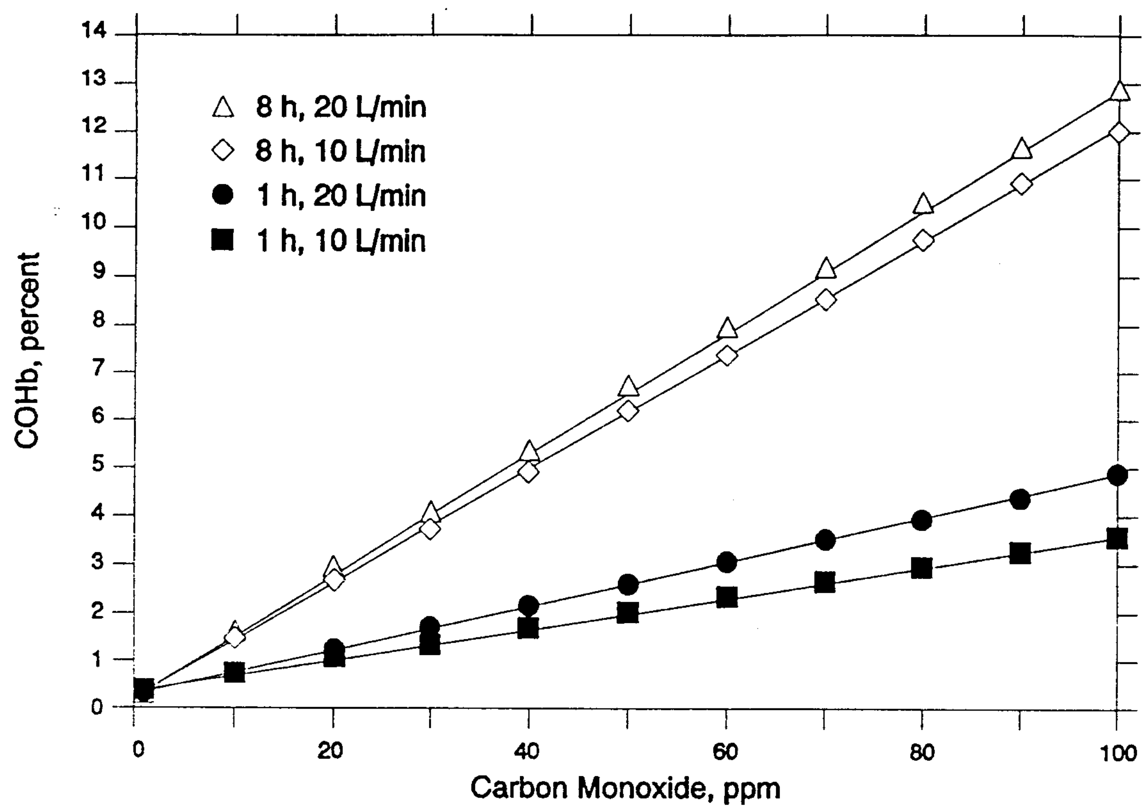


Figure A-1b Relationship between carbon monoxide exposure and carboxyhemoglobin (COHb) levels in the blood. Predicted COHb levels resulting from 1- and 8-h exposures to carbon monoxide at rest (alveolar ventilation rate of 10 L/min) and with light exercise (20 L/min) are based on the Coburn-Forster-Kane equation (Coburn et al., 1965) using the following assumed parameters for nonsmoking adults: altitude = 0 ft, initial level = 0.5%, Haldane coefficient = 218, blood volume = 5.5 L, hemoglobin level = 15 g/100 mL, lung diffusivity = 30 mL/torr/min, and endogenous rate = 0.007 mL/min. See glossary of terms and symbols for abbreviations and acronyms.

time required to reach equilibrium and since persons suffering from angina could not be expected, reasonably, to engage in heavy exercise for several hours at a time, the 1-hr standard is of greater importance in protecting that at-risk group.[2] Given recent medical evidence on cardiovascular effects, it appears unlikely that the 1-hr federal standard for CO will be reduced from its current value of 35 ppm_v. The current state standard 1-hr standard of 20 ppm_v was based upon a 2.0% COHb level (CARB, 1989).

A separate issue dealing with health, but only indirectly related to conformity, regards the question of exposure of vehicle occupants to high levels of CO. Several studies have occurred over the years. Perhaps of greatest relevance to California driving conditions were those by Petersen and Sabersky (1975), Petersen and Allen (1982), the SCAQMD (1989), and Ott et al. (1993). In the two studies by Petersen, it was demonstrated that the average ratio of CO concentrations in vehicles to fixed-site monitoring measurements was 3.9 while the ratio of interior to immediate exterior concentrations was 0.92. The SCAQMD (1989) study indicated that levels from 2 to 4 times greater than outdoor air were observed in vehicles for CO, benzene, toluene, xylene, ethylene dibromide, ethylene dichloride and lead. However, it was not clearly stated whether the individual vehicle's exhaust was determined not to contribute significantly to the exposure. The average in-vehicle concentrations were below the federal and state 1-hr standards. Nevertheless, the maximum in-vehicle concentration observed was about 46 ppm_v, representing two 1/2-hour to 1-hour exposures (1- to 2-hr average) during round-trip commutes. One can speculate that on cold mornings corresponding to CO episodes, car heaters will be in operation and a somewhat lesser 'egree of exchange of ambient air with the interior of the vehicle will occur. Nevertheless, Petersen and Allen found that "comfort state" (i.e., windows open/closed, fan on/off, etc.) had little incremental effect on the CO concentration in the vehicle. Because typical commuting times range from 30 minutes to an hour at a time, reduction of in-vehicle CO levels during commuting hours would be desirable, because a higher in-vehicle concentration can elevate the baseline COHb concentration of an

---

[2] The 8-hr standard is still significant because in a "worst case" scenario, the baseline COHb level would be set by the 8-hr average concentration. It should also be recognized that CO can be largely treated as a conservative pollutant. Hence if outdoor ambient concentrations increase, then non-ambient concentrations, i.e., indoors or within a vehicle, will increase eventually leading to a increase in baseline COHb levels. Thus although the ambient air quality standard is not applicable to a non-ambient outdoor environment, the baseline COHb concentration of an individual, when first entering the outdoor ambient environment, may have already been impacted by the outdoor concentration of CO.

individual, thereby leading to shorter exposure durations to ambient concentrations in order to reach a given COHb level. Generally speaking, reduced congestion and improved traffic flow will lead to lower on-road CO concentrations, hence lower in-vehicle exposures.

Implications for Receptor Siting and Background Determination

Ideally, selection of receptor locations for modeling studies to determine health risk would be based on a "reasonable likelihood of exposure" to a significant dose. Because the averaging times for the CO standard have been selected to account for dose, then a reasonable likelihood of continuous exposure for those durations, one and eight hours respectively, would be a suitable criterion. It is recommended that general guidance for receptor locations and timing include the following considerations:

1) where publicly accessible pathways are located adjacent to traffic corridors, especially those known to be used for exercise for periods up to one-hour or longer and possibly used by persons of diminished respiratory capacity, e.g. bike paths, walking/jogging trails, parks, schoolyards, etc. - the 1-hr standard should be considered most significant and background and receptors selected accordingly;

2) where individuals with diminished respiratory capacity are likely to spend time long periods of time, e.g., sanitariums, hospitals, retirement homes - 8-hr standard most significant, but it is not possible to relate indoor concentration to ambient concentration, especially on cold winter nights - indoor concentrations are expected to be significantly lower than outdoor concentrations in the absence of an indoor CO source; for modeling purposes, the modeler should be aware of possible receptors, but by themselves those receptors should not be used to determine project conformity;

3) where sidewalk vendors establish businesses - both 1-hr and 8-hr standards may be significant, but it is unlikely that 8-hr nighttime exposures occur;

4) where people are known to spend nighttimes outdoors - 8-hr standard most significant;

5) for background determination for the 8-hr standard, areas corresponding to "neighborhood scale" as defined by the USEPA, are recommended.

References

Allred, E.N., E.R. Bleecker, B.R. Chaitman, T.E. Dahms, S.O. Gottlieb, J.D. Hackney, M. Pagano, R.H. Selvester, S.M. Walden, J. Warren (1989a). "Short-term effects of carbon monoxide exposure on the exercise performance of subjects with coronary artery disease," *N. Engl. J. Med.*, Vol. 321:1426-1432.

