where it approaches the accuracy of on-line monitoring equipment.

Model outputs are comprehensive and adequately address a system analysis throughout an airshed region. The model can be useful for determining impacts from alternative major transportation facilities, transportation system concept variations, and proposed air pollution control strategies. Revisions in model capabilities and accuracy are being made continuously; however, care should be exercised to avoid a model that is beyond the state of the art for pollution monitoring and requirements for data base inputs.

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Photochemical Oxidants in Phoenix

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The standard for photochemical oxidants is often exceeded during the summer in the Salt River Valley in the vicinity of Phoenix. Assessment of the photochemical oxidant problem in Phoenix is complicated by relatively low concentrations of nitrogen oxides in the morning, winds that switch direction in the middle of the day, and large changes in mixing height. In this paper, current measurements, modeling efforts, and control strategies are discussed as they apply to Phoenix. Although linear rollback or semiempirical correlations based on smog-chamber or actual measurements are now used to evaluate transportation strategies, better results could be obtained from mathematical air pollution simulation models. The linear rollback analysis currently used by local transportation planners shows that continued inspection and maintenance programs for automobiles and some vapor recovery programs will be required to reduce the maximum photochemical oxidant concentrations in Phoenix to levels below standard. The purpose of this paper is to review the current status of the photochemical oxidant problem in Phoenix and to make projections for the future.

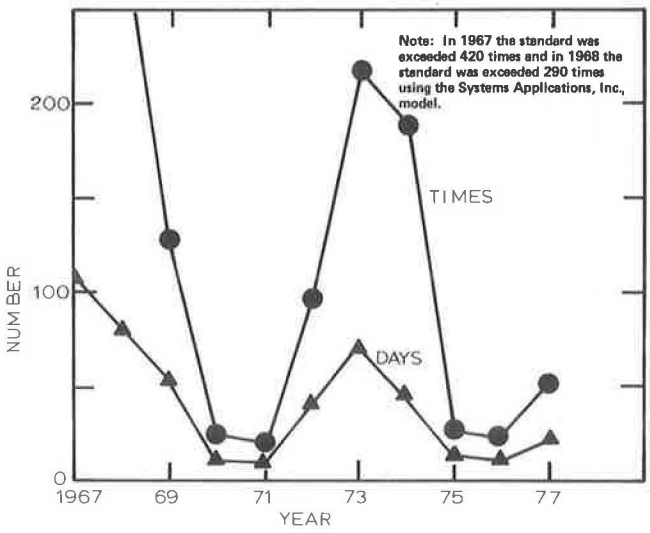
Although the 1-h photochemical oxidant standard is often violated during the summer months in Phoenix, the frequency of violations varies considerably from year to year. Some form of control of nonmethane hydrocarbon (NMHC) and nitrogen oxide (NO) emissions is necessary to reduce the photochemical oxidant concentrations in the future. A limited amount of measurement data indicates that approximately a 50 percent reduction in NMHCs will be necessary by 1982.

In 1974, the Phoenix standard metropolitan statistical area was designated an air quality maintenance area for carbon monoxide (CO) and photochemical oxidants. Since then, considerable effort has been expended by the state departments of transportation and health services and the U.S. Environmental Protection Agency (EPA) to prepare an implementation plan for Phoenix. Yearly revisions will require continuous evaluation of the progress toward attainment of the standard.

PHOTOCHEMICAL OXIDANT MEASUREMENTS

A long-term record is available at only one location in Phoenix; however, in 1974 the method of analysis was changed from continous colorimetric to continuous ultraviolet absorption. Thus, comparisons between pre- and post-1974 data may not be meaningful. At the central Phoenix location maintained by Maricopa County, the number of violations of the 1-h oxidant standard of 160 $\mu g/m^3$ and the number of days on which the violations occurred are shown in Figure 1 for 1967 through August 1977. Clearly, more information is needed to evaluate the trends. The maximum measured hourly average concentration showed a drop from approximately 370 $\mu g/m^3$ to 250 $\mu g/m^3$ from 1973 through 1976 at the same central Phoenix location. However, in 1976 Aerovironment, Inc., performed a study at two locations, one about 19 km southwest of this site and the other 19 km east; a maximum con-

Figure 1. Number of times and number of days the oxidant standard was exceeded for the years 1967 through August 1977 at the Phoenix central station.



centration of over 400 $\mu g/m^3$ was measured. The central Phoenix station is site 1 in Figure 2 and the Aerovironment, Inc., sites are 23 and 8. Also, the number of days exceeding the standard at the western Aerovironment, Inc., site was about 30 compared to 10 for the entire year at the central Phoenix site.

