

Traffic Flow and Air Quality in a Mountain Community

PAUL E. BENSON, WILLIAM A. NOKES, and ROBERT L. CRAMER

ABSTRACT

The air-quality impacts of a comprehensive transportation improvement project located in the ski resort community of Mammoth Lakes, California, are analyzed by comparing levels of carbon monoxide sampled before and after construction. The project incorporates widening, channelization, installation of fully actuated signals, and construction of bus stop shelters. The elements of a transportation control plan designed to mitigate potential air-quality impacts of the project are described and their effectiveness is assessed.

Mammoth Lakes, located in the Eastern Sierra Region at an elevation of 8,200 ft, is an area of burgeoning growth centered around the largest single ski resort operation in California. By 1980 a combination of traffic congestion, wood-burning stoves, and winter meteorology had caused a significant decline in the region's air quality. Traffic congestion along State Route 203, particularly at the Lake Mary Road intersection, was a major contributor to this problem. Route 203 provided the only access to the main ski-lift facilities and therefore experienced heavy congestion on holiday weekends during the ski season.

To reduce congestion and improve traffic safety on Route 203, a transportation improvement project was constructed in 1981-1982. The route was widened to four lanes, delineation was improved, and several intersections, including Lake Mary Road, were upgraded with fully actuated traffic signals. Bus stop shelters were constructed in an effort to promote the use of an existing bus service and further reduce traffic congestion within the corridor. The improvements were expected to double the capacity of the route and reduce carbon monoxide (CO) emissions by improving traffic flow. However, CO emissions would drop only if the added capacity did not induce substantial increases in traffic volume.

During the planning phase of the project, a transportation control plan was developed to mitigate any adverse air-quality impacts brought on by the increased capacity of the route (1). The plan contained strategies designed to increase use of public transit, improve traffic flow, and control traffic volumes. The major components of the plan included parking restrictions, construction of transit amenities, and an expansion of the county road system to help relieve congestion on Route 203. Operational improvements such as staggered ski-lift closing times, a "ski-back" trail, and lighting of ski runs for night skiing were also included. Future expansion of ski facilities would only be permitted if peak traffic volumes on Route 203 did not increase. Transit service was to be required for any new facilities, but no expansion of parking capacity would be allowed.

To check the adequacy of the mitigation measures, the plan included a provision for pre- and postconstruction CO monitoring. The preconstruction aerometric survey was conducted as a joint effort between California Department of Transportation

(Caltrans) District 9 and the Transportation Laboratory during the winter of 1980-1981. A postconstruction survey was conducted during the winter of 1982-1983. In this paper the results of this before-and-after study are discussed and the effectiveness of the transportation improvements at mitigating air-quality problems associated with traffic congestion is evaluated.

CARBON MONOXIDE MONITORING PROGRAM

The junction of Route 203 and Lake Mary Road shown in Figure 1 carries traffic on three primary legs. The fourth (southerly) leg, planned for extension and widening by others, now carries less than 1 percent of the traffic handled by the intersection. During the 1980-1981 ski season, the intersection was controlled by a pretimed, two-phase signal with lights mounted at the corners. Roadway width limitations permitted only two approach lanes per leg with

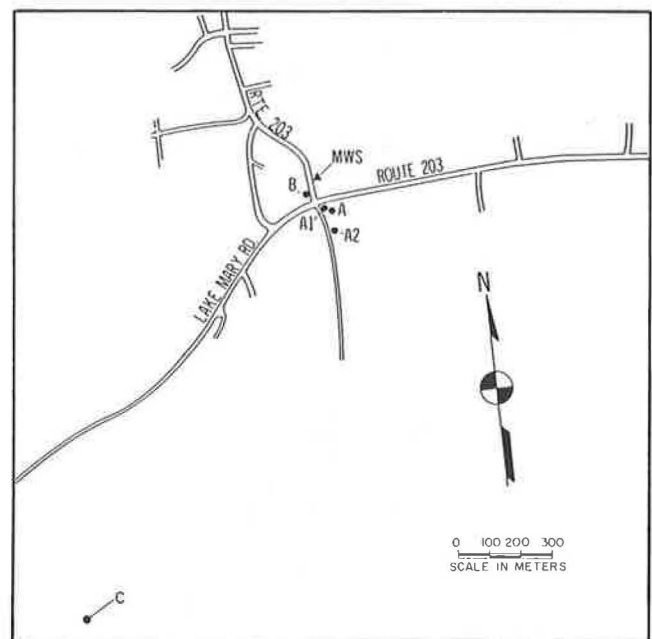


FIGURE 1 Sampling locations for the 1980-1981 and 1982-1983 air-quality monitoring programs at Mammoth Lakes, California.

no room for channelization. Widening of the route made room for three approach lanes on eastbound Route 203 and Lake Mary Road and four lanes on westbound Route 203. A fully actuated three-phase signal was also installed.