Allred, E.N., E.R. Bleecker, B.R. Chaitman, T.E. Dahms, S.O. Gottlieb, J.D. Hackney, D. Hayes, M. Pagano, R.H. Selvester, S.M. Walden, J. Warren (1989b). "Acute effects of carbon monoxide exposure on individuals with coronary artery disease," Research report No. 25, Health Effects Institute, Cambridge, MA.

Allred, E.N., E.R. Bleecker, B.R. Chaitman, T.E. Dahms, S.O. Gottlieb, J.D. Hackney, M. Pagano, R.H. Selvester, S.M. Walden, J. Warren (1991). "Effects of carbon monoxide on myocardial ischemia," *Environmental Health Perspectives*, Vol. 91:89-132.

California Air Resources Board (1989). "Adequacy of the Statewide Carbon Monoxide Ambient Air Quality Standard: The Impact of Recent Health Effects Studies," Staff Report.

Kleinman, M.T., D.M. Davidson, R.B. Vandagriff, V.J. Caiozzo, J.L. Whittenberger (1989). "Effects of short-term exposure to carbon monoxide in subjects with coronary artery disease," *Archives of Environmental Health*, Vol. 44(6):361-9.

Ott, W., P. Switzer, and N. Willits (1993). "Trends of In-Vehicle CO Exposures on a California Arterial Highway Over One Decade," Presented at the 86th Annual Meeting of the Air and Waste Management Association, Denver, CO., June 14-18.

Petersen, G.A. and R.H. Sabersky (1975). "Measurements of pollutants inside an automobile," *J. Air Poll. Control Assoc.*, Vol. 25:1028.

Petersen, W.B. and R. Allen (1982). "Carbon monoxide exposures to Los Angeles area commuters," *J. Air Poll. Control Assoc.*, Vol. 32:826.

South Coast Air Quality Management District (1989). "In-Vehicle Characterization Study in the South Coast Air Basin," Staff Report.

USEPA (1984). "Revised Evaluation of Health Effects Associated with Carbon Monoxide Exposure: An Addendum to the 1979 Air Quality Criteria Document for Carbon Monoxide," EPA-600/8-83-033F.

USEPA (1991). "Air Quality Criteria for Carbon Monoxide," EPA/600/8-90/045F, Environmental Criteria and Assessment Office, USEPA, Research Triangle Park, NC 27711.

Appendix B

Description of Puff Model Used to Compute Hypothetical Trajectories

I. Introduction

It is well known that the conventional continuous point or line source Gaussian models (commonly used for screening purposes in air pollution dispersion modeling) cannot be applied to light wind speed conditions. Model assumptions are not satisfied in that case. However, actual exceedances of the ambient CO standard often occur during cold winter nights, when winds speeds are below anemometer threshold, i.e., those conditions prevail. In addition to the problem of defining a mean wind speed and direction, another possible reason that conventional Gaussian models used in transportation modeling are inadequate may be the treatment of buoyancy that results from the heat released by passing vehicles. Although the CALINE3 and CALINE4 models include a scheme for enhancing the initial dispersion of the plume as a function of wind speed (via residence time over the roadway), the plume centerline remains at the surface. The purpose of the puff model described in this Appendix is to compute a "puff" trajectory, i.e., a change in the height of the mass of air associated with the exhaust, of the puff center with travel time. Mechanical mixing is reduced under extremely stable conditions reducing the initial dilution of the hot exhause. However, the hot exhaust results in t a buoyant rise during the extremely stable atmospheric conditions that are also present during CO episodes.

The purpose of modeling the exhaust from the roadway with a puff model was simply to qualitatively demonstrate the possibility that "puff rise" might be a significant effect. There was no attempt to refine the model to provide quantitative results nor to validate the model formulation. The puff model is based on the conceptual formulation given by Sheih (1978) and utilizes six marker particles to track puff location and size. In Sheih's approach, the positions of the six particles are calculated at a time step by using the parameters and variables associated with the previous time step. During the computational process, at every time step, wind advection, puff diffusion, and puff rise due to the buoyancy effects are taken into account.

To simplify the model, the following assumptions were used. First, it's assumed that there was no wind shear, neither directional nor nondirectional, i.e., as the result of a velocity gradient in the horizontal wind with height. The shape of each puff was assumed to be a symmetric ellipsoid. Second, a crosswind condition was assumed, i.e., the wind was always blowing perpendicular to the roadway. We believe that condition will lead to the least amount of buoyant rise for a given downwind distance and hence if the effect was found to be significant in that case, it would be significant for all other cases of wind direction. Finally every case tested in this model was assumed to occur under extremely stable and very low wind speed conditions; determination of puff trajectories under these conditions was the main concern of this study.

II. Wind Advection

Since no wind shear and a crosswind condition were assumed, all six particles moved in the same direction during a time step. The impact of wind advection is to control the position of puffs, not the size of each puff, i.e., the puff shape is not distorted by advection. The wind advection expression can be written as follows:

$$S_i = u_i \Delta t$$

where, [u1, u2, ..., u6] =
[u(P1), u(P2), v(P3), v(P4), w(P5), w(P6)].

III. Puff Diffusion

In order to describe the puff displacement due to turbulent diffusion, the simple analytical solution given by Sutton (1953) was used. Considering that the turbulence is constant within a time step, the expression for diffusion can be written as a finite-difference approximation of the time derivative as follows:

$$\Delta l_i = \left(\frac{K_i}{2t}\right)^{0.5} \Delta t$$

where, Δl_i is the displacement due to puff diffusion,
K_i is the eddy diffusivity in the i direction,
t is the puff travel time,
Δt is a time step.

To simplify the equation, it was assumed that the horizontal eddy diffusivity was equal to vertical diffusivity (K_h=K_z). Second, to allow the puff to mix with the ambient air and to grow reasonably, a value of 0.1 m^2/sec was assigned to the eddy diffusivity. Under very stable conditions, these values greatly overestimate the diffusivity and would lead to greater diffusion than would really occur. Again, if the puff rise had a significant effect in this case, it would likely be important in reality.

IV. Puff Rise

With assumptions similar to those of Morton et al. (1956), the governing equations of puff rise are based on the conservation laws of volume (mass), momentum, and heat for an instantaneous source. The equations are

1) $$\frac{d}{dt}\left(\frac{4}{3}\pi b^3\right) = 4\pi b^2 \beta w_p$$

2) $$\frac{d}{dt}\left(\frac{4}{3}\pi b^3 \rho w_p\right) = \frac{4}{3}\pi b^3 g(\rho_a - \rho)$$

3) $$\frac{d}{dt}\left(\frac{4}{3}\pi b^3 g \frac{\rho_a - \rho}{\rho_{ref}}\right) = \frac{4}{3}\pi b^3 s w_p$$

where, b is the equivalent radius of the puff,
β is the entrainment constant,
w_p is vertical velocity of the puff,
ρ is density of the puff,
ρ_a is density of the ambient air,
ρ_{ref} is density of reference,
g is gravitational acceleration,
s is the ambient vertical density gradient parameter.

By simplifying the equations and substituting the first equation into the third, it is possible to obtain an expression to describe ρ. By using forward differences in derivatives and the average values of the puff radius for the non-derivative variables, the expression to describe ρ, w_p, and simultaneous first order differential equations can be expressed as follows:

$$b_{av} = \frac{(b_n + b_{n+1})}{2}$$

$$\frac{db}{dt} = \frac{(b_{n+1} - b_n)}{\Delta t}$$

where, b_n is the puff radius at the previous time step,
b_{n+1} is the puff radius after one time step, which can be calculated each time step,

The time step, Δt was set to 5 seconds for purposes of the this study.

$$\frac{db}{dt}=\frac{\left(3\beta g w_p \frac{(\rho_a-\rho)}{\rho_{ref}}+b_{av} s w_p\right)}{\frac{b_{av} g}{\rho_{ref}}}$$

$$\frac{dw_p}{dt}=\frac{\left(b_{av} g(\rho_a-\rho)-3\frac{db}{dt}\rho w_p-b_{av}\frac{d\rho}{dt}w_p\right)}{b_{av}\rho}$$

A modified Euler method, also referred to as the Euler predictor-corrector method, was used to solve two simultaneous first-order differential equations for each time step. From the values of w_p, the puff rise, p_r, was computed:

$$p_r=\beta\left(\frac{|w_{p,n}|+|w_{p,n+1}|}{2}\right)\Delta t$$

where $w_{p,n}$ is the vertical velocity of the puff at the previous time step,
$w_{p,n+1}$ is the vertical velocity of the puff after one time step solving the differential equations.