An examination of the meteorology of the area and the distribution of concentrations will show how such a large difference can occur. Most high oxidant measurements occur in the summer months (June, July, and August), when the solar insolation is highest for the year. A complex wind pattern over the whole metropolitan area joins with the influences of solar heating, topography, and pressure gradient winds. Figure 2 shows the major topographical features and the location of monitoring sites in the Phoenix area. The average wind speed during the summer months along the Salt River near the lettering "Phoenix" on the map is approximately 2.5 m/s from the east between 2:00 a.m. and 12:00 p.m. After noon, the wind shifts direction (so that it is from the west) but the speed remains 2.5 m/s until 2:00 p.m. The afternoon winds increase in magnitude to reach over 4 m/s at 4:00 p.m. and remain at this velocity until midnight. Throughout the day, the winds correspond to downslope in the morning and upslope in the afternoon. Near the locations labeled Tolleson and Scottsdale on the map, upslope is toward the north, and the wind patterns are correspondingly different from those in Phoenix. Late afternoon winds throughout the area are dominated by the circulation about the thermal low pressure in the Pacific Ocean, southwest of Phoenix. On some days each month the thermal low is weak and winds decay after 2:00 p.m. until almost calm conditions exist after sundown. Such days usually give the highest measurements of photochemical oxidant.

Figure 1 indicates that much longer records are required to assess adequately the magnitude of an oxidant problem in Phoenix. Perhaps a better indication of the maximum concentrations can be found from a frequency distribution plot. Figure 3 shows a graph for the combined months of June 1975 and June and July 1977 at the central Phoenix location. A log-normal curve that approximates these data has a maximum at 114 $\mu g/m^3$. Twenty-five percent of the days would have maximum concentrations over 160 $\mu g/m^3$ according to the log-normal approximation. The data at the Aerovironment, Inc., sites for a 6-week period beginning in late May 1976 are shown in Figure 4. The maximum is at 160 $\mu g/m^3$; 60 percent of the measurements are over 160 $\mu g/m^3$. The two sets of data cannot be compared in 1976 because the record is incomplete for the central Phoenix site. When similar days are com-

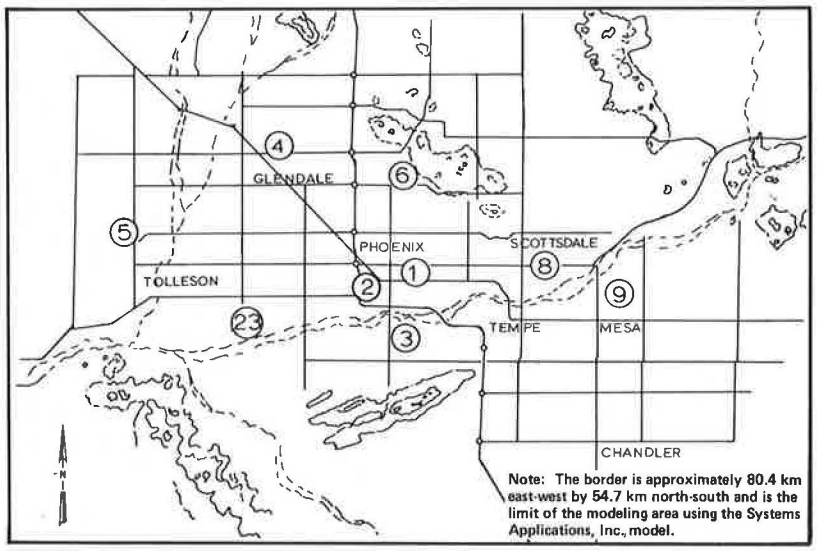


Figure 2. Map of the Phoenix area showing major monitoring sites as circled numbers.