CO concentrations were sampled at five sites shown in Figure 1 during the pre- and postconstruction surveys. Four of the sampling sites were clustered around the Route 203-Lake Mary Road intersection. The fifth site, located approximately 1 km southwest of the intersection, provided a measure of ambient CO concentration for the area. A mechanical weather station located at the intersection recorded wind direction, wind speed, and temperature at a height of 10 m. A larger meteorological tower located about 1.5 km east of the intersection measured wind speed and temperature at heights of 10 and 18 m.

Air samples were collected over 1-hr intervals using continuous-flow bag samplers. The bags were returned to the District 9 Laboratory and tested for CO within 48 hr of collection by using nondispersive infrared analysis. Days that were favorable for skiing, particularly weekends and holidays, were monitored. In the 1980-1981 season, samples were collected on 63 days from December through February. For the 1982-1983 season, 45 days were sampled from November through February. Although some 24-hr sampling was done, most was conducted between the hours of 7:00 a.m. and 7:00 p.m.

Traffic counts were made at the intersection by District 9 personnel during the peak ski weekends for each season. For the 1980-1981 season, counts were made in February on the weekend following Lincoln's Birthday. For the 1982-1983 season, counts were made in December on the weekend before New Year's Day. The counts recorded 15-min volumes by direction and vehicle type from 7:00 a.m. to 7:00 p.m.

DATA ANALYSIS AND DISCUSSION

The hourly CO concentrations recorded for each day were stratified into three measures of air-quality impact: the daily 8-hr maximum, the 1-hr morning maximum, and the 1-hr evening maximum. Morning and evening maximums were taken from days with valid measurements at Sites A and B for the hours of 7:00 to 10:00 a.m. and 4:00 to 7:00 p.m., respectively. Daily 8-hr maximums were recorded when no more than 2 consecutive hr or 3 hr total were missing for Sites A and B from 7:00 a.m. to 7:00 p.m. Missing values on days satisfying these criteria were approximated by linear interpolation (2). The resulting number of days analyzed by season and averaging time are as follows:

Averaging Time (hr)	No. of Days	
	1980-1981	1982-1983
1 (a.m.)	35	37
1 (p.m.)	33	40
8	31	38

The two ski seasons involved in this analysis were far from similar in nature. The 1980-1981 season started much later than normal, with most of the peak ski days occurring during February and March of 1981. By contrast, the 1982-1983 season was much longer, with capacity crowds arriving by Thanksgiving of 1982 and operations tapering off in the spring of 1983. In order to compare air-quality measurements for the two seasons, factors independent of the transportation improvements that might have an impact on air quality had to be considered. These factors were meteorology, demand volume, and vehicle emissions.

Meteorology was the first factor to be considered. An attempt to normalize the data by using wind speed, temperature, and stability measurements was made. However, significant gaps in the meteorological data base and excessive scatter in the normalized results forced this approach to be abandoned. Instead, average hourly wind speeds measured at the intersection from 7:00 to 10:00 a.m. and 4:00 to 7:00 p.m. were examined to see whether there was a significant difference between the two seasons. Based on over 200 hr of available data, no significant difference was found between the seasonal means for either morning or evening conditions. Furthermore, similar low-wind-speed weather conditions favorable for skiing were expected to correlate with peak traffic volumes and CO concentrations regardless of which season was considered. Therefore, the overall effects of meteorology on corridor CO concentrations were assumed to be approximately equal for the two seasons.

The second factor to be accounted for was demand volume. Because traffic counts were not available for most of the days sampled, a surrogate measure was needed to quantify this factor. Daily sales of ski-lift tickets reported to the Forest Service, U.S. Department of Agriculture (USDA), by the ski operator were used for this purpose. Because Route 203 was the only road that served the main ski-lift facility, ticket sales offered the most direct measure of demand volume available. The distribution of number of days analyzed by ticket sales category for each daily maximum is given in Figure 2 for both the 1980-1981 and 1982-1983 seasons. All three distributions show a substantially greater number of days with high ticket sales sampled in the 1982-1983 season. Average daily ticket sales were 97 percent higher than those in the 1980-1981 season. Ticket sales on peak ski days were similar for both seasons, but there were many more peak days in the 1982-1983 season.

