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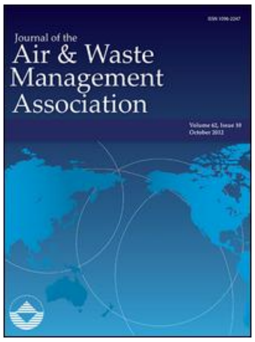

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A Reevaluation of Carbon Monoxide: Past Trends, Future Concentrations, and Implications for Conformity "Hot-Spot" Policies

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ABSTRACT

Control of CO is one of the great air-quality management success stories of the past 20 years. This paper evaluates whether past progress will continue into the future and whether changes in microscale CO concentrations are comparable to reductions observed at the regional scale. Neighborhood and microscale CO concentrations were evaluated at six northern and southern California monitoring sites. The study also included a review of CO emission, concentration, and exposure trends and on-road motor vehicle-based CO emission control programs for California and the United States. Consistent with California and national trends, CO concentrations declined at each of the six study locations from 1988 through 1998. Microscale concentrations declined at the same rate as did neighborhood-scale concentrations. Rollback analyses demonstrated that microscale concentrations will continue to decline through at least 2010–2020. Within a few years, microscale violations of the CO National Ambient Air Quality Standards (NAAQS) will be unlikely in California except under extraordinary circumstances.

IMPLICATIONS

Declining CO concentrations, as evidenced by both neighborhood scale and microscale CO concentration reductions, suggest that a reassessment of the existing microscale conformity requirements is needed. The microscale conformity regulations apply at all times and require quantitative "hot-spot" analyses to demonstrate that transportation projects eliminate or reduce the severity and number of localized CO violations. As currently written, the conformity requirements are static and do not take into account the decline in the severity and extent of CO problems. The study findings suggest that the conformity requirements to conduct transportation-project-level CO analyses could be limited appropriately to unusual circumstances identified through interagency consultation.

INTRODUCTION

Emissions and concentration data of CO were evaluated to determine whether "hot-spot," or microscale, CO analyses continue to be appropriate for transportation projects. The control of CO air pollution is one of the major success stories in the air-quality management field. Over the past 25 years, federal and California regulations have mandated the introduction of cleaner-operating motor vehicles, cleaner-burning automotive fuels, and motor vehicle inspection and maintenance (I/M) programs, all of which have significantly reduced per-vehicle CO emissions. Reductions in motor vehicle CO emissions have resulted in substantial declines in CO concentrations because motor vehicles are responsible for up to 95% of CO emissions in most urban areas.[1] Monitoring data for the past 20 years show consistent declines in CO concentrations under a wide array of conditions, for example, at regional-scale monitoring sites, at microscale sites proximate to heavy traffic, and inside operating motor vehicles. The U.S. Environmental Protection Agency (EPA) recently reported that for the 10-year period of 1989–1998, exceedances of the federal 8-hr CO National Ambient Air Quality Standards (NAAQS) have declined 98%.[1] EPA noted "…a consistent decline in CO concentrations during the past 20 years. Nationally, the 1998 composite average ambient concentration is 58% lower than 1979, and is the lowest level recorded during the past 20 years of monitoring."[1]

The decline in CO emissions is remarkable given the increase in motor vehicle use and fuel consumption. The number of registered vehicles in the United States, including passenger cars, motorcycles, trucks, and buses, has climbed from 161 million in 1980 to more than 215 million in 1998, a 33% increase. The number of vehicle miles traveled (VMT) on U.S. urban and rural roads increased from 1.5 trillion in 1980 to more than 2.6 trillion VMT in 1998, a 73% increase. From 1980 to 1997, U.S. petroleum consumption rose from 93.5 million to more than 140 million barrels of oil per day.[2] California trends have been consistent with national trends; California experienced

VMT growth of 38% during the 1970s, 62% in the 1980s, and 18% in the 1990s.[3] Yet, as vehicle use grew, CO concentrations dropped substantially. In California's South Coast Air Basin, for example, maximum observed 8-hr CO concentrations fell from 25.8 ppm in 1980 to 11.2 ppm in 1999.[4]

Federal conformity regulations require microscale CO modeling analyses for many proposed transportation projects. The conformity microscale regulations apply at all times and require quantitative hot-spot analyses to demonstrate that transportation projects eliminate or reduce the severity and number of localized CO violations.[5] As currently written, the conformity requirements are static and are applied independently of the decline in CO problems.

Table 1. California CO emission trends and forecasts, 1985–2010 (annual average t/day).

Emission Source	1985	1990	1995	2000	2010
All sources	40,427	35,062	26,870	20,591	12,944
Stationary sources	424	475	368	349	384
Area-wide sources	1753	1980	2017	2343	2651
On-road mobile sources	35,064	28,925	20,951	14,691	6856
Gasoline vehicles	34,840	28,656	20,733	14,538	6738
Diesel vehicles	224	269	219	153	118
Other mobile sources	3185	3682	3533	3207	3053

Source: California Air Resources Board. *The 2001 California Almanac of Emissions & Air Quality*; Planning and Technical Support Division: Sacramento, CA, 2001; Table 3–5, p 101.

Given the decline in CO as an air-quality problem, and the continued conformity requirement for quantitative CO hot-spot analyses, there is interest within the transportation planning community to evaluate the future of CO problems and to assess whether the conformity regulations should be revised to provide additional flexibility. This study analyzes microscale and neighborhood-scale CO measurements at six California locations and reviews CO emission and concentration trends and state and federal CO emission control programs. The study design addressed three research questions:

(1) Are past declines in CO emissions and concentrations expected to continue into the future?
(2) Are microscale CO concentrations declining at a rate different than regional-scale CO concentrations?
(3) What are likely scenarios for future microscale CO concentrations?

EMISSION, CONCENTRATION, AND EXPOSURE TRENDS

Emissions, concentrations, and exposures of CO have declined dramatically over the past 20 years and are expected to show continued declines over at least the next 10 or more years. A more detailed review of these trends is available in a companion study.[6]

Emission Trends

On-road motor vehicle CO emissions declined 20% in California from 1985 through 1997. The California Air Resources Board (CARB) expects this trend to continue at least until 2010.[7] Table 1 illustrates statewide emissions trends for 1985–2010; the table documents the substantial decline in on-road motor vehicle and total CO emissions. Similar trends are observed for individual California air basins.[4]

National CO emissions trends mirror the decline observed in California. EPA annually reports national emissions and concentration trends throughout the United States. For the 10-year period 1989–1998, EPA documents a 16% nationwide decline in CO emissions. On-road mobile source CO emissions have declined 24% during this time period, despite a 23% rise in motor VMT.[1] EPA documents that, over the past 10 years, the fraction of total CO emissions originating from on-road mobile sources has declined. For example, from 1988 to 1997, on-road mobile sources declined from 61 to 57% of the national CO emission inventory.[8] The national decline in the importance of on-road mobile sources is consistent with California data, which show that on-road sources accounted for 87% of total CO emissions in 1985 but are projected to account for only 53% of total CO emissions in 2010 (see Table 1).

Concentration Trends

The CO NAAQS include a 1-hr, 35-ppm standard and an 8-hr, 9.0-ppm standard. Both the 1- and 8-hr standards require areas not to exceed either standard more than one time per year. In practice, the 8-hr requirement is the health standard targeted by air-quality control districts and is also the controlling standard for attainment. As of 1999, the only areas in California that continue to exceed the 8-hr CO NAAQS are the South Coast Air Basin portion of Los Angeles County and the city of Calexico in the Salton Sea Air Basin.[7] Table 2 includes data documenting the substantial decline in the number of days California air basins exceeded federal 8-hr CO air-quality standards.

The federal deadline to attain the CO NAAQS in Los Angeles was December 31, 2000. The Los Angeles area 1997 Air Quality Management Plan (AQMP) projected attainment of the CO NAAQS in Los Angeles by the year 2000 and projected declining CO emissions through 2010. Recent monitoring data from the Los Angeles region indicate that the South Coast Air Basin has not yet achieved

Table 2. Number of days California areas exceeded the federal 8-hr CO NAAQS.