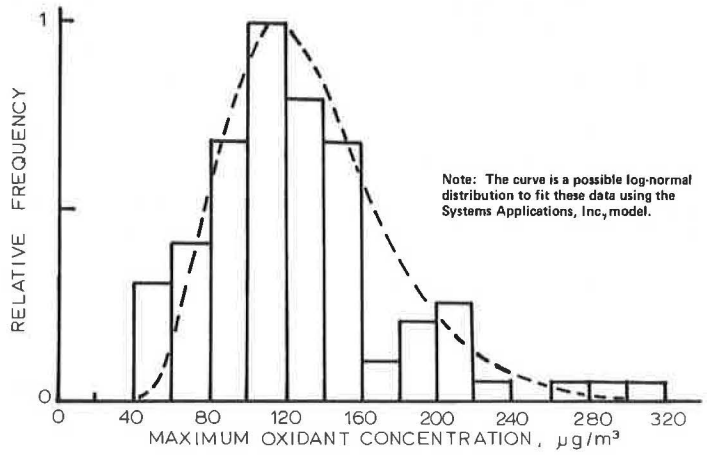


Figure 3. Frequency of occurrence of maximum daily oxidant concentration for June and July in 1975 and 1977 at the Phoenix central station.

Figure 4. Frequency of occurrence of maximum daily oxidant concentrations in the early summer 1976 at Aerovironment sites.

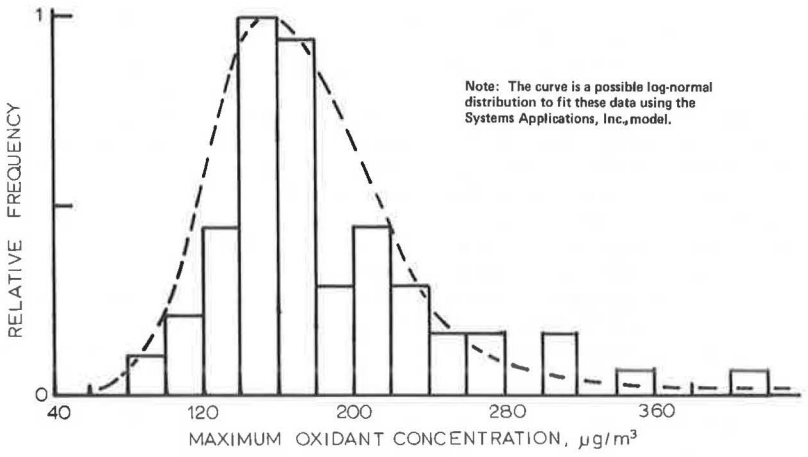
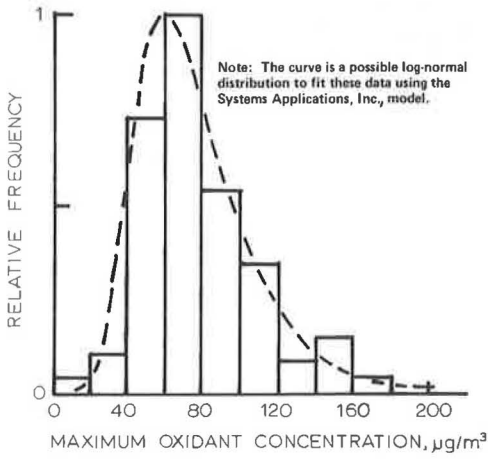


Figure 5. Frequency of occurrence of maximum daily oxidant concentrations for the winter 1974-1975 at site 5.



pared, the Aerovironment, Inc., locations have higher oxidant concentrations and the concentrations in the western location are higher than those in the eastern.

The typical wind pattern moves the most concentrated cloud of urban pollutants in the morning to the southwest from the center of Phoenix. After noon the oxidant concentration is highest and the cloud is near the western Aerovironment, Inc., site. Figures 3 and 4 are reasonable representations of daily maximum oxidant levels in the summer at any location in Phoenix. The differences are due to the short record and particular meteorology of the time period for the measurements. For the remainder of the year the curves are similar in shape but displaced toward lower concentrations. For example, at location 5 in Figure 1, the maximum daily oxidant distribution over a 12-week period during the winter of 1974-1975 is shown in Figure 5. The log-normal curve has a maximum at 60 $\mu g/m^3$. Only 2 percent of the total would be over 160 $\mu g/m^3$ for this log-normal distribution.