The final factor to be considered was the change in composite vehicle emissions between seasons. The 1982-1983 vehicle fleet contained a higher percentage of new vehicles with better emission controls than the 1980-1981 fleet. Composite CO emissions for the two seasons were estimated by using a California emission factor program (3). An average decrease from 1980-1981 emissions of 10 percent was forecast.

Of the three factors considered, the change in average demand volume between the two seasons was the most important. It was expected that higher ticket sales would result in more congestion and therefore higher CO concentrations at the intersection. To test this idea, 8-hr daily maximum CO concentrations were plotted against ticket sales for the intersection sites and ambient site. Regression lines and 95 percent confidence limits were constructed for each season (see Figure 3). As expected, CO concentrations at the intersection sites generally increased as ticket sales increased. A similar but weaker trend was apparent for the ambient site.

The two regression lines in Figure 3b indicate that the transportation improvements led to an average reduction in 8-hr CO concentrations near the intersection of about 50 percent for days with low to medium ticket sales. For days with high ticket sales (>10,000), the average reduction ranged from 13 to 25 percent, or about the amount expected from improved control technology alone. This suggests that the improvements to the intersection had a measurable positive effect on nearby air quality for low to medium traffic volumes but were not effective at improving air quality as volumes approached the ca-

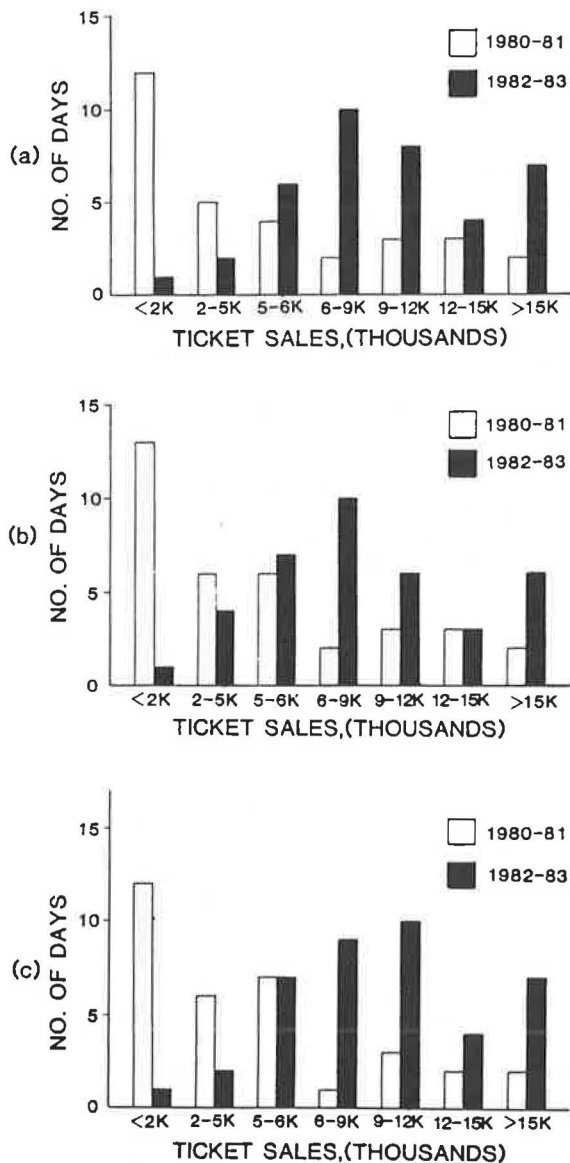


FIGURE 2 Number of days analyzed distributed by ski-lift ticket sales category for (a) 8-hr, (b) 1-hr a.m., and (c) 1-hr p.m.

capacity of the intersection. Plots similar to Figure 3b for the morning and evening 1-hr maximums showed the same tendency.

The responsiveness of the fully actuated signal is the probable cause for the air-quality improvements measured during periods of low to medium traffic volumes. Studies show that CO emission rates during accelerations are two to five times higher than average rates (4). By decreasing the number of vehicle stops, the new signal reduced the number of accelerations at the intersection and therefore lowered CO emissions. As conditions approached the capacity of the intersection, more vehicles were forced to stop and the number of accelerations climbed to preconstruction levels.