California Air Basin	1980	1985	1990	1995	1999
Lake Tahoe Air Basin	27	28	5	0	0
Sacramento Valley Air Basin	10	12	12	0	0
Salton Sea Air Basin	n/a	n/a	n/a	15	11
San Diego Air Basin	1	3	0	0	0
San Francisco Bay Area Air Basin	13	21	2	0	0
San Joaquin Valley Air Basin	26	7	9	0	0
South Central Coast Air Basin	6	3	0	0	0
South Coast Air Basin	92	54	42	14	7

Source: California Air Resources Board. *The 2001 California Almanac of Emissions & Air Quality*; Planning and Technical Support Division: Sacramento, CA, 2001; Table A-17, p 399.

attainment of the CO NAAQS but is continuing its steady progress toward reduced days above the federal standards. The South Coast Air Basin exceeded the federal 8-hr CO NAAQS on 13 days in 1998, on 8 days in 1999, and on 2 days in 2000.[9] Table 3 indicates days above the CO NAAQS at the Lynwood monitoring site in Los Angeles; Lynwood experiences the region's highest CO concentrations.

Calexico (Salton Sea Air Basin) appears to be the sole exception to California's consistent progress toward reducing CO exceedances and concentrations. Calexico exceeded the federal 8-hr CO NAAQS on 9 days in 1996, 12 days in 1997, 8 days in 1998, and 13 days in 1999.[9,10] Calexico is an anomalous situation given its population of ~30,000 and its proximity to the U.S.–Mexico border. CARB attributes Calexico's high CO concentrations to cross-border traffic, which presumably includes higher-emitting vehicles certified to meet Mexican emissions standards.[4]

National concentration trends are consistent with the overall decline in CO emissions nationwide. In 1991, following passage of the 1990 Clean Air Act Amendments, EPA designated 42 metropolitan areas as CO NAAQS nonattainment. In 1998 and 1999, only six metropolitan areas nationwide failed to meet the CO NAAQS. Two of these areas, Los Angeles and Calexico, are in California. The remaining areas include Fairbanks, AK; Las Vegas, NV; Des Moines, IA; and Weirton, WV. Outside California, only Fairbanks exceeded the CO NAAQS in 1999 (Fairbanks exceeded the NAAQS on 2 days).[9]

Table 3. Days above the national CO 8-hr standard at Lynwood in the South Coast Air Basin.

Calendar Year	Days above the Federal CO NAAQS
1996	20
1997	12
1998	11
1999	7
2000	2

Source: California Air Resources Board. *Highest Four Daily Maximum 8-hr CO Averages and Number of Days above the 8-hr Standard at Lynwood*. Available at http://www.arb.ca.gov/adam/cgi-bin/db2www.exe/adamquery.mac/start (accessed March 22, 2002).

Exposure Trends

Consistent with the decline in motor vehicle CO emissions and ambient CO concentrations, motor vehicle occupants have experienced substantial reductions in exposures to CO. Based on 16 CO exposure studies conducted in the United States, EPA's CO Criteria Document estimates a reduction of ~90% in observed in-vehicle CO concentrations between 1965 and 1992.[8] Overall, EPA's research concludes that "[i]mplementation of motor vehicle emission standards, catalytic converters, motor vehicle I/M programs, and cleaner burning fuels during the past three decades have reduced the CO exposures of urban commuters."[8] Flachsbart reviewed CO exposure trends throughout the United States and other nations to assist in the development of the CO Criteria Document.[11] Flachsbart's findings are consistent with the EPA assessment.

MOTOR VEHICLE CO CONTROL PROGRAMS

Three major control programs have contributed to reduced per-vehicle CO emissions: exhaust standards, cleaner burning fuels, and motor vehicle I/M programs.

Exhaust Standards

California tailpipe CO emissions standards for new light-duty vehicles have dropped from 51 g/mi for the 1966 model year to 1.7 g/mi for the 1994 model year "ultralow-emitting vehicles" (ULEVs). Nationally, exhaust emissions standards fell by 93% from 1968 (51 g/mi) to 1981 (3.4 g/mi). As vehicle fleet turnover replaces higher-emitting vehicles with newer models certified to more stringent exhaust standards, overall on-road motor vehicle fleet emissions are projected to decline, despite forecasted growth in on-road VMT. The California Department of Transportation forecasts 22% VMT growth during the 2000s and 20% VMT growth during the 2010s.[3] The CARB estimates that California-wide on-road CO emissions will decline from 12,637 t/day in 2000 to 5755 t/day in 2010.[12]

Cleaner Burning Fuels

Beginning in the winter of 1992–1993, California implemented an oxygenated gasoline program to reduce motor vehicle CO emissions. The program resulted in an approximate 5–10% reduction in ambient CO concentrations.[13] Methyl tertiary butyl ether (MTBE) accounted for ~95% of the oxygenate used.[13] Because of concerns about MTBE contamination in various water supplies, CARB rescinded the oxygenated fuels requirement for much of California beginning with the 1998–1999 winter season. However, state and federal requirements call for continued oxygenated fuels use in several areas. For example, several southern California areas, including Los Angeles, are still required to include oxygenates during the winter season. Federal rules include an oxygenate requirement for O_3 nonattainment areas, requiring both the San Diego and Sacramento areas to continue a year-round oxygenate program. CARB estimated that rescinding the wintertime oxygenate program would result in an increase of ~9% in motor vehicle CO emissions for the affected areas.[14] CARB estimated that the 9% emissions increase was a "worst case" scenario and forecasted that following the elimination of the fuels requirement, CO emissions would "…remain well below levels required to maintain the carbon monoxide standard."[14]

I/M Programs

California implemented a motor vehicle I/M program, called Smog Check, beginning in 1984 and an enhanced program, called Smog Check II, in 1998. The original Smog Check program reduced motor vehicle CO emissions by ~15%.[15] During the summer of 2000, both the CARB and the California I/M Review Committee (IMRC) evaluated the newly implemented Smog Check II program and estimated that, in 1999, it reduced CO emissions by 13–28%.[16,17]

Future California CO Controls

Further motor vehicle CO emissions reductions, beyond those already committed to in California's AQMPs, will occur over time. Emissions projections included in the California CO State Implementation Plan (SIP) do not take credit for a number of control programs that are adopted or planned.[14] Examples include

(1) Oxygenated fuels use—The California CO SIP does not take credit for oxygenated fuels use, despite ongoing state and federal oxygenated fuels program requirements in several California areas, such as Los Angeles and Sacramento.

(2) I/M program improvements—The CO SIP does not take credit for 1998 and later improvements to basic I/M or for enhanced I/M. In addition, in August 2000, the CARB committed to further improve the Smog Check II Program to reduce emissions of hydrocarbons (HCs) and NO_x. These program improvements likely will include subsidiary CO benefits as more high-polluting vehicles are identified and repaired.