Parameters and variables used to compute puff rise included:

1. Temperature difference (temdiff)

To compute the temperature difference between the ambient air and an initial puff, the following values were used:

- specific energy for gasoline = $1.25*10^5$ BTU/gal
- fuel economy = 15 mile/gal
- traffic account for # of lanes = 790 vehicles/hr
- heat loss factor = 0.6
- height of initial mixing zone (h) = 3 m
- air density (r) = 1.275 kg/m3
- wind speed (u) = 0.1 m/sec
- specific heat at constant pressure (cp) = 1004 J/deg-kg

The relationship between Q, the heat released per unit time and unit length by vehicles travelling on the roadway, and the expression of temdiff are expressed as follows:

Q (J/sec-m) = r*u*h*c_p*temdiff ⇨ $temdiff=\frac{Q}{\rho*u*h*c_p}$

2. Temperature lapse rate $\left(\frac{\partial T_a}{\partial z}\right)$

A measured lapse rate in the Lynwood area corresponding to a winter night, 0.17 deg/m, was used to represent the case of an extremely stable atmosphere. Hence, the ambient vertical density gradient parameter, s (s^{-2}), can be expressed as

$$s = -\left(\frac{g}{\rho_{ref}}\right)\frac{\partial\rho}{\partial z} \approx \frac{g}{T_a}\left(\frac{\partial T_a}{\partial z} + 0.01^{\circ}C/m\right)$$

3. Buoyancy parameter F_0 (m^4s^{-2})

$$F_0 = \frac{4\pi b^3{}_{int} g(\rho_a - \rho)}{3\rho_{ref}} \approx \frac{g}{T_{int}}(T_{int} - T_a)\frac{4}{3}\pi b^3{}_{int}$$

where b_{int} is the equivalent puff radius at initial condition,
T_{int} is the puff temperature at initial condition,
T_a is the ambient air temperature at reference height.

4. Entrainment constant (β)

In these calculations, a value of, 0.14, was used as the entrainment constant as suggested by Shieh (1978), although Morton et al. (1956) concluded that a constant of 0.285 be used for isolated instantaneous puffs. The choice of a smaller value for the entrainment constant was taken because of the line source geometry of the heat release, i.e., entrainment would not occur from the sides of the puff as in the case of an isolated instantaneous puff. Also, if the traffic density was sufficiently high, a series of instantaneous puffs, one following another occurs, again reducing the amount of entrainment relative to an isolated puff.

V. Initial puff size ($i\sigma_x$, $i\sigma_y$, and $i\sigma_z$)

An initial puff size was assumed for the puff in order to account for turbulent mixing above the roadway. The values in the x and y directions, $i\sigma_x$ and $i\sigma_y$, were taken to be equal and equal to the width of one lane. Based upon an assumed value for the initial mixing height above a road, we selected an initial puff size in the z direction, $i\sigma_z$. Hence, the values used in this program are

$i\sigma_x = i\sigma_y = 3.5$ m

$i\sigma_z = 1.5$ m

Puff trajectories shown in the body of the report correspond to these parameterizations.

Reference:

Hsieh, C.M. (1978), "A Puff Pollutant Dispersion Model with Wind Shear and Dynamic Plume Rise." Atmos. Environ., Vol. 12, pp. 1933-1938.

APPENDIX C

Sources of CO in the Vicinity of Lynwood

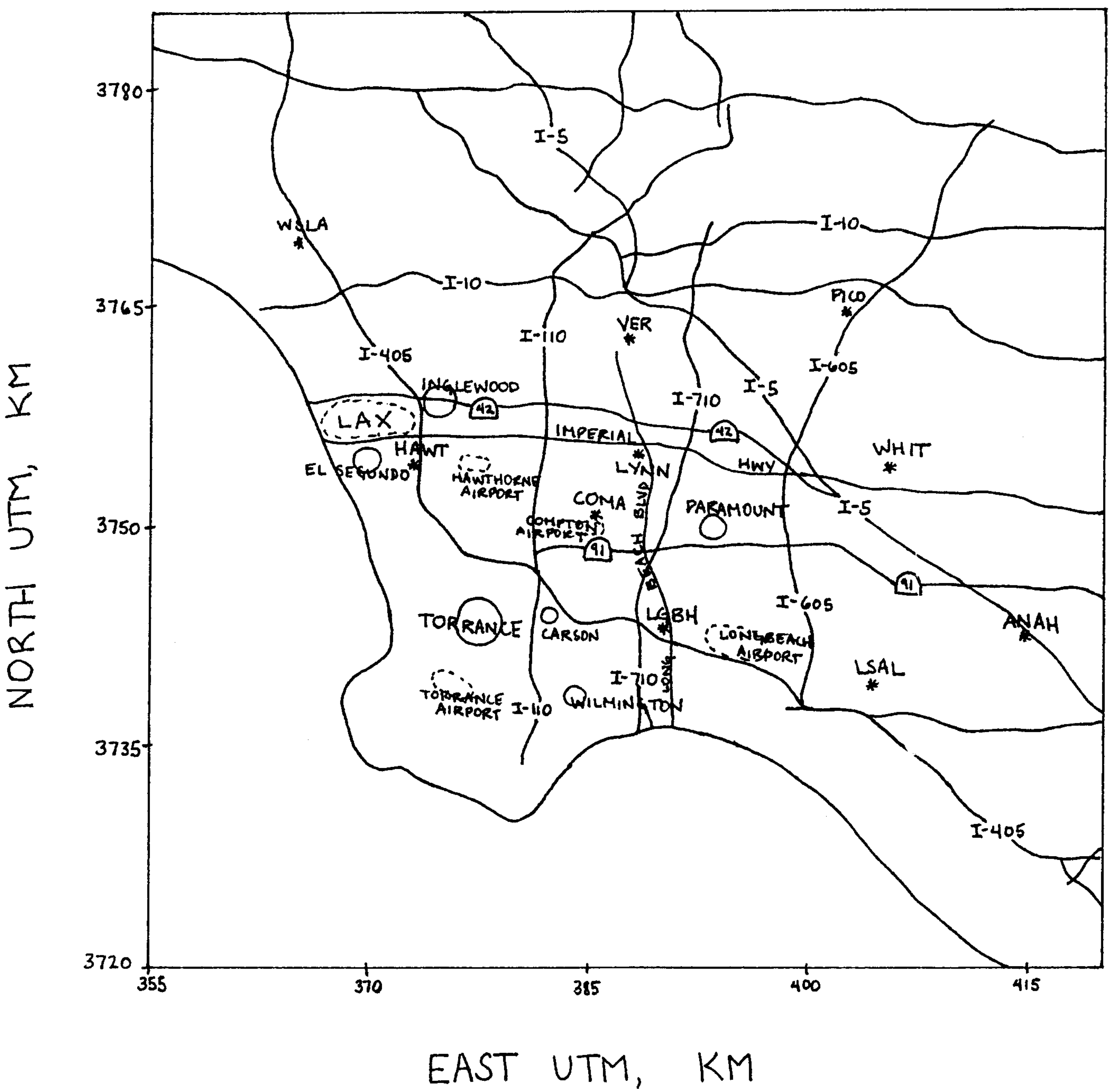
An order-of-magnitude analysis of CO emission sources in and around Lynwood was performed. The purpose of the analysis was to determine the relative importance of sources and to determine if some source(s) may have been overlooked. The analysis is qualitative in nature and did not use officially sanctioned emission factors. A summary of the findings and methodology employed to estimate emissions for a variety of source categories is contained in this appendix.

Distribution of Major Sources Around the Lynwood Station

The City of Lynwood is located about 16 km (10 miles) south of downtown Los Angeles (LA), about 16 km east of LA International Airport, and about 16 km north and east of the locations of major crude oil refineries (see Figure C-1). Lynwood is also surrounded by major freeways and highways. Freeway 110 is about 4 km west of Lynwood, and Freeway 710 is about 4 km east of Lynwood, both run north-south. Imperial highway runs right through Lynwood east-west. Long Beach Boulevard, the busiest street in Lynwood, runs through Lynwood along a north-south line. The intersection of Imperial Highway and Long Beach Boulevard is within 200 m of the station. State Highway 42 goes east-west and is about 2.5 km north of Lynwood. Rosecrans Avenue, a major street on the southern edge of the city, runs east-west. State Highway 91 goes east-west and is about 5 km south of Lynwood. The nearly completed Century Freeway is about 800 m south of the Lynwood station, parallel to Imperial highway and will run through Lynwood east-west.