Cumulative frequency distributions for the three daily maximums are given by season in Figure 4. For the lower half of the 8-hr daily maximum distributions in Figure 4a, measurements from the 1980-1981 season tend to be 0.5 to 1 ppm higher than equivalent 1982-1983 values. The distribution of 1-hr evening maximums given in Figure 4c shows an average

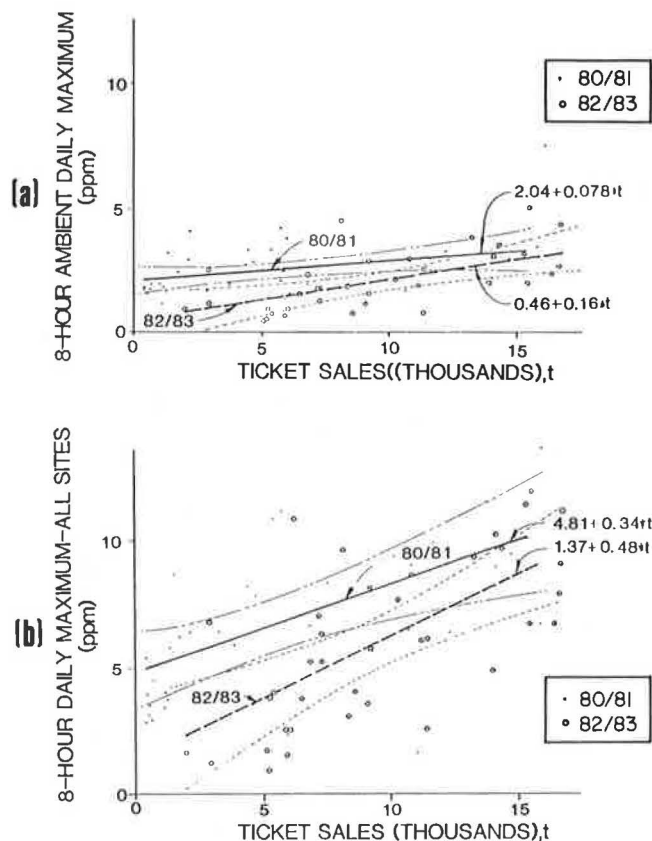


FIGURE 3 Daily maximum 8-hr CO concentration versus ticket sales for the 1980-1981 and 1982-1983 seasons: (a) ambient (Site C), (b) all sites.

decrease in observed concentrations between the seasons of about 2.5 ppm over the range of results. The distribution of morning 1-hr maximums given in Figure 4b also shows about a 2.5-ppm improvement, but only for the upper quartile. Considering the far greater number of days sampled with high ticket sales during the 1982-1983 season, these results indicate that the Route 203 project helped improve overall air quality in the vicinity of the corridor. However, the graphs also show that state and federal standards were still being violated.

Plots of the seasonal maximums (i.e., the highest daily maximums recorded during the season) stratified by ticket sales are given in Figure 5. For both the morning and evening 1-hr maximums, measurements made during the 1982-1983 season were lower for five out of six ticket sales categories. For 8-hr maximums, four of the six categories showed improvement. On average, however, the improvements were no greater than the 18 percent reduction expected from newer vehicle emission controls.

In Figures 4 and 5, the number and size of 1-hr standard violations are greatest during the morning hours. However, these concentration peaks did not coincide with peak traffic volumes. Peak volumes occurred in the evening when either weather conditions or ski-lift closure forced skiers off the mountain at a single time. Based on traffic counts made on the days with highest ticket sales, evening 1-hr peak volumes were 35 to 55 percent higher than morning peaks.

There are a number of possible reasons why the highest CO concentrations did not coincide with the peak evening traffic volumes. A greater incidence of stagnant conditions during the morning hours was one