(3) On-board diagnostics (OBD)—Beginning with the 1996 model year, the CARB required full phase-in of the OBD-II program. OBD-II triggers illumination of a dashboard malfunction indicator light (MIL) when an on-board computer senses that an emission control system component has malfunctioned. Although the CARB established OBD-II program requirements to achieve HC and NO_x reductions, CO benefits also will occur. A recent American Petroleum Institute (API) study of high-emitting vehicles showed that approximately half of the excess emissions from fuel-injected vehicles are caused by electrical component failures related to the emission control system.[18] The API found that for fuel-injected vehicles, virtually all HC repairs, and approximately half of the NO_x repairs, also resulted in CO emissions reductions.[18]

(4) LEV-II—The CARB amended its low-emitting vehicle (LEV) program in late 1998 and established LEV-II regulations that take effect with the 2004 model year. LEV-II includes at least three actions that will reduce CO emissions. First, LEV-II extends passenger car exhaust standards to most sport utility vehicles (SUVs), thereby reducing CO tailpipe standards for SUVs. For most SUVs (~90%), this means that, rather than meeting 50,000-mi exhaust standards of 4.4 or 5.0 g/mi of CO, the standard will be 3.4 g/mi. Second, LEV-II increases emission control durability standards from 100,000 to 120,000 mi for passenger cars and light trucks. Third, LEV-II tightens fleet-average emission standards during 2004–2010, including creating a "super-ultralow-emission vehicle" category with CO emissions less than half those of ultralow-emission vehicles.[19]

(5) Federal Test Procedure (FTP) improvements—EPA and the state of California have established additions to the FTP to examine CO and other emissions under more realistic driving conditions. EPA estimates that the supplemental FTP, along with additional emission standards changes, will result in an 11% reduction in CO emissions in the United States.[20]

(6) Low-sulfur fuel—Sulfur can adsorb to catalytic converters, diminishing their ability to remove CO and other pollutants. A CARB analysis of a sample vehicle fleet found that a 10-ppm reduction in sulfur content could lead to an almost 1% reduction in CO emissions.[21] California has mandated the use of reduced-sulfur gasoline as part of the Reformulated Gasoline Phase 3 standards. Beginning December 31, 2002, average gasoline sulfur content will be lowered to 15 ppm from 30 ppm, with a cap of 60 ppm. The cap then will be lowered to 30 ppm, starting in 2005.[22]

Future Federal CO Controls

EPA, through its Tier 2 motor vehicle standards, has mandated that light-duty trucks must meet passenger vehicle emission standards, with phase-in beginning in 2004. A portion of the overall VMT in California is driven by vehicles purchased outside California, so the new federal emission standards will help reduce CO emissions in California.[23] EPA also has mandated lowering the sulfur content of gasoline sold outside California. Currently, gasoline sold outside California can have a sulfur content of ~300 ppm. The new standards limit gasoline sulfur content to an average of ~120 ppm and a cap of 300 ppm in 2004. The Tier 2 standards reduce the average sulfur content produced by most refiners to 30 ppm, with a cap of 80 ppm, by 2006.[23] California implemented similar standards in 1996.

CALIFORNIA CASE STUDIES: LOS ANGELES, RIVERSIDE, AND SACRAMENTO

Overview

The study team used data from northern and southern California to explore the relationship between regional and microscale CO problems. The analyses involved three steps.

1. Determine how well microscale concentrations track the overall decline in regional CO concentrations by analyzing data from microscale monitors located near high-density traffic activity centers and data from nearby neighborhood monitors that provide regional CO concentration values.
2. Examine how robust the regional versus microscale relationship is across several CO concentration metrics, including highest-observed CO concentrations, second-highest values, and other observations. This paper includes results for second-highest values; a companion report includes illustrations of other metrics. [6]
3. Establish microscale-to-regional relationships based on monitored concentration data, regression-based emission and concentration trend analyses, and a “rollback” analysis that projected future CO concentrations.

Los Angeles and Riverside (South Coast Air Basin) Analysis Sites

Four CO monitoring sites were chosen within the South Coast Air Basin. Two sites were selected from the Los Angeles area to represent worst-case urban area CO concentrations. Two sites were selected to represent Riverside, a suburban area outside the urban core but generally on the downwind side of the South Coast Air Basin with a more inland meteorological regime. Each pair of monitors consisted of a microscale monitor and the nearest neighborhood-scale monitor.

The Los Angeles area sites were Lynwood and Hawthorne. The Lynwood monitor is designated as a microscale monitor and has experienced some of the highest CO concentrations monitored in California.[24] The Lynwood site is located near the intersection of two busy arterials, Imperial Boulevard and Long Beach Boulevard, in a mixed-use area of south-central Los Angeles. The Hawthorne site is the neighborhood-scale monitor nearest to the Lynwood station. The Hawthorne monitoring station is ~10 mi to the west (and generally upwind) of the Lynwood monitor. It is located near the 405 freeway but is otherwise in a “neighborhood” setting with various buildings and trees to the north and south of the monitor.[25]

The Riverside monitors are located in Magnolia and Rubidoux. The Magnolia site is designated as a microscale monitor. It is located near the intersection of Magnolia and Arlington Boulevards, both heavily trafficked routes, in a mixed-use residential and storefront business area. The Rubidoux site is a neighborhood-scale monitor. It is ~4.5 mi north of the Magnolia station, in a relatively rural area. In the immediate vicinity are a vacant lot, a senior citizens apartment complex, a residential neighborhood that includes homes and livestock (horses and other animals) boarding areas, and a shopping center beyond the vacant lot.[26]

Sacramento Analysis Sites

Two sites, El Camino and Del Paso, were selected for the Sacramento Valley Air Basin. The El Camino site is near an intersection and is a designated microscale monitor. The Del Paso site is designated as a neighborhood-scale monitor and is ~1 mi east-northeast of the El Camino monitor. The Del Paso site is in a suburban, residential area and is in a small neighborhood park adjacent to an elementary school. The area has relatively low traffic density and is north and east of the downtown Sacramento area. The El Camino site is near the intersection of El Camino and Watt Avenues. The monitor is ~10 ft from El Camino Avenue on a median strip with the road on one side and the north end of the Country Club Plaza Shopping Center parking lot on the other side. The area experiences relatively high traffic density, particularly because Watt Avenue is one of the main Sacramento arterials.[27]

Data Sources

CO monitoring data from 1988 through 1998 were obtained for the four Southern California monitors from the Meteorology Section of the South Coast Air Quality Management District (SCAQMD). The total basin and on-road CO emissions estimates for the South Coast Air Basin used in the data analysis were taken from the South Coast Air Basin’s 1997 AQMP.[28] Sacramento monitoring data were obtained from the CARB.[29] The Sacramento emissions data were taken from the *Proposed Carbon Monoxide Redesignation Request and Maintenance Plan for Ten Federal Planning Areas*.[30]

Analysis Methods

The first analysis objective was to establish observable trends for each monitoring site and then compare the trend lines for the neighborhood and microscale site pairs. The analysis proceeded by plotting, for each site, CO concentration and emissions data from approximately 1990 to 1998. For each site and each year of monitoring data, the second-highest 8-hr concentrations were calculated and plotted. (Illustrations of 1-hr concentration analyses, as well as a variety of 1- and 8-hr thresholds such as maximum, 20th highest, and 100th highest concentrations, are available in Eisinger et al.[6]) To facilitate site-to-site comparisons, the emissions and concentration data both were normalized by dividing by their respective 1990 values and then plotted. The 1990 base year was chosen because it was the first year for which there were both concentration and emissions data available for this study. In addition, a fitted trend line through the concentration and emissions data was added to each plot.

A rollback analysis also was performed on the second highest 8-hr concentration curves. The goal of the rollback analysis was to project forward in time the expected CO concentrations. Analyses were projected to 2020 for southern California (the worst-polluted region) and to 2010 for Sacramento. The rollback analysis steps are as follows:

1. The projected CO total basin emissions (1999 and beyond) were divided by a base-year value (the 1997 total basin emission estimate for the southern California sites; the 1995 total basin emission estimate for the Sacramento sites). Thus, for each future year, a ratio value (F_r) of future total basin emissions to base-year emissions was created.
2. The base-year (1997 for southern California sites, 1995 for Sacramento sites) concentration value then was multiplied by F_r for each future year.
3. To smooth out meteorological variability, F_r was applied to the base-year concentration values located on the fitted observed concentration trend line, not on the actual concentration data points.

ANALYSIS RESULTS

Overview and Interpretation of Figures

Results are apparent by comparing microscale and regional findings as represented in six figures that include 8-hr concentration data, emissions data, trend lines, and rollback analysis results for southern California and Sacramento. Figures 1–6 incorporate the information essential for understanding the results of the case studies and are worth explaining in some detail. The plots portray seven important pieces of information.