One question regarding Lynwood was whether the emission sources surrounding the monitoring station was similar to that of other locations in the basin. Table C-1 presents data regarding population, income, and population density in Lynwood. To put Lynwood into perspective, similar information for LA county and another nearby community are presented as well. Per-capita income in Lynwood is less than half of that in LA county, and population density in Lynwood is almost six times as high as in LA county as a whole, but it is about the same as in the neighboring community of Hawthorne. The higher population density in Lynwood will result in heavy traffic volume on local streets and is coupled with an older vehicle population, as verified by license plate counts obtained during the 1989 intensive study. Furthermore, residential sources of CO emission might be greater as the result of a larger proportion of older homes.

Figure C-1



3780
3765
3750
3735
3720
355
370
385
400
415
NORTH UTM, KM
EAST UTM, KM
I-5
WSLA
I-10
I-10
PICO
I-110
VER
I-405
I-605
I-710
I-5
INGLEWOOD
42
LAX
IMPERIAL
42
HAWT
WHIT
EL SEGUNDO
HAWTHORNE AIRPORT
LYNN
HWY
COMA
PARAMOUNT
I-5
COMPTON AIRPORT
BEACH BLVD
91
91
I-605
TORRANCE
CARSON
LGBH
LONG BEACH AIRPORT
ANAH
LSAL
I-710
TORRANCE AIRPORT
I-110
WILMINGTON
LONG
I-405

Mobile Sources

1. Motor Vehicles on Major Freeways, Highways, and Streets in and Around Lynwood

1.1. Traffic Counts

Table C-2 presents traffic counts on major freeways, highways and streets in and around Lynwood. Note that in the table, the AM hour is defined as the period between 7:00 am and 8:00 am in Lynwood, but the morning hour is the period between 8:00 am and 9:00 am in the rest of the basin (SCAQMD, 1992). As one can see from the table, AM and PM hour traffic volumes are available for Imperial highway and Long Beach boulevard, while peak hour and daily average traffic volume are available for two highways and two freeways.

On-road traffic is a mixture of autos, light-duty trucks (LDTs), medium-duty trucks (MDTs), heavy-duty trucks (HDTs), and other motor vehicles. To divide total traffic volume into each vehicle type, the following vehicle mix was used: 1) 62.8% autos, 2) 22.7% LDTs, 3) 6.0% MDTs, and 4) 8.5% HDTs. This vehicle mix was calculated from the information contained in the DTIM model (a traffic simulation model developed by Caltrans). Other vehicle types, such as motorcycles, account for a negligible amount of total traffic volume, and therefore were ignored here. Table C-3 presents the number of vehicles by each vehicle type for peak hour traffic volume and for daily average traffic volume.

Table C-1. Demographic Data for Lynwood and LA County or Hawthorne (Based on 1990 Census Data)

	Lynwood	L.A. County (Hawthorne)
Population	61,945	8,863,164 (71,349)[1a]
Total Square Miles	4.9	4,000 (5.9)[a]
Population per Square Mile	12,641	2,216 (12,093)[a]
Per Household Annual Income ($)	25,961	39,035 (29,881)[a]
Per Capita Annual Income ($)	7,260	16,149
Unemployment (%)	12.5	7.4
Population below Poverty (%)	21.8	15.1

[a] Data for the community of Hawthorne are used here for comparison of population density.

Table C-2. Traffic Counts (Number of Vehicles per Hour, both Directions)

Location	Peak Hour	AM Hour[d]	PM Hour[e]	Daily Average
Imperial Highway near Long Beach Boulevard[a]	3,420[c]	2,977	3,420	1,881[f]
Long Beach Boulevard near Imperial Highway[a]	2,094[c]	1,235	2,094	1,152[f]
Highway 42 near Long Beach Boulevard[b]	2,500	-	-	1,375
Highway 91 near Long Beach Boulevard[b]	18,200	-	-	9,833
Freeway 110 near Imperial Highway[b]	15,100	-	-	9,020
Freeway 710 near Imperial Highway[b]	15,000	-	-	7,917

[a] From SCAQMD (1992).
[b] From Caltrans (1992).
[c] PM hour traffic volume is assumed to be peak hour traffic volume here.
[d] AM hour is defined between 7am and 8am in Lynwood.
[e] PM hour is defined between 4pm and 5pm in Lynwood.
[f] Daily average traffic volume is assumed to be 55% of peak hour traffic volume here. The percentage is calculated from the traffic volume on the two freeways and the two highways presented in this table.

Table C-3. Number of Vehicles By Each Vehicle Type for Peak Hour Traffic and for Daily Average Traffic (Vehicles per hour)

	Autos	LDTs.	MDTs	HDTs
Peak Hour Traffic:				
Imperial Highway near Long Beach Boulevard	2,148	776	205	291
Long Beach Boulevard near Imperial Highway	1,315	475	126	178
Highway 42 near Long Beach Boulevard	1,570	568	150	213
Highway 91 near Long Beach Boulevard	11,430	4,131	1,092	1,547
Freeway 110 near Imperial Highway	9,483	3,428	906	1,284
Freeway 710 near Imperial Highway	9,420	3,405	900	1,275
Daily Average Traffic:				
Imperial Highway near Long Beach Boulevard	1,181	427	113	160
Long Beach Boulevard near Imperial Highway	723	262	69	98
Highway 42 near Long Beach Boulevard	864	312	83	117
Highway 91 near Long Beach Boulevard	6,175	2,232	590	836
Freeway 110 near Imperial Highway	5,665	2,048	541	767
Freeway 710 near Imperial Highway	4,969	1,176	475	673

1.2. Total Emissions

To calculate total emissions from motor vehicles for each location, the above traffic volume data should be used in a traffic simulation model to generate vehicle miles traveled (VMT). The VMT combined with emission factors in grams per mile could be used to calculate the total amount of emissions. This would have been a complicated process. In this study, a simpler approach was used to estimate the magnitude of the total emissions from motor vehicles on the major freeways, highways and streets that might reasonably impact the area. Since the city of Lynwood occupies an area of roughly two miles by two miles, emissions along a two-mile (3.2 km) section were calculated for each of the routes.

Emission factors in grams per mile are affected by vehicle age and vehicle travel speed. Stedman et al. (1991) found: 1) vehicles traveling on Imperial Highway and Long Beach Boulevard were about 8.73 years old; 2) vehicles traveling on Freeway 710 were 6.09 years old; 3) vehicles in the rest of the South Coast air basin were about 5.5 years old. Consequently, it was assumed that average age of vehicles traveling on Imperial Highway and on Long Beach Boulevard is 8.73 years, and that the age of vehicles traveling on Freeways 710 and 110 and on Highways 42 and 91 was 6.09 years. Stedman et al. established a formula to calculate the CO concentration in exhaust gases as a function of vehicle age. Based on their formula and above vehicle age information, these ratios of CO emission factors for different routes were calculated, as follows: 1) 1.0 for basinwide; 2) 1.14 for Freeways 710 and 110 and Highways 42 and 91; 3) 1.73 for Imperial Highway and Long Beach Boulevard. It was further assumed that average vehicle speed was 50 miles per hour (mph) for freeways 710 and 110, 35 mph for Highways 42 and 91, and 25 mph for Imperial Highway and Long Beach Boulevard. A more sophisticated analysis would have examined the effect on emissions of different periods of time, e.g., peak c.f. off-peak speeds.

Based on the above assumptions regarding CO emission factor ratios with vehicle age and vehicle speed in each location, CO emission factors in grams per mile for each location were estimated and are presented in Table C-4.

With the estimated total traffic volume and emission factors for each location, total CO emissions along the 3.2 km section of each route were calculated. The calculated total CO emissions are presented in Table C-5.

Table C-4. CO Emission Factors by Vehicle Type (grams per mile)[a]

	Autos	LDTs	MDTs	HDTs
Imperial Highway near Long Beach Boulevard	12.28	16.59	11.80	20.66
Long Beach Boulevard near Imperial Highway	12.28	16.59	11.80	20.66
Highway 42 near Long Beach Boulevard	5.78	7.81	5.55	9.75
Highway 91 near Long Beach Boulevard	5.78	7.81	5.55	9.75
Freeway 110 near Imperial Highway	4.05	5.47	3.89	8.31
Freeway 710 near Imperial Highway	4.05	5.47	3.89	8.31

[a] Based on assumed average speed in each location, CO emission factors are selected from EMFAC output data (CARB, 1991). In selecting CO emission factors from EMFAC output data, catalyst-equipped autos, LDTs, and MDTs fueled with gasoline, and HDTs fueled with diesel are assumed. Emission factors were then adjusted with relative CO emission factor ratios with vehicle age.