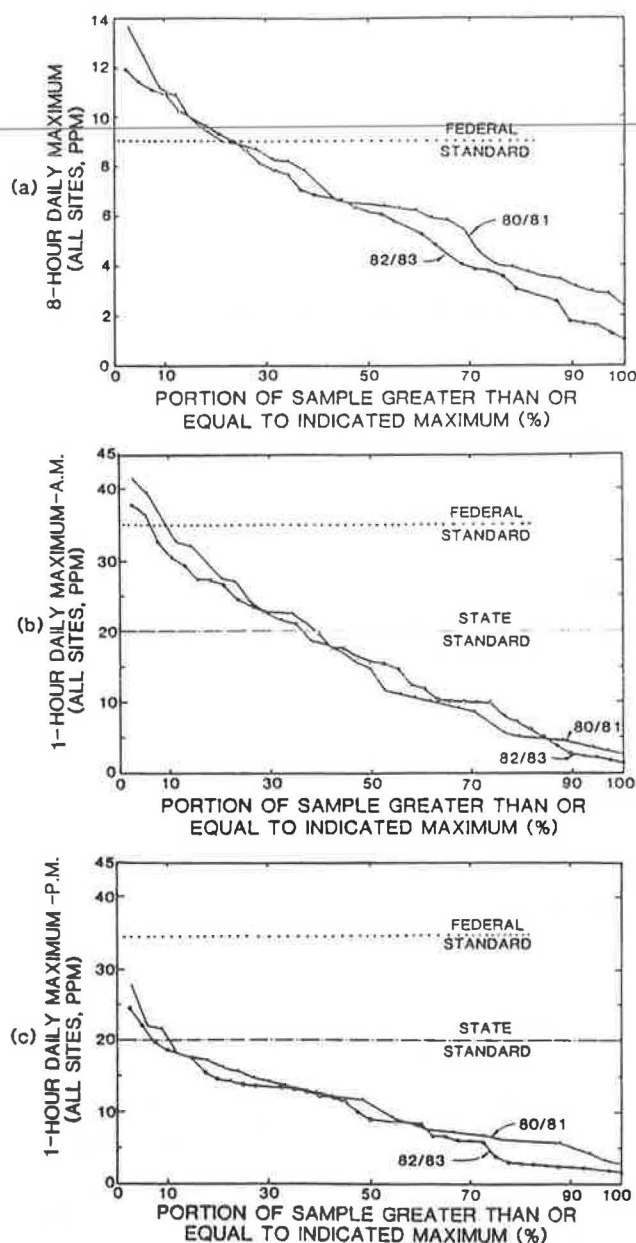


FIGURE 4 Cumulative frequency distributions of daily maximums for the 1980-1981 and 1982-1983 seasons: (a) 8-hr, (b) 1-hr a.m., and (c) 1-hr p.m.

possibility. However, the number of hours with wind speeds less than 2 m/sec was only 5 percent higher in the morning. A more likely reason concerns the effect of temperature on vehicle emissions. Colder morning temperatures cause considerably higher emissions for vehicles in the cold-start phase (i.e., first 505 sec). The proximity of many of the lodges and condominiums to the intersection meant that a large percentage of the morning ski traffic was in the cold-start phase. Fewer cold-start vehicles were expected in the evening because of the estimated 10-min travel time between the main ski-lift facility and the intersection.

A second significant contributing factor to the high morning concentrations is the average 4 percent grade of Route 203 near the intersection. Accelerations to 25 mph on a 4 percent grade can result in a fivefold increase in average vehicle emissions (4). In the morning, vehicles climb this grade, often

slowing down or stopping to make the right-hand turn at the intersection. In the evening, the dominant downhill flow of traffic needs less effort to accelerate through the intersection and emissions decrease accordingly.

In Figure 6, the range of concentrations for each daily maximum are plotted by site for days with ticket sales exceeding 10,000. Seasonal high measurements for 1-hr concentrations made during 1982-1983 at the four intersection sites are lower than their respective 1980-1981 values. Again, however, the average reductions are no better than the 18 percent expected for the 1982-1983 vehicle fleet. Results for the 8-hr daily maximums in Figure 6a show improvements at Sites A and Al, but not at Sites A2 and B. Ambient concentrations measured at Site C show little or no improvement between the seasons.

The lack of significant reductions in ambient results and 8-hr seasonal maximums for the 1982-1983 season suggests that contributions from another pollutant source may have overshadowed the effects of the projected 18 percent reduction in vehicle emissions. Wood-burning stoves and fireplaces are standard features in the condominiums and cabins of Mammoth Lakes. Each condominium unit is stocked with a full supply of wood at the beginning of the ski season and restocked as the season progresses. According to studies by the Environmental Protection Agency (EPA), average CO emissions can range from 15 to 30 g/kg of fuel for fireplaces and 91 to 370 g/kg for stoves (5). At average burn rates used for certification testing by EPA, CO emission rates ranging from 2.5 to 5 g/min for fireplaces and 11 to 44 g/min for stoves can be expected. Composite idle emission rates used for modeling Route 203 vehicle emissions (described in a companion paper by Benson et al. in this Record) were approximately 8 g/min. The stoves and fireplaces are therefore likely to contribute to the Mammoth Lakes CO problem at a level comparable with that of transportation sources. These contributions will tend to mask emissions reductions achieved by transportation sources, especially over longer averaging times or at locations removed from primary transportation routes.

EFFECTIVENESS OF THE TRANSPORTATION CONTROL PLAN (TCP)

By the 1982-1983 ski season, construction of the bus stop shelters and staggering of ski-lift closing times were the only elements of the TCP implemented. It was hoped that the shelters would help increase ridership on the existing bus line and thereby reduce the demand volume on Route 203. District 9 personnel observed that the shelters were useful for indicating the location of bus stops otherwise obscured by roadside snowbanks. However, they also noted that patrons rarely used the shelters, preferring to wait outside. According to the owner of the bus line, weather was the only factor that had a significant influence on ridership. On days when chain controls were posted, ridership increased dramatically.