1. Historical emissions data. These data points extend from 1990 to 1995 in Sacramento and from 1990 to 1997 in southern California;
2. Emissions projections. These data points represent air district forecasted CO emissions for future years (2000–2010 for Sacramento, 1998–2020 for southern California);
3. Concentration data. These are observed CO concentration measurements, as reported by the CARB, for 1988 through 1998;
4. Trend lines fitted by regression through the historical emissions data. Trend lines were created based on historical emissions data (data through 1995 in Sacramento and through 1997 in southern California). The trend line then was plotted as if it carried forward in time to the last analysis year (2010 in Sacramento, 2020 in southern California). By comparing the trend line to the emissions projections, the rate at which CO emissions declined in the past can be compared with the rate at which CO is expected to decline in the future. The trend lines include the algebraic descriptions of the fitted lines. The algebraic descriptions provide a numerical comparison of the rate at which emissions have declined with the rate at which concentrations have declined. In the algebraic description, the exponential term is the key determinant to the rate at which the lines trend downward. The more negative the exponential value (i.e., the larger the absolute value of the exponent), the greater rate at which the trend line declines;
5. Trend lines fitted by regression through the concentration data. These trend lines end at the last observed CO concentration value. They serve two purposes. First, the fitted lines help smooth out year-to-year variability that may be caused by changing meteorological conditions. Second, the lines help the reader visually separate past concentration observations from the projected future concentrations predicted by the rollback analysis;
6. Rollback analysis results. Future CO concentrations as predicted by the rollback analysis are plotted, extending from the trend lines fitted through the concentration data; and
7. CO NAAQS. The y axis of the plots is scaled to allow comparisons to 1990. Both the concentration and emission data have been normalized to a 1990 value of 1.0. To facilitate an understanding of how the normalized concentrations compare to real-world values, the plots include a horizontal line to indicate where a concentration equal to the NAAQS would fall on the plot. The NAAQS concentration line is also a normalized

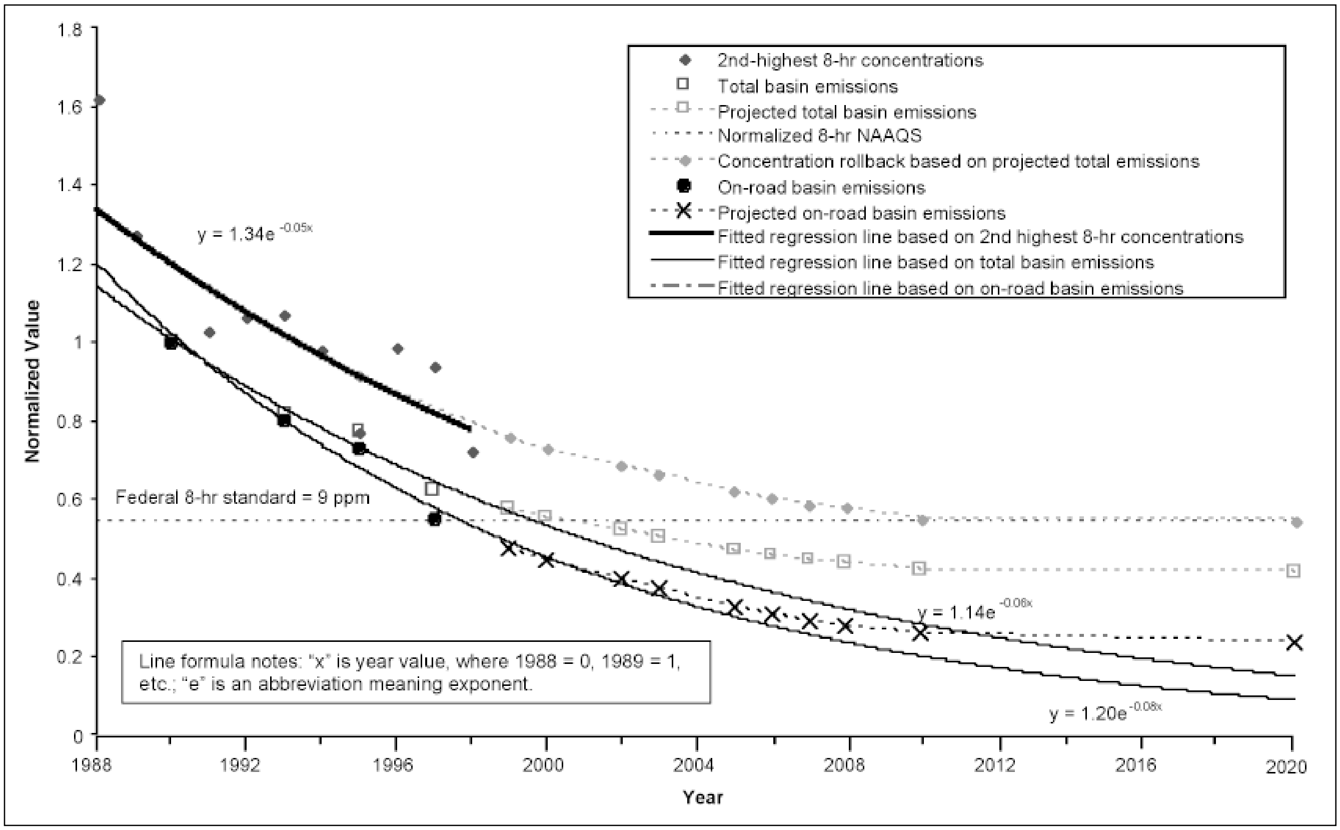

Figure 1. Lynwood (microscale): normalized emissions and second-highest 8-hr concentrations, with concentration rollback based on total basin emissions.

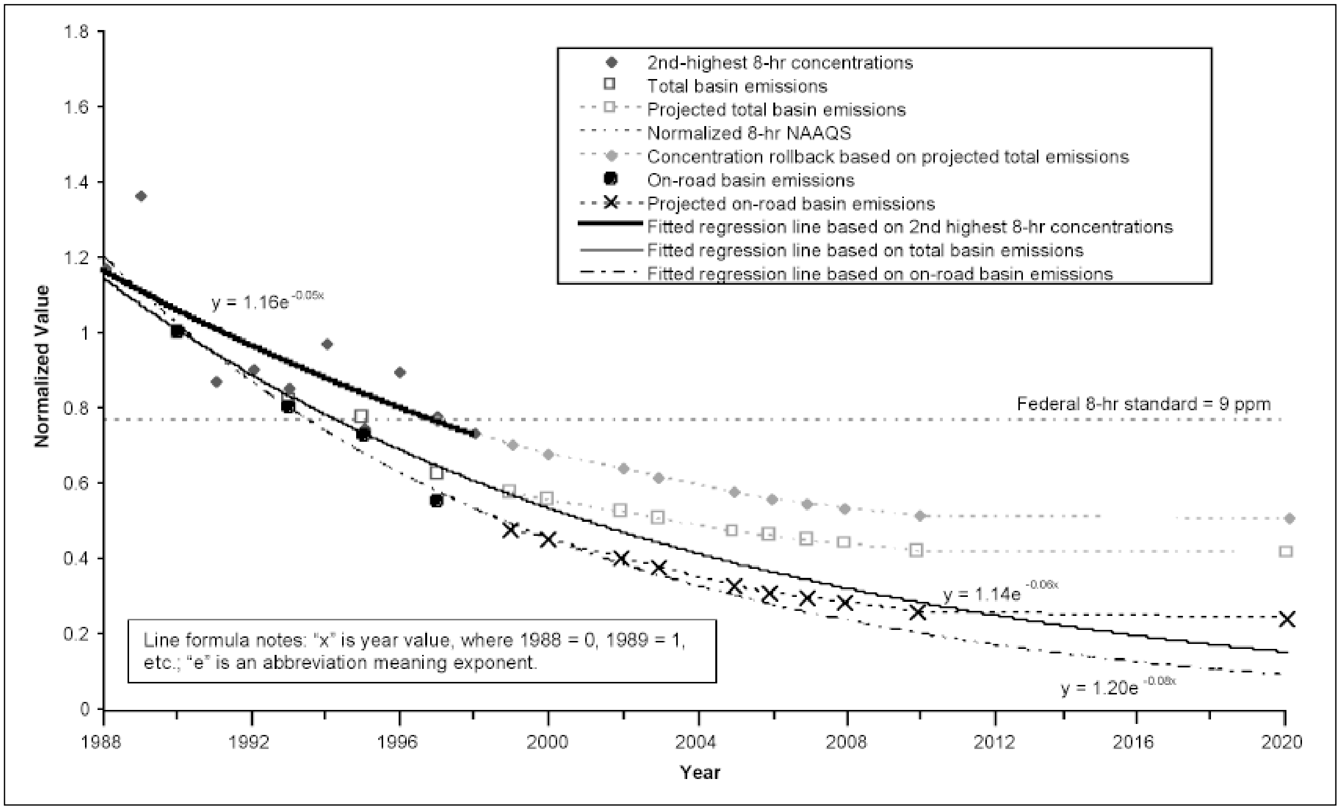

Figure 2. Hawthorne (neighborhood): normalized emissions and second-highest 8-hr concentrations, with concentration rollback based on total basin emissions.