Log-normal distribution patterns appear to be typical in the Phoenix area; concentrations in the summer are about twice those in the winter. This also corresponds to the difference in radiation intensity for these seasons. If the data shown in Figures 3 and 4 are characteristic of long-term averages, there is considerable variation spatially within the metropolitan area. Over a 1-year period, the meteorological pattern could shift the distribution measured at one location so that 10 to 60 percent of the days in June, July, and August would have maximum concentrations that exceed 160 $\mu g/m^3$.

Oxidant concentration changes during a day of high maximum concentrations are shown in Figure 6. The average daily traffic and the solar insolation curves are also given for comparison. The peak concentration at the central Phoenix location generally occurs about noon. However, at the Aerovironment, Inc., sites, the peak on high oxidant days occurred at approximately 4:00 p.m., as shown in Figure 7. The NMHC, NO, and NO_2 concentrations are also shown in Figure 7. The smog-chamber-like pattern in the afternoon may indicate some air stagnation. The lag in the peak at the Aerovironment, Inc., site could be a result of winds blowing the air mass from Phoenix to the southwest and then back again followed by stagnation in the afternoon. Normally, vigorous upward mixing is present in the desert during the day even if horizontal wind speeds are low. Any limitations on this mixing should also increase the pollutant concentrations.

NMHC EMISSION SOURCES

Currently, controls on emissions of NMHCs are the only proposed strategy for the reduction of photochemical oxidants in Phoenix. The emissions for the 1975 base year and for future years as estimated by the Technical Operations Committee of the Phoenix Air Quality Maintenance Area (AQMA) Task Force are given in Table 1. Transportation-related activities accounted for 80 percent of the total NMHC emissions in 1975. When the reactivity of the hydrocarbon species and the temporal distribution of emissions are taken into account, the influence of automobiles and trucks is even greater. Future estimations were based on projected population increases prepared by the state of Arizona Department of Economic Security. These estimates predict an increase in Maricopa County from 1.3 million people in 1975 to 2.3 million people in 2000. The projected traffic emissions were estimated by EPA (1). Details of the calculations are given in reports by the Maricopa Association of Governments (2) and the Arizona Department of Health Services (3, 4). Revised estimates based on the Clean Air Act Amendments of 1977 are currently in progress.

Table 1 shows that the replacement of older automobiles by newer models, which have more emission controls, results in lower total NMHC emissions until 1995. Then, the effects of increased population will reverse the trend. The problem faced by transporta-

Figure 6. Variations in O_3, traffic volume, and solar isolation at the Phoenix central location (June 14, 1977).

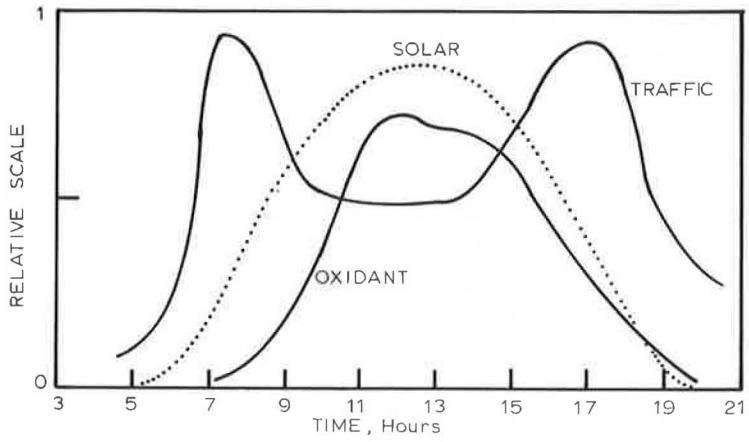


Figure 7. Measured concentrations of NMHC, nitrogen oxides (NO and NO_2), and O_3, at Aerovironment site 23 (June 27, 1976).