Daily passenger counts made by the bus operator for the 1981-1982 and 1982-1983 seasons were examined for evidence of increases in ridership. Because the shelters were not constructed until the summer of 1982, counts from the 1981-1982 season were considered representative of preconstruction conditions. The daily passenger counts averaged about 7.5 percent of the ski-lift ticket sales for both seasons. No evidence was found to indicate an increase in ridership.

A comparison of traffic volumes handled by the

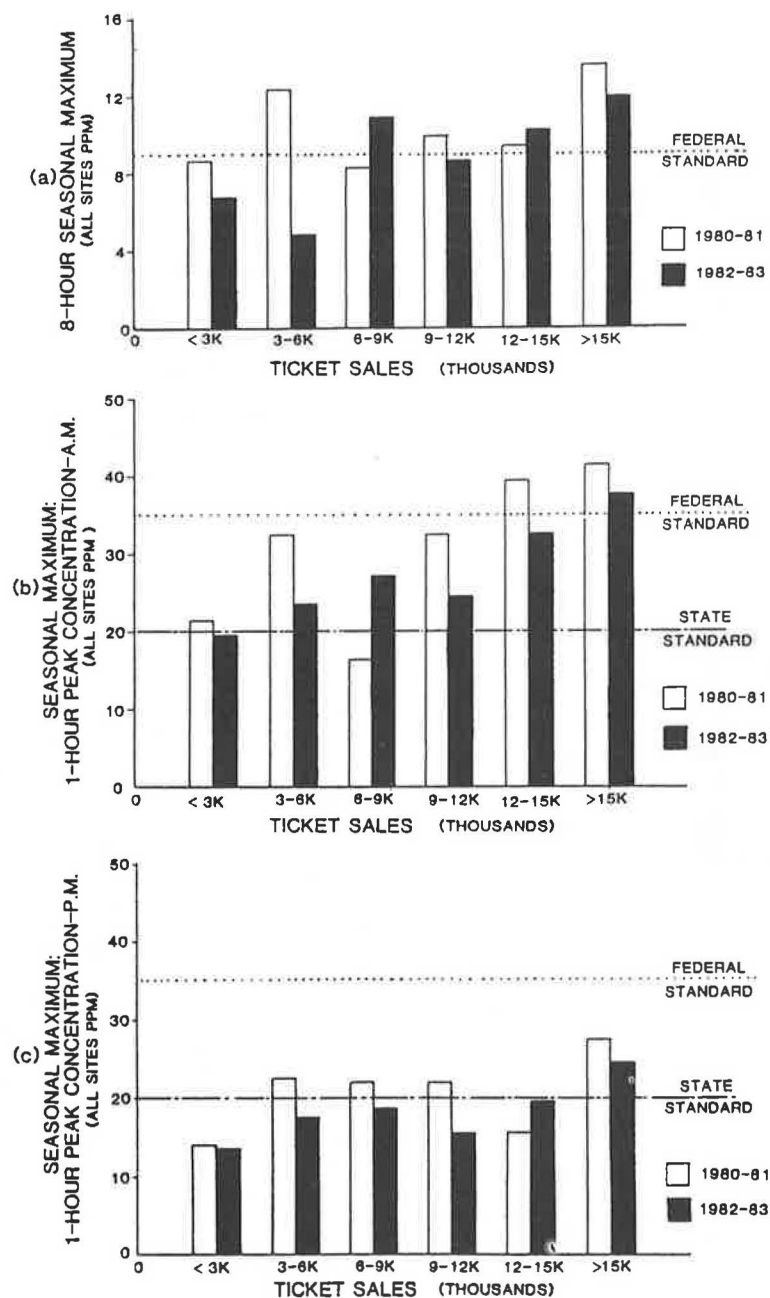


FIGURE 5 Seasonal maximum CO concentrations taken from all sites and distributed by ticket sales category for (a) 8-hr, (b) 1-hr a.m., and (c) 1-hr p.m.

intersection on the peak ski-lift ticket sales days for the 1980-1981 and 1982-1983 seasons was made to see whether fewer skiers were driving their own cars to the main ski-lift facility.

Ticket sales for the peak day in 1982-1983 were only 6 percent higher than those in the 1980-1981 peak, but the intersection carried approximately 20 percent more traffic during the 12-hr period from 7:00 a.m. to 7:00 p.m. If the shelters had a positive impact on bus ridership, it was apparently overshadowed by increases in private vehicle use motivated by the reduced traffic congestion.