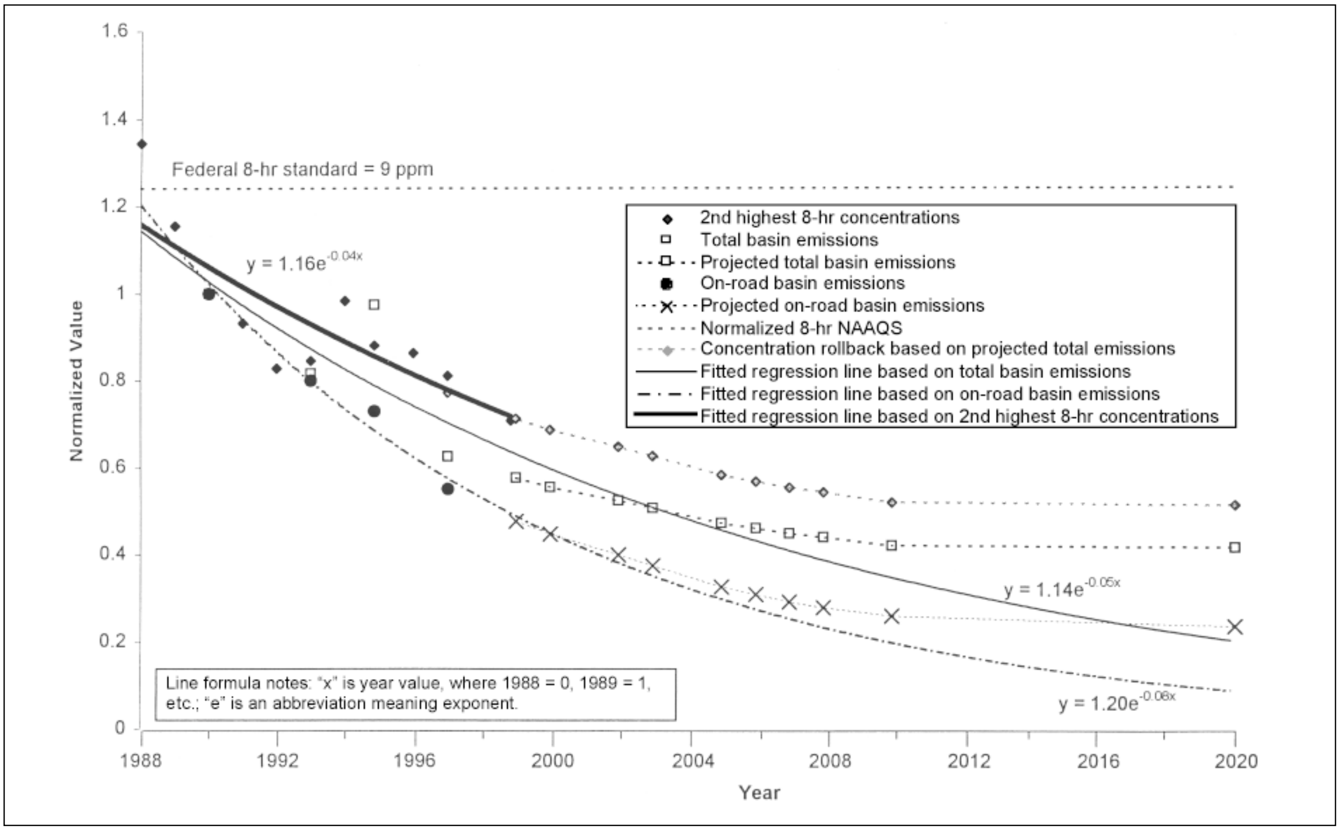

Figure 3. Magnolia (microscale): normalized emissions and second-highest 8-hr concentrations, with concentration rollback based on total basin emissions.

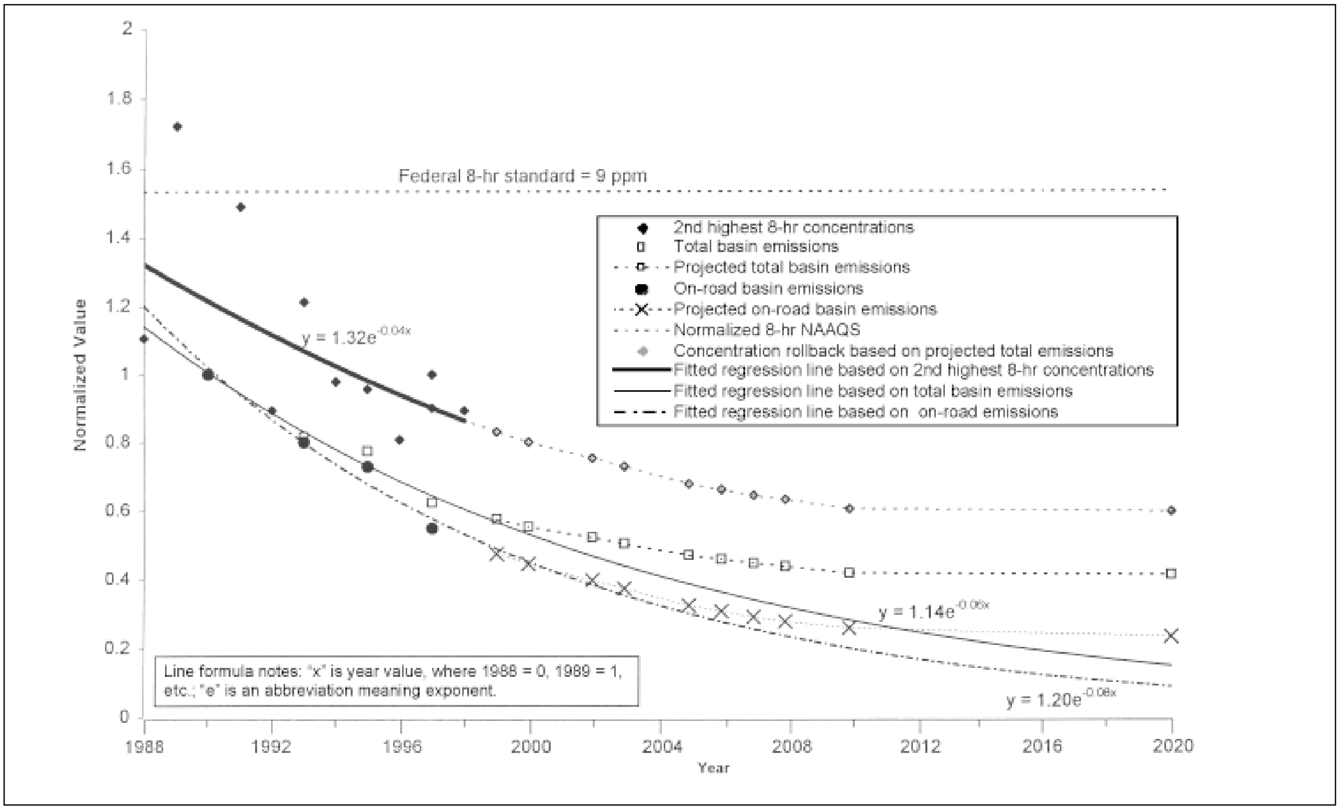

Figure 4. Rubidoux (neighborhood): normalized emissions and second-highest 8-hr concentrations, with concentration rollback based on total basin emissions.