Table C-5. Total CO Emissions in the 3.2 km Section of Each Route

Route	Total CO Emissions
Peak Hour (grams per hour):	
Imperial Highway	95,365
Long Beach Boulevard	58,385
Highway 42	32,840
Highway 91	239,659
Freeway 110	139,421
Freeway 710	141,745
Daily Average (grams per day):	
Imperial Highway	1,258,829
Long Beach Boulevard	771,076
Highway 42	433,537
Highway 91	3,098,348
Freeway 110	2,045,955
Freeway 710	1,637,133
Approximate Total	9,200,000

2. Other Mobile Sources

2.1. Motor Vehicles Traveling on Local Streets

The pattern of commuting to work in Lynwood is similar to that in LA county. That is, the majority of people in Lynwood drive alone to work (Table C-6). Because Lynwood has a relatively high population density (Table C-1), heavy traffic volume is expected on local streets there. Heavy traffic and high CO emission factors (Table C-4) together cause a large amount of CO emissions from local streets in Lynwood. However, we were unable to quantify the amount of CO emissions from local streets because of lack of traffic count data for local streets.

2.2. Motor Vehicles in the Activity Area Around the Air Quality Monitoring Station

As mentioned previously, many indirect sources generate vehicle activities around the Lynwood air quality monitoring station. For example, vehicles go to the shopping center across Long Beach Boulevard, fast food restaurants, a video store and the U.S. post office. The U.S. post office operates a fleet of delivery trucks. Vehicles activities in the activity area include idling, parking, engine starts, and acceleration and deceleration. These activities may produce more emissions than vehicles moving on streets. For example, engine start emissions, especially cold start emissions, are much higher than stabilized running emissions. Accelerations, especially hard accelerations, produce significant amounts of CO emissions. One hard acceleration can produce the amount of CO emissions equal to one half of the total CO emissions for a typical urban trip (Groblicki, 1990). Together, these vehicle activities could contribute a significant amount of the CO emissions reaching the air quality samplers in the monitoring station. However, we were also unable to quantify the amount of CO emissions from these vehicle activities in the activity area because of lack of vehicle activity data.

Table C-6. Pattern of Commuting to Work (Based on 1990 Census Data)

	Lynwood	LA County
% of People Driving Alone	63.0	70.1
% of People in Carpools	24.5	15.1
% of People Using Public Transit	6.1	6.5
% of People Using Other Means	1.5	1.3
% of People Walking	4.6	6.0
Travel Time to Work (minute)	28.0	26.5
% of Work Trips between 6am and 9am	61.7	66.0

Stationary Sources

1. Emissions from Natural Gas (NG) Consumption in Lynwood

Housing unit density in Lynwood is about five times as high as that in LA county as a whole. Table C-7, also shows that housing units in Lynwood are older than those in LA County. In addition, a higher percentage of housing units are heated with natural gas (NG) in Lynwood than in LA County. In the winter, the older and presumably less well-insulated housing units in Lynwood could consume a larger amount of NG; i.e., CO emissions density from NG consumption could be large in Lynwood.

Data on NG consumption in Lynwood were obtained from Southern California Gas Company. NG consumption in Lynwood is presented in Table C-8. NG consumption for the months of December and January is presented here because the violation of the ambient CO standard typically occurs in the late fall and winter.

Table C-9 summarizes emission factors of well-maintained NG combustion units estimated by the U.S. Environmental Protection Agency (USEPA) and the Gas Research Institute (GRI). The table demonstrates that the USEPA may significantly underestimate in use emission factors for NG combustion.

The GRI estimated emission factors for NG furnaces, cooking stoves and ovens, and NG space heaters. Residential NG consumption in Lynwood was not broken down into cooking, space heating and production of hot water. Therefore, GRI's disaggregated emission factors could not be used. We have assumed an aggregated CO emission factor of 150 lb per million cubic feet for well-maintained residential NG consumption.

It also was assumed that one half of the residential NG units in Lynwood were poorly maintained (i.e., 7,262 units; see Table C-7). The GRI (1985) estimated that poor air infiltration caused by closing air shutters, resulting in a yellow-tipping flame, increased CO emissions by more than 300% compared with CO emissions of NG combustion with a blue flame in well-maintained furnaces. Hence, we assumed that emissions from residential units in Lynwood were increased by 300%. Therefore, the average CO emission factor of residential NG combustion units in Lynwood was taken as 300 lbs per million cubic feet.

There are no regulations for controlling CO emissions from gas-fired commercial or industrial boilers. It was assumed here that in-use CO emission factors for commercial and industrial boilers increased from USEPA's estimated CO emissions by the same percentage as occurs with residential NG combustion units, i.e., actual in-use emission factors for commercial and industrial boilers were 9.4 times as much as USEPA's estimates (375/40, the CO emission factors for residential NG units assumed by us and estimated by USEPA, respectively).

Table C-7. Housing Characteristics in Lynwood and in LA County (Based on 1990 Census Data)

	Lynwood	LA County
Total Housing Units	14,525	3,163,343
% of Housing Units Built Before 1960	67.5	50.7
% of Housing Units Heated by Natural Gas	81.5	76.8
Housing Density (Units per Square Mile)	3,631	791

Table C-8. NG Consumption in Lynwood (thousand cubic feet per month, Average of December of 1989 and January of 1990)

Sector	Residential	Commercial	Industrial
NG Consumption	82,040	18,843	18,723

Table C-9. CO Emission Factors of Well-Maintained NG Combustion Units ($lb/10^6$-ft^3)

	Residential furnace	Commercial boiler	Small Industrial boiler
USEPA (1992)	40	27	61
GRI (1985)	43-366	-	-
	100-296[a]	N/A	N/A
	39[b]	N/A	N/A

[a] For cooking stoves and ovens.
[b] For space heaters.

Table C-10. Assumed In-Use CO Emission Factors for NG Combustion Units in Lynwood ($lb/10^6$ ft^3)

Sector	Residential	Commercial	Industrial
Emission Factor	375	253	572

Using the total NG consumption and the approximate CO emission factors, total CO emissions in Lynwood were estimated and are presented in Table C-11, below. The purpose for making these estimates was to gain insight into the possible magnitude of CO emissions from gas-fired equipment, normally thought to be insignificant. The numbers presented in Table C-11 have large uncertainties associated with them and are not meant to be interpreted as actual emissions.

Table C-11. CO Emissions from NG Combustion in Lynwood (Grams per Day, Average of December and January)

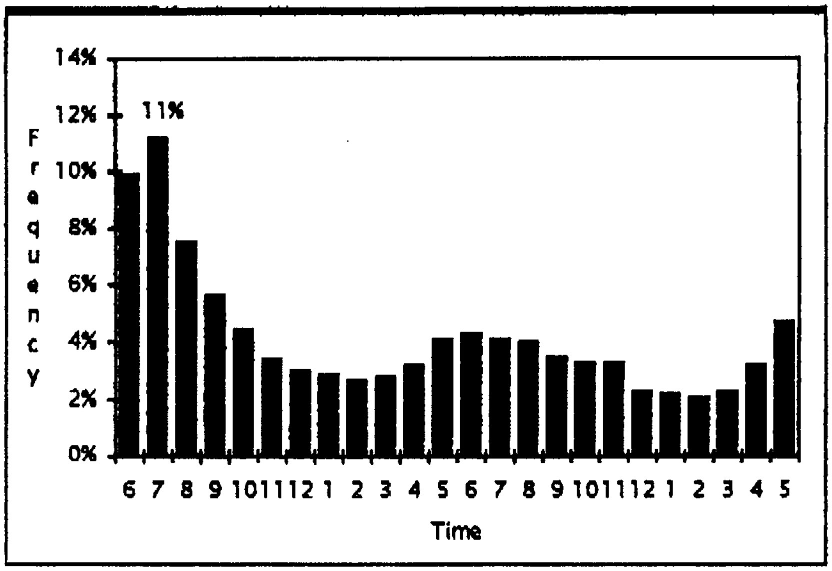
Sector	CO Emissions
Residential	360,000
Commercial	70,000
Industrial	157,000
Approximate Total	600,000

In comparison with the vehicular emissions from the 3.2 km long segments, the totals are an order-of-magnitude smaller but non-negligible, especially when consideration is given to the probable periods of time over which residential CO emissions peak, i.e., nighttime and early morning hours.