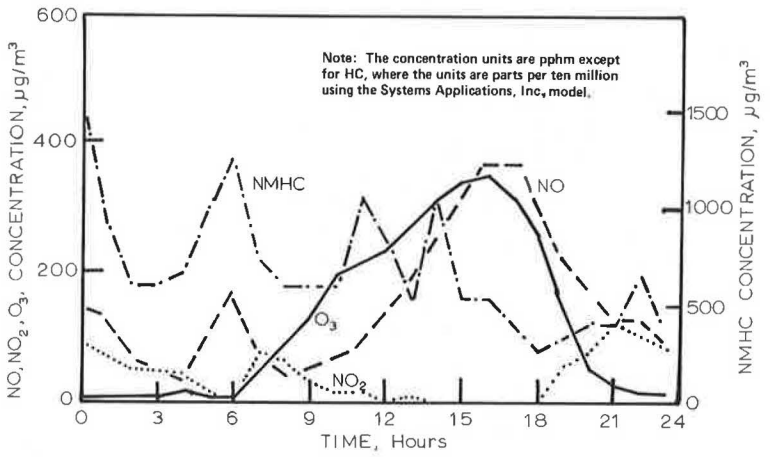


Table 1. Phoenix NMHC emissions.

	Emissions (Mg/d)					
Emission Source	1975	1980	1985	1990	1995	2000
Traffic[a]	131.6	95.9	61.2	43.6	46.5	52.3
Commercial	0.3	0.3	0.4	0.4	0.4	0.5
Industrial	1.3	1.5	1.5	2.1	2.6	3.5
Miscellaneous[b]	45.2	43.6	40.9	38.1	33.5	37.5
Airports	2.6	2.7	2.7	2.8	3.0	3.1
Railroads	2.0	1.8	2.1	2.3	2.5	2.7
Point sources	12.3	12.3	12.3	12.3	12.3	12.2
Total	195.3	158.1	121.1	101.6	100.8	111.8

Note: 1 Mg = 1.1 tons.

[a] Includes some improvements for future projections.
[b] About 50 percent relates to gasoline handling operations.

tion planners is to find out how much more reduction is necessary to comply with air quality standard regulations so that the standards are reached in 1982 and air quality is maintained at that level.

EVALUATION OF NECESSARY REDUCTIONS IN NMHC

The Technical Operations Committee of the AQMA task force selected 1975 as the base year for analysis. The second highest oxidant measurement in 1975 was 250 $\mu g/m^3$ at the central Phoenix station. The use of the Appendix J method (5) to determine the necessary reduction in NMHC to reach 160 $\mu g/m^3$ results in a 38 percent reduction. Table 1 shows that such a reduction is achieved in 1985. Additional controls or transportation strategies are necessary to meet a 1982 deadline.

An alternative to Appendix J is the linear rollback method (6). The necessary reduction for the 1975 base year is 100 $\mu g/m^3$ or 38 percent of the second highest measurement. Roth and others (7) show that linear rollback for concentrations higher than 250 $\mu g/m^3$ results in a smaller reduction in hydrocarbons to meet the standard. In Phoenix, Appendix J or linear rollback gives the same results.

Criticism of the Appendix J and linear rollback methods has been considerable, and other methods of analysis are under study. Most of the current technology is summarized by Roth and others (7). In Phoenix, the question of what to use as a basis for the evaluation is of at least equal importance. Indications are that the EPA western region will require 1977 to be the base year for air quality analysis in Phoenix. No methods use the frequency distribution, although the log-normal curves show that a mean concentration of about 60 $\mu g/m^3$ would be necessary in the summer to reduce the possibility of exceeding the standard to less than 2 percent of the days. Assuming a linear relationship between hydrocarbon emissions and oxidant, a 48 percent reduction from the 1977 average would be required. All of the other methods work on the high concentration days and try to predict the necessary reduction for the second highest day to meet the standard. We have looked at all of the days that exceed the standard over the past 10 years to see if any of the empirical methods correlate with the Phoenix data.