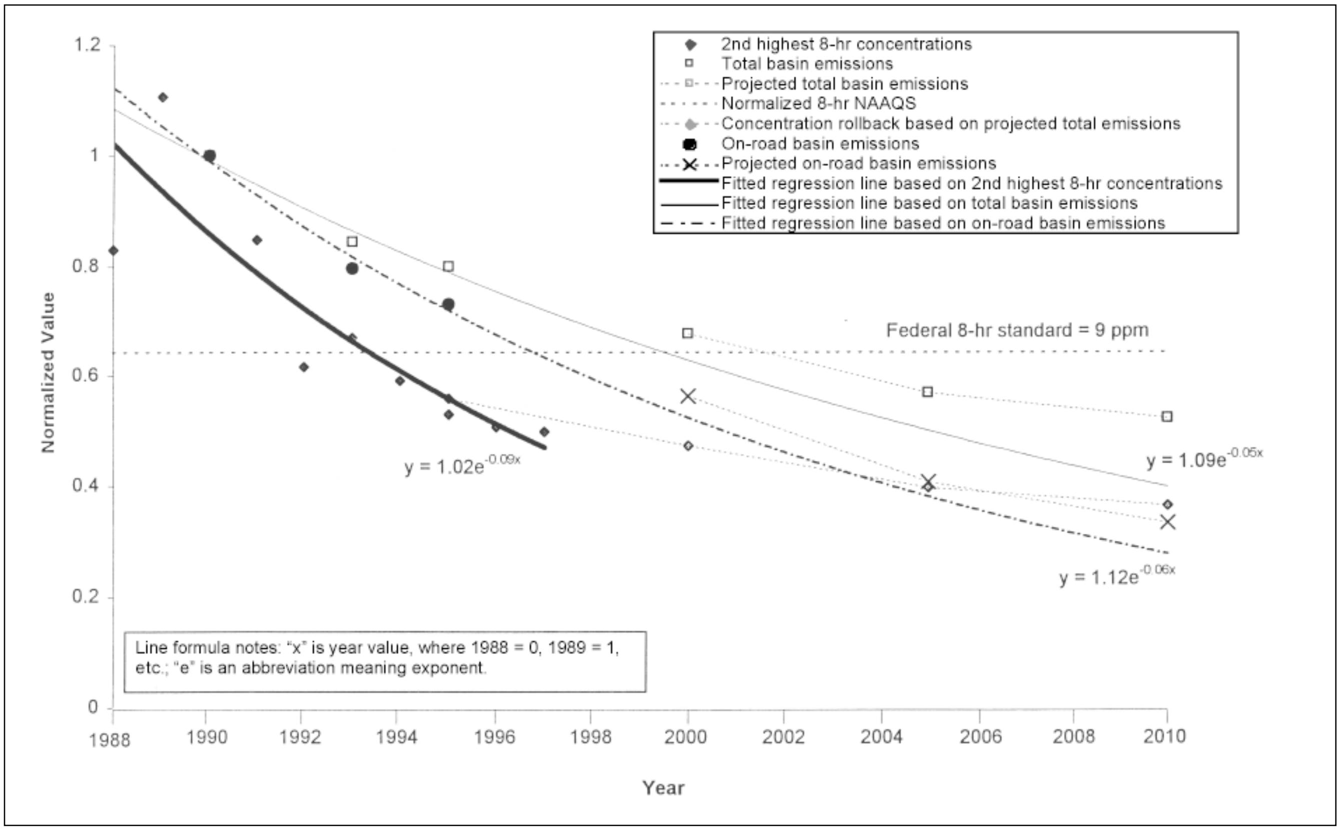

Figure 5. El Camino (microscale): normalized emissions and second-highest 8-hr concentrations, with concentration rollback based on total basin emissions.

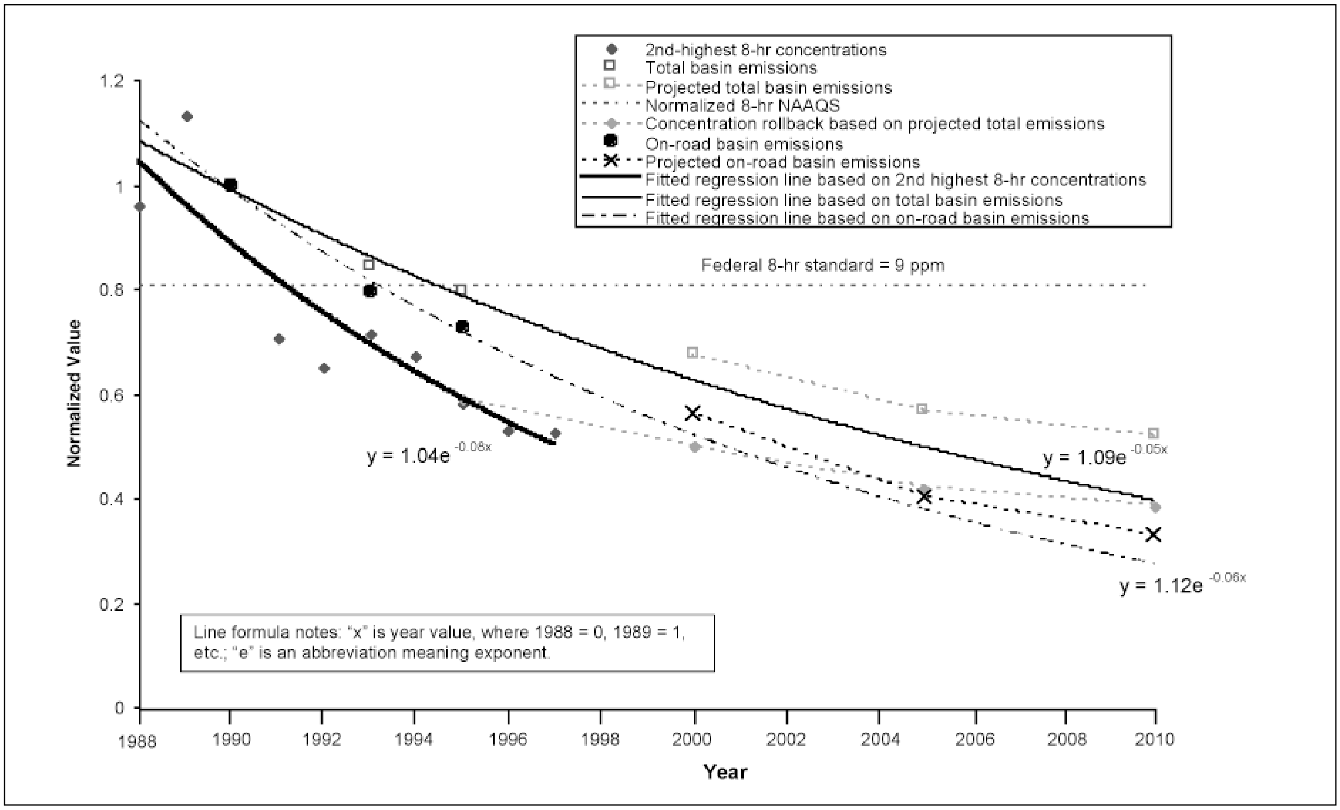

Figure 6. Del Paso (neighborhood): normalized emissions and second-highest 8-hr concentrations, with concentration rollback based on total basin emissions.

Table 4. Example data normalization technique used to create Figures 1–6.