The Southern California Gas Company (So Cal Gas) conducted a survey of diurnal residential gas consumption during the winter of 1992-93. Data from that study encompass the entire service area including large portions of Southern California, extending as far south as San Diego and therefore are not specific to Lynwood. These data were summarized in an internal company report (So Cal Gas, 1993) that indicated that the incidence of peak hourly usage occurred most frequently from 0600 to 0900 hours, accounting for 29% of the peak incidence as illustrated in Figure C-2. Onset of the incidence of maximum daily gas usage began as early as 0400 hours. Interestingly, a secondary peak began about 1700 and lasted until 2300 hours. The total incidence of the peak hour usage that occurred during those hours was about 26 percent. We hypothesize that on the coldest nights, peak consumption may occur with greater frequency during the nighttime or early morning period (i.e., coldest hours). Peak incidence shows a slight decline from 2300 to 2400 hours, presumably as people go to sleep and turn down heaters. While these data do not indicate actual gas consumption, they reflect what common experience suggests: gas consumption in residences coincides with activities such as cooking, bathing and heating. On the coldest days, one suspects that total consumption also increases, and in fact, most utilities have models of consumption specific to their geographic service area that are based on factors such as season and degree-day.

Figure C-2

Residential customers use the most amount of gas generally from 7-8AM



2. CO Emissions from Refineries

Many major crude refineries are located south and west of Lynwood. These refineries produce large amounts of CO emissions according to the SCAQMD inventory. CO emissions from these major refineries are presented in Table C-12, below. The table shows that CO emissions from the refineries around Lynwood are significant. (Refer to Figure C-1 for location relative to Lynwood.)

Table C-12. CO Emissions from Refineries (Grams per Day, from SCAQMD, 1991)

Refinery	Location (City)	CO Emissions
Chevron USA	Segundo	8,590,815
Mobil Oil Corp.	Torrance	1,383,328
Texaco	Wilmington	928,024
Champlin Petrol	Wilmington	888,216
Union Oil Co.	Wilmington	709,826
Shell Oil	Carson	455,304
Philips Oil Co.	El Segundo	451,572
Texaco Inc.	Carson	323,440
ARCO Refinery	Carson	152,017
Shell Oil	Wilmington	16,936
Paramount Petroleum	Paramount	110,218
Chevron USA	Inglewood	106,984
Fletcher Oil	Carson	54,736
Stauffer Chemical	Carson	52,248
Approximate Total		14,000,000

3. Emissions from the Airports Around Lynwood

There are several airports around Lynwood. Aircraft taking off and landing produce significant amounts of CO emissions and are included in the SCAQMD inventory. Also, airport stationary facilities produce CO emissions. Table C-13, below, presents CO emissions from the airports around Lynwood. (Refer to Figure C-1 for location relative to Lynwood.)

Table C-13. CO Emissions from Airports around Lynwood (Grams per Day, from SCAQMD, 1991)

Airport	CO Emissions
LA International Airport[a]	18,442,300
Long Beach Airport[b]	5,417,620
Torrance Municipal Airport[b]	2,299,161
Hawthorne Airport[b]	1,266,641
Compton Airport[b]	1,167,867
Approximate Total	28,000,000

[a] CO emissions from LA International Airport include both aircraft emissions and emissions from airport stationary facilities.

[b] CO emissions from these airports include aircraft emissions only.

4. Other Major Stationary Sources

Some other major stationary sources are located around Lynwood. Table C-14 presents CO emissions from some of them. (Refer to Figure C-1 for location relative to Lynwood.)

Table C-14. CO Emissions from Major Stationary Sources around Lynwood (Grams per Day, from SCAQMD, 1991)

Source	Location (City)	CO Emissions
So. Cal. Edison Plant	Long Beach	1,201,704
So. Cal. Edison Plant	Long Beach	1,141,992
So. Cal. Edison Plant	Redondo Beach	903,144
LADWP Steam Plant	Long Beach	699,128
Douglas Aircraft	Long Beach	639,416
Trumbull Asphalt	Compton	599,608
Hughes Aircraft	El Segundo	460,280
So. Cal. Edison Plant	El Segundo	447,840
Proctor & Gamble	Long Beach	273,680
Douglas Aircraft	Torrance	174,160
Harbor General Hospital	Torrance	156,993
GATX Tank Storage	Carson	126,888
LADWP Harbor Station	Wilmington	74,640
Approximate Total		6,900,000

APPENDIX D

Comments Received on Draft Final Report and Responses

Written comments were received from the South Coast Air Quality Management District (SCAQMD) and the Air Resources Board that addressed the draft final report. Those comments are included in this Appendix along with responses to the SCAQMD's comments. The ARM chose to defer additional comments pending review of the SCAQMD's comments. Therefore, responses were directed only to the SCAQMD's comments.

General Comments

1) Local CO Emission Calculation - It is not clear why the authors performed the local emission calculations outlined on pages 21-27. The California Air Resources Board provides gridded on-road and stationary source CO emissions for the South Coast Air Basin (Basin). The resolution is five kilometers, which is approximately the scale needed by the authors. This inventory is the official one for the Basin and should be used for the analysis performed here.

The authors also demonstrate that the stationary source emissions could be underestimated by a significant amount and therefore could be an important contributor to the high CO concentrations observed in the late evening. It is generally assumed that the greatest uncertainty in the CO emission inventory is in the on-road mobile source category not the stationary source category.

At the onset of the study, the exact sources for the higher concentrations observed at Lynwood relative to other SCAQMD stations were not known. The 1989 intensive study clearly demonstrated that CO peaks occurred well after traffic counts had peaked. Subsequent analysis of the monitoring data by DRI suggested that some local sources might be responsible for at least a portion of the CO measured at the Lynwood station. For these reasons, it was decided to re-examine the relative significance of sources in the area. Furthermore, although the existing CO inventory provided aggregated amounts, it was decided that an analysis examining the types and magnitudes of the sources and their temporal patterns of emissions would be worthwhile as a check on conventional assumptions about

their nature. The analysis was an order-of-magnitude analysis in order to determine if some source(s) may have been overlooked.

Furthermore, although the greatest source of uncertainty is associated with CO motor vehicle emissions, that source of uncertainty is suspected of being systematic in nature, i.e., fleet emissions would increase but the temporal pattern of emissions would not change. It could be that vehicle fleet age in the Lynwood area is older, as determined by the license plate survey, but again traffic counts had peaked well after the nighttime CO peak. Therefore an attempt was made to determine if there were nighttime sources that could be as large as the on-road vehicle contribution.

After the review was conducted, we determined that it is unlikely that any local non-vehicular source could account for more than a few ppm of CO during the nighttime episode. Therefore, this section of the report has little impact on the conclusions or recommendations. Therefore, in the revised report it has been moved to Appendix C and the report simply summarizes some of the more interesting findings. For example, the nature of the natural gas emission estimates. It is quite likely that just as their are high emitters in the vehicle fleet, there are also high emitters among gas-fired residential appliances. Anecdotal evidence of CO asphyxiation from improperly maintained natural gas-fired units is a reminder.

2) Estimating Background CO Concentrations - It is suggested that the Urban Airshed Model (UAM) be used to establish background CO concentrations. This may not be the best use of the limited regional modeling resources. The South Coast AQMD has a very extensive CO monitoring network; it should be used for estimating background CO concentrations. (It might be advisable to eliminate Lynwood as a background station due to its unrepresentativeness. Also, as recommended in the report, the other monitoring stations in the Basin should be evaluated to determine if they meet EPA criteria for a neighborhood scale station. Only those that meet the criteria would be used as a background stations.)

We are not expressing the opinion that existing monitoring station data should not be used, but that the existing network, even in the SoCAB is relatively sparse, requiring project-specific monitoring in some cases. We are suggesting that the UAM be utilized to fill in the gaps. The UAM is computationally intensive when used to model photochemical air pollutants, but less so for modeling CO since the photochemistry module can be turned off. It is also input data intensive in the case of modeling CO, but we believe that much of the input data have already been collected and are available to input to the model. The

difficulty is in generating realistic mixing depth and wind field scenarios for a few 8-hr periods during the CO season. However, we believe that the resource expenditures to do that, in the larger air districts that have or are developing photochemical modeling capability, would be less than to mount project-specific field sampling studies for the duration called for in the current protocol.

3) Use of the UAM for Microscale CO Modeling - The authors are correct in concluding that the UAM cannot be used for microscale CO modeling; the resolution required (i.e., tens of meters) precludes its use. Neither the model nor the emissions inventory can handle such fine resolution.

No additional comment required.

4) CALINE4 for Microscale CO Modeling - The report concludes that the CALINE4 model is inappropriate for simulating 8-hour periods for the following reasons: 1) it was not designed to handle wind speeds less that 1 m/sec; and 20 it is not designed to handle buoyant sources. (The wind speed limitation does not have anything to do with the simulation period. Also, it should be noted that the documentation for CALINE4 indicates that wind speeds down to 0.5 m/sec can be simulated.)