The staggered closing of the ski lifts appeared to have no effect on evening peak-hour traffic volumes. Counts for the peak hour of 4:00 to 5:00 p.m. were up 33 percent from 1980-1981 levels on peak ski days. The added capacity of the route may have masked the positive effects of this operational im-

provement by accommodating residual demand not measured in the constrained 1980-1981 peak volumes.

Since the 1982-1983 ski season, several more elements of the TCP have been implemented. Caltrans has constructed a bus terminal at the main ski-lift facility, descriptions of transit service have been incorporated into promotional literature, and bus fares have been reduced by 50 percent.

Implementation of other major elements has been delayed, however:

- Expansion of the local road system has not taken place. Mammoth Lakes has incorporated since adoption of the TCP, so the county no longer has responsibility for implementation of this element. Further delay is expected as a result of a lawsuit and shortage of funds.

- Additional parking restrictions along Route

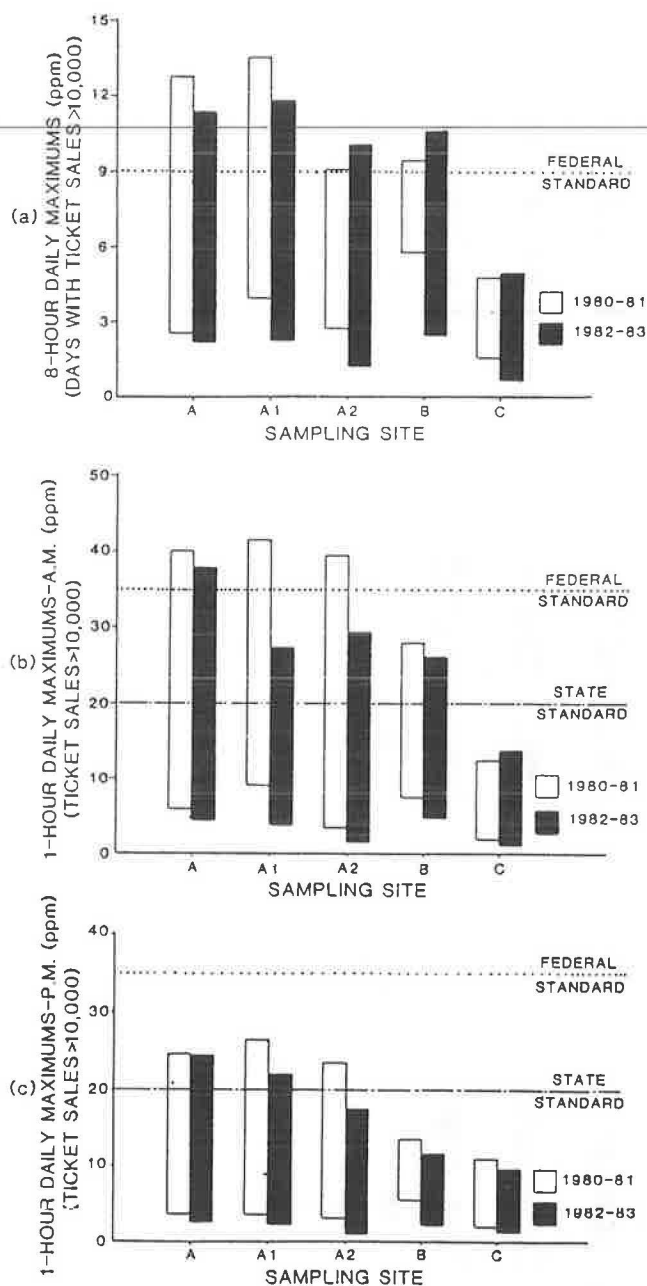


FIGURE 6 Range of daily maximum CO concentrations distributed by sampling site for (a) 8-hr, (b) 1-hr a.m., and (c) 1-hr p.m.

203 have not been made. These restrictions were meant to maximize use of developing transit facilities. Future transit development is uncertain at this time, however, because the previous bus operator is no longer in business. For the interim, the ski operator is providing scheduled service. An integrated transit plan has just been completed and is likely to be implemented as growth continues in the area.

- No ski runs have been lighted for nighttime use. It was hoped that this measure would help relieve peak evening traffic congestion.

- Additional development of ski facilities along Route 203 has not yet taken place. This includes construction of a ski-back trail, tram, and warming hut. Each of these access or egress points

to the lift system were to be serviced by transit only.

Even though many elements of the TCP have not been implemented, CO concentrations at Mammoth Lakes have stabilized at an acceptable level. Measurements by the local air pollution control district show no further violations of state or federal CO standards after 1982 (6). Though not considered in the original TCP, a decision by the USDA Forest Service and the ski operator to redirect expansion outside the Route 203 corridor is probably responsible for this success. This was made possible by a fortuitous land purchase and cooperative trade arrangement between the Forest Service and a private-sector concern. By assuming responsibility for transit operations, the ski operator has also been able to fully integrate bus and ski-lift schedules. He has incorporated transit and walk-in access wherever facilities have been expanded and has not created additional parking.