One empirical method is to construct graphs using smog-chamber results. The effect of both nitrogen oxides (NO_x) and NMHC can be evaluated when a mixture is irradiated over a fixed period. When the 6:00 to

9:00 a.m. average NO_x and NMHC are used to predict maximum O_3 concentrations, the predictions are high for Phoenix. For example, in Figure 7 the average NO_x is 300 $\mu g/m^3$ and the average hydrocarbons are 730 $\mu g/m^3$ as carbon over the 6:00 to 9:00 a.m. period. The correlation with smog-chamber results given by Dimitriades (8) gives a maximum oxidant concentration of 600 $\mu g/m^3$ compared to the measured 370 $\mu g/m^3$. For this particular day the reductions in hydrocarbons necessary to meet the standards would be about 65 percent from Appendix J and 70 percent from the smog-chamber results. We assume no change in NO_x, use the smog-chamber studies of Dimitriades, and base the reduction on the hydrocarbon concentration to give 160 $\mu g/m^3$.

Another method used to assess the oxidant control problem is to use actual atmospheric data. That is, curves are constructed of the isopleths of maximum oxidant as a function of 6:00 to 9:00 a.m. NO_x and NMHC. EPA (9) has prepared one such curve using data from Philadelphia, Washington, and Denver. The Phoenix measurements fit well on this correlation, except for cases of high hydrocarbon and low NO_x. Unfortunately, that condition often represents the yearly maximum in Phoenix. There are not enough data at the present time to construct a correlation of this type for Phoenix that will work for the low NO_x state often found. In addition, the air parcel that gives the 6:00 to 9:00 a.m. NO_x and NMHC is not the same as the one that gives the maximum oxidant reading when measurements are taken at a fixed location.

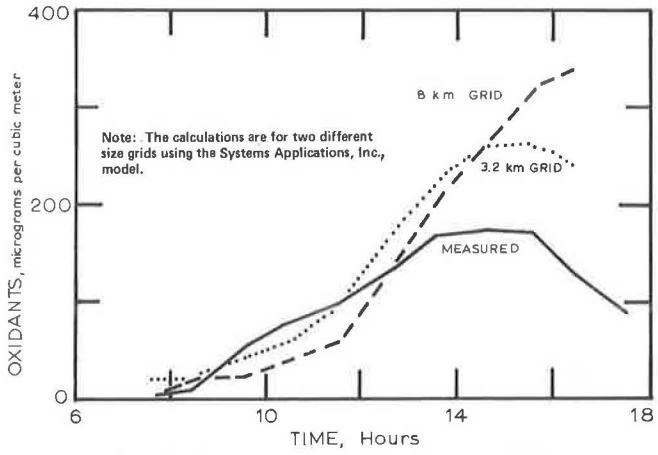
Some of the problems associated with the oxidant control methodologies previously discussed can be removed when a physicochemical model is used. Two studies have been made in Phoenix, one by Aerovironment, Inc., using a trajectory model and one at Arizona State University using a grid point model. The results of the Aerovironment, Inc., study (10) that used a REM-2 to evaluate the environmental impact of a new freeway development will be available in the near future.

The Arizona State University study, supported by the Office of University Research of the U.S. Department of Transportation, uses the Systems Applications, Inc., 1973 model (11, 12) to calculate the photochemical oxidant concentration in Phoenix. Inputs to this model are hourly average wind speed, wind direction, mixing height, traffic emissions, and fixed-source emissions. Only one class of reactive hydrocarbons is considered in this model, so only 15 reactions are used to simulate the atmospheric changes. The emissions were obtained from the AWMA study by Aerovironment, Inc., and the Arizona State Department of Transportation. Several changes were necessary to use the Systems Applications, Inc., model for Phoenix. The original model was set up for Los Angeles, where a constant mixing height is permissible. Major changes were to allow variation of the mixing height and a different treatment of the boundary conditions. Details can be found in the final report (13).

Calculations were made for a typical day in the summer of 1975. The wind speed was set low enough so that the grid map covering the outlined area in Figure 2 could be used: Then the plume created in the morning rush hour stays within the modeling area.