Given the mechanical and thermal turbulence associated with highways it is not necessary for a highway model to simulate buoyant sources. It is unlikely that exhaust CO from on-road traffic would form an elevated plume which could then mix to ground level downwind from the roadway. The data shown in Figure 18 do not support authors' hypothesis that on-road emissions, under calm and stable conditions, would become elevated and impact areas displaced from the roadway. It is pointed out that two cases on Figure 18 show a CO peak at 44 feet above grade and it is speculated that this is the result of the transport of upwind traffic emissions. It is more likely that the elevated peak is due to another source category which has elevated release characteristics.

The text has been corrected to state that 0.5 m/s is the guidance given in the CALINE4 documentation. However, as a general guideline, continuous source Gaussian models become highly inaccurate at low wind speed, i.e., less than about 1 m/s. The point that was being made, or at least attempted to be made, in the report is that in the Lynwood area, the wind speeds dropped below anemometer threshold, which we believe to be about 0.25 m/s for periods of several hours at a time during the nighttime episodes. Therefore, use of a continuous emission Gaussian model will not yield satisfactory results. We have also clarified that the CALINE4 model does have an

algorithm that captures some of the effects of thermal emissions in the initial mixing above the roadway. However, the algorithm still treats the emission source centerline as being located at the ground. Therefore, concentrations always will decrease as one moves away from the source.

We disagree with the second set of comments that buoyancy from roadway sources are unimportant. It is precisely under the CO episode condition, low wind speed and thermally stable atmospheres, that we believe buoyancy becomes important. We have attempted to illustrate the possible importance of buoyancy in the section of the main report entitled "Analysis of Buoyancy Effects." The importance of buoyancy is a question that is not resolved, but is presented as a recommendation for further research. We believe adequate caveats are provided on the data examples used that indicate that they are not definitive.

5) Alternate Procedure for Demonstrating Conformity - An alternate procedure for evaluating impacts from projects is proposed in the report. It is suggested that if the new project's emissions do not result in an increase in the existing local emissions, then the project could proceed. This is too lenient a requirement in nonattainment areas, where improvement is required by law. It may also be too lenient a requirement in areas that attain the CO standard but do not attain the ozone standard. Maintaining constant CO emissions will probably tend to maintain constant ozone precursor emissions. Such a situation is unacceptable in an ozone nonattainment area.

Also, the authors need to more fully describe their proposal. For example, what is meant by "existing conditions"? Is that 1987 (i.e., the California Clean Air Act base year), 1990 (i.e., the base year for the federal Clean Air Act Amendments of 1990), or is it the year the project takes place? Also, what is meant by "total emissions"? Is that total on-road CO emissions or total (i.e., sum of stationary and mobile) CO emissions?

We are not in a position to determine public policy. The recommendation is simply based on use of a consistent rationale. It may be decided that projects should only be permitted to proceed if they demonstrate an overall decrease in emissions and also without causing exceedance of the 1-hr standard, however, those are policy decisions. We are also not in a position to determine the base case scenario. We are simply recommending that for whatever base case scenario has been selected or agreed upon in the attainment planning process, that in the future, emissions, at a minimum, should not increase.

Specific Comments on Executive Summary

1) P.2, 1st paragraph., 2nd sentence.

The sentence is clearly in error. According to the South Coast AQMD, basinwide CO emissions in 1990 are estimated to be 5642 tons/day with on-road sources contributing 4916 tons/day and stationary sources contributing only 204 tons/day. It is not clear where "40 tpd" comes from in the sentence. Also comparison should not be made on a basinwide basis but on a local area basis. The California Air Resources Board's gridded CO emission inventory could be used. Its resolution is five kilometers.

The reference source used was the SCAQMD Draft Federal Attainment Plan for Carbon Monoxide, June, 1992. The citation is from Table 4-1, p. D-4-2, and refers to the 38 tpd in the 1989 base case "area" emissions scenario. We thought that we should use values consistent with the attainment plan for conformity purposes. We have updated the value to that given in the more recent Final Federal Attainment Plan for Carbon Monoxide November, 1992 that indicates 204 tpd for stationary sources. The purpose for making the comparison was only to illustrate the overwhelming magnitude of the vehicular source contribution. No definitive reason was uncovered during the study for Lynwood to have a larger relative stationary source contribution than the basin as a whole.

2) Page 4, 3rd complete paragraph

See General Comment #4.

See response to general comment 4.

3) Page 6, 1st complete paragraph

The first recommendation may not be necessary. It is clear from the literature review performed here that CO episode conditions are associated with calm (or near calm), stable conditions. Therefore, neutral stability as recommended by the EPA may not be appropriate. The South Coast AQMD suggests that stability F and wind speeds from 0.5 to 1.0 m/sec represent worst-case meteorological conditions for CO episodes.

The second recommendation may be appropriate given the results of the Lynwood study. The report has clearly shown that the a.m. and p.m. episodes at Lynwood are different and require different persistence factors. It would be more convincing if it is demonstrated that the early morning and evening episodes for other monitoring stations differ in a similar manner as Lynwood.

Further, it might be appropriate to eliminate Lynwood as a background station due to its unrepresentativeness.

4) P.6, Monitoring for Background CO.
See response to General Comment 2.

See General Comment #2.

5) P.7, 1st paragraph.

See response to General Comments #3 and #4.

See General Comments #3 and #4.

Specific Comments on Main Report

1) Page 6, 1st paragrap, 2nd complete sentence.

It is stated that ".. the January 9th early morning maximum is clearly associated with the traffic counts at the intersection of Long Beach Blvd. and Imperial Hwy." How is that conclusion reached given that Figure 4a does not have traffic data for the morning CO episode on January 9?

All traffic co nt data that were available were not presented in the report in order to keep the report a manageable length. January 9, 1990 was a Tuesday and traffic patterns were expected to be similar to those for other weekdays for which data were available. We agree that a reader would not be able to confirm the conclusion other than to refer to the original reports.

2) Page 6, last paragraph

It is misleading to compare the Lynwood socioeconomic data to the Los Angeles County average. Lynwood's socioeconomic data should be compared to that of other monitoring sites with high CO concentrations, such as, Hawthorne, Los Angeles, Burbank, and Reseda. It is noted that Hawthorne is provided in Table 1; however, Lynwood should be compared to other communities exhibiting high CO concentrations.

We did not intentionally mean to mislead the readers by comparing demographic data from Lynwood with Hawthorne and LA County as a whole. However, nothing from the demographic data served as the basis for any conclusions

drawn from the report. We have relegated the emissions estimates to an Appendix for that reason. They may result in a distraction from the findings, but were reported because they were performed as part of the study.

3) Page 21, 1.2 Total Emissions

See General Comment #1. It is not clear why the authors are performing the emission calculations outlined here. The California Air Resources Board provides gridded on-road CO emissions for the South Coast Air Basin. Its resolution is five kilometers, approximately what is estimated here. This inventory is the official one for the Basin and should be used for the analysis performed here.

The emission estimate was performed as an order-of-magnitude analysis and caveats to that effect have been placed in the report. The different values of NG emission factors reported by the GRI from those given by the USEPA were an interesting finding and it was desirable to determine if, as in the case of high-emitting vehicles, the higher emissions could make a significant difference. Again, there is no definitive evidence that NG sources are impacting the LYNN monitor, but the order-of-magnitude analysis indicates that perhaps as much as about 3 ppm CO could be contributed under episode conditions if high emitting residential and commercial sources are present.

4) P.25, 1. Emissions from Natural Gas (NG Consumption in Lynwood

Emissions from Natural Gas, See comment 3 above.

5) P.27, last paragraph

The data provided in Figure 14 do not convincingly support the author's hypothesis that the magnitude and timing of the nighttime CO peak can be explained by increased stationary source activity. According to Figure 14, the residential NG consumption peak coincides with the early morning traffic peak; the late evening peak is not much of a peak.

The data shown are the residential gas consumption peak <u>incidence</u> and they do not reflect gas consumption exactly. What is shown is that the peak incidence of gas consumption occurs with some frequency (26%) during the nighttime period 1700 to 2300 hrs. The latter portion of that time period is when vehicular emissions (based on traffic count) are diminishing and stable low wind speed conditions begin. The point is that the gas consumption

remains relatively high during such periods and therefore, NG's proportional contribution to the ambient CO concentration increases.

6) P.31, 1st paragraph, 2nd sentence

See Executive Summary Comment #1.