CONCLUSIONS

The results of this study show that CO concentrations near the Route 203-Lake Mary Road intersection were reduced following construction of a comprehensive transportation improvement project. For low to medium traffic volumes, these reductions were due in part to the increased capacity of the intersection and the responsiveness of the fully actuated, three-phase signal. For traffic volumes approaching the capacity of the intersection, the reductions were due exclusively to the higher proportion of new vehicles with better emission controls in the post-construction vehicle fleet.

No significant improvements to ambient air quality as measured at Site C were seen. It is possible that increased CO emissions from wood-burning stoves and fireplaces masked projected reductions in vehicle fleet emissions. In any case, it was never expected that reductions in vehicle emissions brought about by relieving traffic congestion on a single route would have a measurable effect on areawide ambient concentrations.

No evidence was found in the 1982-1983 data to indicate that the bus shelters had a positive effect on transit use. The increased capacity of the route may have actually lured users away by decreasing congestion. Fortunately, subsequent expansion did not exploit this increased capacity.

In summary, experience has shown that transportation projects designed to improve traffic flow can also enhance air quality, but only if measures are taken to ensure that increased capacity is not exploited. In the case of Mammoth Lakes, expansion of facilities serviced by other roads relieved pressure on Route 203, helping to retain the reductions in traffic congestion created by the project. It is not clear whether the restrictions of the TCP or the potential for lost business (given a return to pre-construction congestion) provided the impetus for this decision. What is clear is that the environmental process forced consideration of problems that might have otherwise been overlooked, and that these problems were dealt with by both the private and public sector in a cooperative and constructive manner.

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REFERENCES

1. Transportation Systems Management and Air Quality Mitigation Plan for State Highway Route 203 in the Vicinity of Mammoth Lakes in Mono County. California Department of Transportation, Sacramento, Aug. 1980.
2. W.S. Meisel and T.E. Dushane. Monitoring Carbon Monoxide Concentrations in Urban Areas. NCHRP Report 200. TRB, National Research Council, Washington, D.C., April 1979.
3. D.M. Coats, R.W. Bushey, and E.C. Shirley. Mobile Source Emission Factors. Report CA/TL-80/15. Transportation Laboratory, California Department of Transportation, Sacramento, May 1980.
4. P.E. Benson. Caline 4--A Dispersion Model for Predicting Air Pollution Concentrations Near Roadways. Report FHWA/CA/TL-84/15. Transportation Laboratory, California Department of Transportation, Sacramento, Nov. 1984.
5. R.E. Hall and D.G. DeAngelis. EPA's Research Program for Controlling Residential Wood Combustion Emissions. Journal of the Air Pollution Control Association, Vol. 30, 1980, pp. 862-867.
6. California Air Quality Data, Annual Summary, Vols. XIV-XVI. California Air Resources Board, Sacramento, 1982-1984.

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Evaluation of the CALINE4 Line Source Dispersion Model for Complex Terrain Application

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ABSTRACT

CALINE4, the latest version of the California Line Source Dispersion Model, is evaluated for use in complex terrain. Data from air-quality studies connected with a transportation improvement project along State Route 203 at Mammoth Lakes, California, are used for this purpose. A comprehensive tracer gas release experiment performed after completion of the project is described. Based on comparisons with the CALINE3 model and previous results for CALINE4 in flat terrain, model performance for receptors near the roadway in complex terrain is judged adequate for impact assessment purposes. Predictions for more distant receptors are much less reliable.

The California Line Source Dispersion Model, CALINE3 (1), is used throughout the country as a tool for evaluating the potential microscale air-quality impacts of transportation projects. The U.S. Environmental Protection Agency (EPA) has approved the model for general use with the provision that it not be used for studying projects in complex terrain (2). This restriction is made because of the assumptions on which the model is based.

CALINE3 uses a quasi-empirical Gaussian solution

to the Fickian diffusion equation to model pollutant dispersion. This approach assumes a homogeneous wind flow field (both vertically and horizontally), steady-state conditions, and negligible along-wind diffusion. These assumptions can never be met exactly in any real-world application. However, for sites in relatively flat terrain and wind speeds above 0.5 m/sec, they are considered reasonable and yield answers that compare favorably with measured results (1). In this paper the extent to which these assumptions are satisfied for applications in complex terrain is examined.

A significant fraction of transportation projects is built in complex terrain. Because of difficulties

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