Only a single combination of vertical eddy diffusivity and mixing height has been tested. Results for the central station and for the 3.2- and 8-km^2 grids are given in Figure 8. From 7:00 a.m. through 5:00 p.m., the correlation coefficients were 0.86 for the 3.2-km grid and 0.97 for the 8-km grid compared to measured results for one of the higher oxidant days in August 1975. The preliminary results show a hot spot to the

Figure 8. Measured and calculated oxidant concentrations at the Phoenix central station (August 5, 1975).



west of the central station near the Aerovironment site and another hot spot to the east late in the afternoon.

The Systems Applications, Inc., model calculations show that the western hot spot is 60 percent higher than the central station at 11:00 a.m., 36 percent higher at 12:00 p.m., 22 percent higher at 1:00 p.m., 18 percent higher at 2:00 p.m., and only small amounts higher afterward, when the wind shifts. If the wind dies down before noon and limited upward mixing is present, the hot spot would remain in the same position and have higher readings than the central station. Studies are continuing using a Systems Applications, Inc., model that has improved wind fields and chemical kinetics. Although Figure 8 shows much higher calculated oxidant concentrations than those measured, the magnitude is influenced by the eddy diffusivity. Somewhat higher eddy diffusivities are present in Phoenix than the values used in the study presented in Figure 8. Future upper air measurements in Phoenix should result in data that will improve computer simulations.

STRATEGIES TO ACHIEVE REDUCTIONS

More than a 50 percent reduction in photochemical oxidant concentration is necessary to ensure that the number of days exceeding the standard in any year approaches 1. Evaluation of the necessary reactive hydrocarbon and NO_x reductions would require a computer simulation and extensive measurements of mixing parameters. If the linear rollback method is used, hydrocarbon reductions must be 50 percent and strategies to achieve the 50 percent reduction must be found.

The AQMA task force evaluated several strategies for the reduction of NMHC. Some of the reductions will be the result of normal traffic improvements and land planning in the future and are included in the base in Table 1; others will be the result of an inspection and maintenance program, carpooling, and vapor recovery. The base case gives a 30 percent reduction in NMHC from 1975 to 1982. Inspection and maintenance can be evaluated from current EPA projections and gives an additional 10 percent reduction. Carpooling is expected to have only a 2 percent net reduction in NMHC and phase 1 vapor recovery is expected to have a 3 percent reduction. Phase 1 is the recovery of vapors from filling a service station's main supply tanks. Recovery of vapors from each automobile at the pump is called phase 2. Implementation of phase 2 cannot be completed

by 1982. The net reduction by 1982 is 45 percent, although the real effect on oxidant reduction could be larger. All of the strategies are transportation related and would reduce the 6:00 to 9:00 a.m. peak in a greater proportion than 45 percent. Computer modeling is needed to see if the effects of the high early morning hydrocarbon concentration do, indeed, contribute significantly to the oxidant level when relatively high dilution rates are present after that time.

Maricopa County already has an inspection and maintenance program, and other controls will be recommended for implementation in 1978. Given the limited historical record and the high population growth rate of the area, it is difficult to say if these controls will be enough.

ACKNOWLEDGMENTS

I acknowledge the support of the Office of University Research, U.S. Department of Transportation. Data were supplied by the Arizona Transportation and Health Services Departments, the Maricopa County Health Department, and Aerovironment, Inc. David Chen and Daniel Bradford helped with the analyses.

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Monitoring and Modeling of Resuspended Roadway Dust Near Urban Arterials

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The probability that resuspended roadway dust plays a predominant role in many violations of the ambient particulate standards is now widely accepted. Quantification of this effect is needed before control strategies are developed. In addition, there is increasing concern that strategies should, for reasons of health, also address the respirable fraction of total particulates. This paper describes a twofold approach to the problem of identifying the sources of particulates within the city of Philadelphia and presents selected results from the study. One approach used a sampling program designed to investigate the contribution of traffic-related emissions. Measurements were made using conventional high-volume air samplers at four heights near an intersection and at rooftop level on either side of the main street. The U.S. Environmental Protection Agency dichotomous sampler and the GCA ambient particulate monitor were used to discriminate between respirable and nonrespirable particulates. The second approach used diffusion modeling techniques to calculate the contribution of source categories. Also, a test was conducted to