See response to Executive Summary Comment #1.

7) P.31, last paragraph

It is very doubtful that a local source could be contributing to the elevated CO concentrations at the District's Lynwood monitor. The high correlation among the stations shown in Figure 8 do not support the argument made in the paragraph here. Since the stations are spatially separated and still highly correlated it is not possible for a single source, such as the Post Office, to impact all the sites at once.

The reader needs to examine Figure 8 carefully because it has two circular symbols. The upper circle corresponds to the HS8 sampler located on Imperial Highway, and the lower circle is the LYNN monitor some 200 m away and about 2 or 3 ppm lower depending upon the particular time. During the morning peak, the wind was from the north. The HS8 monitor presumably is in closer proximity to vehicular emission sources and a decay in concentration is expected as one moves away from the source. The vertical dispersion parameter for a Gaussian model roughly doubles under F stability conditions as one moves from 100 to 200 meters for either urban or rural coefficients. Yet the LYNN monitor is only about 10% lower than HS8. Arguably, some contribution from Long Beach Blvd. or the intersection might be influencing the LYNN readings, but the point is that there is a possibility that there are non traffic sources contributing to the measured concentrations at LYNN. We have never implied that the intervening local sources are dominant, but only that they may elevate by a few ppm the measured concentrations. What is clear is that, a Gaussian model, will not predict what was measured at the LYNN station.

8) P.32, 1st paragraph, 1st sentence.

It is stated that high CO concentrations measured in the Basin do not necessarily occur in high source regions. the authors have adequately demonstrated this here. It could be demonstrated by comparing the CO emissions rank with the CO concentration rank at each District monitor and then perform some sort of rank correlation.

The suggestion of a rank correlation approach will be taken into advisement. The only problem being that meteorological conditions are likely to be at least as important and cannot be readily taken into account by a simple ranking of emissions and observed concentration.

9) P.34, last paragraph.

Given the mechanical and thermal turbulence associated with highways, the assumption that ground-level emissions will decrease with increasing downwind distance is reasonable. It is unlikely that exhaust CO from on-road traffic would form an elevated plume which could then mix to ground level downwind from the roadway. The data shown in Figure 18 do not support such a hypothesis. The elevated CO concentrations at 40 meters are probably due to transport or another source category which has elevated release characteristics.

We have presented physical arguments based on conservation of energy. It is important to recognize under very low wind speed stable atmospheric conditions, that an air mass has no way to transfer heat away from itself quickly (radiational cooling is not that rapid for a gas). It can only mix and dilute and under such conditions, mixing is impeded under stable conditions. When mixed over the roadway by turbulence, the entire air mass cools but is warmer than its surroundings. Even small temperature rise results in appreciable buoyant rise as indicated by the puff rise analysis. Note that in the puff rise calculations, only 60% of the heat was assumed to be uniformly mixed up to 3 meters above the roadway as the initial condition used to compute the delta T of the puff. Others have also suggested the importance buoyancy under light wind conditions, see references in the text. Therefore we believe that we have adequately made the case that further research into the importance of buoyancy under these extreme conditions be undertaken. The data from the freeway are not meant to be conclusive, but they cannot be realistically attributed to other sources because there is no evidence of the elevated source under other conditions. The possibility that the bag samples were mixed does exist and we acknowledge that possibility.

10) P.38, 1st paragraph, 3rd sentence

It is proposed that the model be executed for an eight hour period instead of applying persistence factors. This requirement would be viewed by the public as burdensome. It is difficult enough to get applications to perform worst-hour modeling. This suggestion increases their work approximately ten-fold (i.e., simulating one hour versus eight hours). In addition, the South Coast AQMD would have to compile detailed meteorology and air quality for the 20 or so stations in the Basin.

The recommendation was made as an alternative to use of the total persistence factor which has conceptual flaws. The recommended alternative (by the authors) for determining conformity with the 8-hr standard requires no dispersion modeling at all, only comparison of as accurate an emissions inventory as can be determined. We believe the public would be better served by adopting such a methodology.

11) P.38, 2nd paragraph.

The first recommendation may not be necessary. It is clear from the literature review performed here that CO episode conditions are associated with calm (or near calm), stable conditions. Therefore, neutral stability as recommended by the EPA may not be appropriate. The South Coast AQMD suggests that stability F and wind speeds from 0.5 to 1.0 m/sec represent worst-case meteorological conditions for CO episodes.

The second recommendation may be appropriate given the results of the Lynwood study. The report has clearly shown that the a.m. and p.m. episodes at Lynwood are different and require different persistence factors. It would be more convincing if it is demonstrated that the early morning and evening episodes for other monitoring stations differ in a similar manner as Lynwood.

I also agree with the last recommendation that the persistence factor should be applied to the modeled difference of the existing project and the new project.

The recommendation for conducting a 1-hr "worst case" modeling effort with assumed conditions of 1 m/s and neutral stability (USEPA) is only intended for application of the total persistence factor approach. In that case, the same conditions that were used to generate the persistence factor from historical data must be applied to the modeled situation. We assume that the 1 m/s, neutral stability condition was used in the generation of the persistence factor by the USEPA. If a 0.5 m/s, F stability is to be applied, then the persistence factor must be re-computed from the data set under those conditions.

12) P.39, Monitoring for Background CO.

Establishing background CO concentrations may not be the best use of the limited regional modeling resources. The South Coast AQMD has a very extensive CO monitoring network; it should be used for estimating background CO concentrations. It might be appropriate to eliminate Lynwood as a background station due to its unrepresentativeness. And the other monitoring stations in the Basin should be evaluated to determine if they meet EPA criteria for a neighborhood scale station. Those that do would be used as a background stations.

Very roughly, the spacing between SCAQMD monitors is about 10 miles or 16 km. Whether all the stations are representative of neighborhood scale is not known to the authors of the report. Depending upon whether a station is removed, such as LYNN, because it does not fit the neighborhood station criterion, the spacing increases to approximately 15 miles or 24 km. We are suggesting that UAM be used to fill in the gaps that may exist, particularly in districts where there are very few stations. We note that UAM does not have to be run every day, just as all the monitoring data are not used to establish the "background." In fact, it is likely that an interpolation procedure based upon running the UAM for one "worst case" day can be used for other days. In districts where monitoring stations are sparse, use of the UAM may be even more valuable and ultimately contribute to the ability of that district to examine strategies for photochemical oxidant reduction as well.

13) P.40, 3rd paragraph.

The reasons given for why Gaussian models are inappropriate for simulating 8-hour periods are invalid. The wind speed limitation does not have anything to do with the simulation period. Also, it should be noted that the documentation for CALINE4 indicates that wind speeds to 0.5 m/sec can be simulated.

Given the mechanical and thermal turbulence associated with highways, it is not necessary for a highway model to simulate buoyant sources. It is unlikely that exhaust CO from on-road traffic would form an elevated plume which could then mix to ground level downwind from the roadway. The data shown in Figure 18 do not support such hypothesis.

I agree with the authors' conclusion that the UAM cannot be used for microscale CO modeling; the resolution required (i.e., tens of meters) preclude its use. Neither the model nor the emissions inventory can handle such fine resolution.

See General Comment #4 and Specific Comments #9.

14) P.41, last paragraph

The authors suggest an alternate procedure for evaluating impacts from projects. They suggest that if the new project's emission do not result in an increase in the existing local emissions, then the project could proceed. This is too lenient a requirement in nonattainment areas, where improvement is required by law. It may also be too lenient a requirement in areas that attain the CO standard but do not attain the ozone standard. Maintaining constant CO emissions will probably tend to maintain constant ozone precursor emissions. Such a situation is unacceptable in an ozone nonattainment area.

Also, the authors need to more fully describe their proposal. For example, what is meant by "existing conditions"? Is that 1987 (i.e., the California Clean Air Act base year), 1990 (i.e., the base year for the federal Clean Air Act Amendments of 1990), or is it the year the project takes place? Also, what is meant by "total emissions"? Is that total on-road CO emissions or total (i.e., mobile plus stationary) CP emissions?

See General Comment #5. We are only recommending a methodology, not the precise conditions that should be applied to determine project conformity.

15) P.42, 1st paragraph, 4th sentence

There is an incorrect use of the term "off-road sources"; off-road sources are planes, trains, ships, construction equipment, etc. I believe the appropriate term should be "stationary sources" or perhaps "other sources".

We have changed the wording in the main report so that it does not use the term "off-road" sources which has a specific connotation and have substituted instead the term, "other sources."

Department of Civil Engineering

University of California, Davis