	Second Highest 8-hr CO Concentrations (ppm)			
	Lynwood		Hawthorne	
Year	Raw Data	Normalized	Raw Data	Normalized
1988	26.8	1.6	13.8	1.2
1989	21.0	1.3	16.0	1.4
1990	16.5	1	11.8	1
1991	17.0	1.0	10.3	0.9

Note: Normalized values obtained by dividing raw value for year *x* by raw value for year 1990. The same technique was used to normalize all emissions and concentration data included in Figures 1–6.

representation; the 8-hr federal CO NAAQS of 9.0 ppm was divided by the 1990-observed second-highest 8-hr CO concentration, and a line was drawn representing the normalized value. For example, in Figure 1, the NAAQS is plotted at a value of ~0.55, which is equal to the 9.0-ppm NAAQS divided by Lynwood's 1990 second-highest 8-hr concentration of 16.5 ppm. Table 4 includes an illustration of how the concentration data were normalized to 1990 values.

The plots facilitate comparisons between emissions and concentrations, between past and forecasted trends, between total basin emissions and on-road mobile emissions, and between microscale and neighborhood conditions. To be conservative, the emission projections shown for southern California are from the baseline projections included in the SCAQMD AQMP rather than from the controlled scenario projections. In addition, as detailed in the control program discussion, forecasted control scenario emissions do not fully reflect emission reduction benefits that will accrue from the CARB and EPA control programs.

Microscale Versus Neighborhood Concentrations

Table 5 presents the second-highest 8-hr average CO concentrations observed at each microscale/neighborhood site pair (Lynwood/Hawthorne, El Camino/Del Paso, and Magnolia/Rubidoux). Several observations can be made from the data in Table 5. First, all sites experienced declining CO concentrations over time. Second, microscale concentrations generally are higher than neighborhood concentrations, although the absolute difference between the two site types diminishes over time as concentrations at both types of sites approach background CO conditions. Third, the lower the initial (1988) CO concentrations, the less pronounced the absolute difference between microscale and neighborhood scale in later years.

Table 6 presents the average annual absolute and percentage change in CO concentrations by site type. For the site pair with the highest initial CO concentrations (Lynwood/Hawthorne), microscale (Lynwood) concentrations annually declined ~3 times more than neighborhood (Hawthorne) concentrations (1.5 compared with 0.5 ppm) and declined at twice the annual percentage rate as the neighborhood site (6.6 compared with 3.3%). The difference between declining microscale and neighborhood concentrations is not as apparent with the other two site pairs, where initial (1988) microscale CO concentrations were less than half the concentrations observed at Lynwood. Table 6 also presents the rate of change for each site pair based on regression data created to reduce variability caused by year-to-year meteorological fluctuations (see Figures 1–6).

Two statistical analyses showed no significant difference between the rate of decline in CO concentrations at microscale and neighborhood-scale sites. Table 7 summarizes one analysis, which used a *t* test to compare the mean annual percent change between site pairs. The data in Table 7 indicate there is no statistically significant difference between the microscale and neighborhood-scale rates of change. In addition, when CO was regressed against year, no significant difference was found in the rate of CO concentration reductions between the site types.

Discussion of Case Studies

Figures 1 and 2 show the analysis results for the Los Angeles area sites: Lynwood (microscale) and Hawthorne (neighborhood). Figures 3 and 4 show the Riverside sites: Magnolia (microscale) and Rubidoux (neighborhood). Figures 5 and 6 represent the Sacramento case study.

Table 5. Second highest 8-hr average CO concentrations (ppm).

	Site Pairs					
Year	Microscale Lynwood	Neighborhood Hawthorne	Microscale El Camino	Neighborhood Del Paso	Microscale Magnolia	Neighborhood Rubidoux
1988	26.8	13.8	11.6	10.7	9.8	6.5
1989	21.0	16.0	15.5	12.6	8.4	10.1
1990	16.5	11.8	14.0	11.1	7.3	5.9
1991	17.0	10.3	11.9	7.9	6.8	8.8
1992	17.5	10.6	8.6	7.3	6.0	5.3
1993	17.7	10.0	9.4	8.0	6.1	7.1
1994	16.1	11.4	8.3	7.5	7.1	5.8
1995	12.8	8.8	7.4	6.5	6.4	5.6
1996	16.3	10.5	7.1	5.9	6.3	4.8
1997	15.5	9.1	7.0	5.9	5.9	5.9
1998	11.9	8.6	n/a	n/a	5.1	5.3

Table 6. Average annual CO concentration decline, as measured across all analysis years.

	Site Pairs					
	1988–1998		1988–1997		1988–1998	
	Microscale Lynwood	Neighborhood Hawthorne	Microscale El Camino	Neighborhood Del Paso	Microscale Magnolia	Neighborhood Rubidoux
Absolute Change Based on Raw Data (ppm)	1.5	0.5	0.5	0.5	0.5	0.1
Mean Annual Percent Change Based on Raw Data	6.6	3.3	4.3	5.6	5.8	–3.4
Mean Annual Percent Change Based on Data Derived from Regression Lines Depicted in Figures 1–6	5.3	4.6	8.3	7.8	4.8	4.2

From the plots in Figures 1–6, it can be seen that measured concentrations showed a decreasing trend at all sites between 1988 and 1998. As demonstrated by the statistical analyses, measured concentrations at microscale monitors are decreasing at the same rate as concentrations at the neighborhood-scale monitors, while the absolute change is larger for the microscale stations. Although not illustrated here, the 1-hr concentrations at the various sites tended to decrease at a faster rate than the corresponding 8-hr concentrations (i.e., the maximum 1-hr concentrations curve for a particular monitor has a steeper slope than the maximum 8-hr concentration curve); and, in general, the concentrations at the peak events (maximum and second highest values) decreased more quickly than did the concentrations at the less extreme events.[6]

Emissions. As Figures 1–6 show, the trend lines through both the estimated total and on-road emissions data (1990–1997 in Southern California; 1990–1995 in Sacramento) decrease more quickly than the forecasts provided by the SCAQMD and the CARB (for 1990 through 2020 in southern California; 1990 through 2010 in Sacramento). For example, the SCAQMD forecasts show that the majority of the emissions reductions between 1990 and 2020 occur in the first 10 years. Thus, the regression through the actual emissions data has a steeper downward slope than the SCAQMD projections; however, the rate difference may not be statistically significant. Forecasted total emissions are expected to decline slowly or remain essentially constant in southern California and to continue to trend downward in Sacramento. A number of additional control programs that were not included in the projections have been adopted. Additional controls for O_3 and particulate matter will likely continue to be adopted in the future and have a side benefit of CO reductions. Thus, the projections are a conservative forecast. The actual emissions trend probably will be steeper than the decline predicted by the SCAQMD and CARB estimates, but probably less steep than the trend line through the historical emissions estimates because the rate of emissions reduction will likely be slower in the future than it was during the 1990s.

Concentrations. Microscale CO concentration declines are primarily a function of the motor vehicle influence at microscale sites. In general, microscale monitors are located near heavily trafficked areas and, thus, reflect a greater contribution of emissions from motor vehicles. In contrast, neighborhood-scale monitors represent motor vehicle contributions as well as area-wide source contributions (stationary, area, and off-road emissions). Emissions data from CARB and the SCAQMD illustrate that area-wide contributions are not decreasing and are becoming a larger fraction of total CO emissions over time (see Table 1). Thus, the fact that microscale concentrations are decreasing at approximately the same rate as neighborhood concentrations for the second-highest annual 8-hr concentration events suggests that an area-wide motor vehicle control strategy will continue to produce emissions

Table 7. Results of *t* test comparing mean annual percent change in CO concentrations between microscale and neighborhood sites.

	Site Pairs					
	Microscale Lynwood	Neighborhood Hawthorne	Microscale El Camino	Neighborhood Del Paso	Microscale Magnolia	Neighborhood Rubidoux
Mean Annual Percent Change Based on Raw Data	6.6	3.3	4.3	5.6	5.8	–3.4
SD (%)	16.1	16.3	17.2	13.6	9.4	35.5
95% Confidence Interval Width (%)	34.0	34.1	36.0	29.0	20.0	75.0

reductions for peak concentrations at microscale monitors that are at least as great as reductions observed at neighborhood monitors.

Relationship between Emissions and Concentrations. For the southern California locations, trends in measured concentrations do not track trends in total emissions as well as might be expected. Emissions estimates are less accurate than the measured concentrations, and it is possible that some portion of the CO emissions (either on-road, off-road, stationary, or area) was not accounted for in the SCAQMD inventory. The southern California concentration trend lines generally match the *total* emissions projections better than the *on-road* emissions projections. This observation is consistent with a hypothesis that there may be some inaccuracy in the on-road portion of the inventory. The SCAQMD emissions projections for southern California included in this article's figures are based on the EMFAC7G model.[28] Following the release of the SCAQMD's 1997 AQMP, the CARB approved a new version of its mobile source emissions modeling tool called EMFAC 2000. EMFAC 2000 estimates CO emissions in the South Coast Air Basin that are 30% higher for the year 2000 and 32% higher for the year 2010 than the CO estimates produced by EMFAC7G.[12]

From the southern California plots, it can be seen that on-road CO emissions estimates are dropping more rapidly than are measured concentrations at both neighborhood and microscale stations over the range of measured data. One explanation for this difference is that, as concentrations drop, a greater percentage of the measured CO is caused by background CO concentration levels (i.e., a greater percentage of observed CO is not caused by vehicular emissions in the surrounding region). As CO concentrations approach background conditions, further emissions reductions have a reduced impact on ambient concentrations.

In Sacramento, both the microscale and neighborhood-scale concentration trends appear to match the on-road emissions projections slightly better than the total emissions projections. This was in contrast to southern California, where the trend lines through the measured concentrations generally matched the total emissions projections better than the on-road emissions projections. The Sacramento data analysis also showed that, unlike at southern California sites, concentrations dropped more rapidly than emissions. A possible explanation for this observation is related to regional growth patterns. It is possible that VMT growth is occurring more on the fringe of the Sacramento Valley Air Basin, while the monitors in this study are located in the urban area. Therefore, the changes in vehicle emissions over time would not be expected to influence the measured concentrations as much as they would if the VMT growth was occurring near the stations. In the South Coast Air Basin, the VMT growth may be distributed more evenly throughout the basin, so that any change in vehicle emissions is more likely to affect concentrations at existing monitoring locations.

Overall, the Sacramento and southern California case studies address the study's main research questions.

- Are past declines in CO emissions and concentrations expected to continue into the future?
- Are microscale CO concentrations declining faster or slower than regional concentrations?
- What are likely scenarios for future microscale CO concentrations?

The case studies indicate that CO emissions and concentrations will continue to decline in the future, although the rate of decline slows beyond the year 2010. The case studies include conservative assumptions and may underpredict future emission reductions. The case studies also illustrate that microscale concentrations have declined at approximately the same rate as that observed at the regional level. The declines at the microscale level are consistent with the importance of on-road motor vehicle emissions at the microscale and the substantial declines achieved in on-road emissions. Analyses show that future (2000 to 2010 and 2020) reductions at both the microscale and the regional scale are likely to occur but at rates slower than those experienced during the 1990–2000 time period.

Finally, the analyses suggest that the relationship between emissions and concentrations trends can differ by air basin. During the 1990–1997 period, Sacramento concentrations dropped more rapidly than did emissions. During the same time period in Los Angeles, emissions dropped more rapidly than did concentrations. These differences do not alter the observed relationship between microscale and regional trends. They indicate interesting possibilities related to the accuracy of emission inventories and perhaps the spatial importance of where emissions occur in relation to regional and microscale monitors.

CONCLUSIONS

Future CO Emissions and Concentrations Will Continue to Decline

Nationally and in California, regional CO problems have lessened dramatically over the past two decades, in large measure because of the introduction of cleaner vehicles, the use of reformulated fuels, and implementation of vehicle I/M programs. The CARB projects that, from 1990 to 2010, California will experience CO emissions reductions of at least 60% (see Table 1). California has experienced substantial drops in observed CO concentrations that are consistent with the emissions reductions achieved (see Table 2). In California, lack of violations of the CO NAAQS has resulted in redesignation to attainment or maintenance areas of all areas of California except Los Angeles and Imperial Counties. Los Angeles continues to demonstrate steady progress toward achieving the CO NAAQS (see Table 3). An exception to California's progress is Calexico, a U.S.–Mexico border area in Imperial County influenced by emissions from motor vehicles of Mexican registration.[4]

National trends mirror those in California. Nationally, as of 1999, only a handful of areas remained in violation of the CO NAAQS, compared with more than 40 areas in 1991. Studies also document significant reductions in human CO exposure based on in-vehicle and personal exposure monitoring and modeling.

Microscale CO Concentrations Have Declined at Approximately the Same Rate as Regional CO Concentrations

This report examined the hypothesis that regional CO emissions reductions have led to decreasing regional and microscale CO concentrations. Based on an analysis of past trends, the evidence obtained supports a hypothesis that concentration reductions observed at microscale stations have declined at nearly the same rate as those observed at neighborhood-scale stations and follow similar trends in estimated regional CO emissions reductions. This is consistent with common sense, given that on-road motor vehicles are an even more dominant contributor at the microscale than at the neighborhood scale, and on-road mobile emissions have dropped significantly while stationary and area source emissions have stayed the same or even increased.

Future Microscale CO Concentrations Will Continue to Decline

Analysis results support the hypothesis that both neighborhood and microscale CO concentrations are declining and will continue to decline. Measured data from the worst nonattainment area in California, the South Coast Air Basin, and the Sacramento Valley Air Basin were analyzed to determine long-term CO trends. On-road emissions are declining and will become a less significant portion of total emissions in the future. In addition, it appears that the microscale data correlate with the regional-scale emissions estimates, which are projected to decrease in the future. Future reductions in regional emissions should lead to continued reductions in concentrations at the microscale level. Microscale concentrations probably will be reduced at a slower rate than past reductions, given the reduced rate at which mobile emissions are declining. The previous analysis suggests that linear rollback methodologies to evaluate CO on a regional scale are also effective tools for projecting microscale concentrations.

POLICY IMPLICATIONS AND RECOMMENDATIONS

Emission decreases and regional attainment are expected to continue. Hence, microscale analysis will not be as important as it was in the past because concentrations at microscale monitors will be increasingly influenced by regional emissions. On-road emissions will continue to decline and constitute a smaller portion of total emissions over time. This trend, combined with the projected increase in stationary, area, and off-road source emissions, suggests that more consideration should be given to control measures for sources other than on-road vehicles. A strategy of regional emissions reductions appears to be an effective means of preventing microscale CO exceedances.

The implications of these findings are significant for the transportation planning community and for the need to conduct transportation project-level CO analyses. California data indicate that in virtually all metropolitan areas outside Los Angeles and where the vehicle fleet meets existing and projected standards, no existing transportation facility is expected to cause a CO violation. Los Angeles has not yet attained the NAAQS, but it is on a path to do so in the near future, and, thus, no existing transportation facilities would be expected to cause CO violations in Los Angeles beginning within a few years. The one exception is the border area of Calexico, which is influenced by emissions from vehicles that do not meet California's stringent emission standards. Thus, for CO analysis purposes, any future transportation project reasonably can be compared to existing facilities in the vast majority of the state. If future transportation projects have similar sizes and characteristics as existing facilities, and the existing facilities do not cause a CO violation, it can be inferred that the planned projects, accounting for changes in background concentration, should not cause violations either. This would allow for the elimination of microscale modeling for most transportation projects. Modeling might still be necessary for projects that are larger than existing facilities or those with extraordinary characteristics, such as projects located in Calexico. These findings suggest that EPA should reevaluate the continued need for the conformity CO hot-spot analysis requirement and consider replacing the requirement for one that applies only under unusual circumstances, such as those evident at the Calexico border site. We recommend using the conformity interagency consultation process to evaluate these unusual circumstances and requiring hot-spot analyses only on a case-by-case basis.

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