THE ORIGIN AND FATE OF AIRBORNE POLLUTANTS WITHIN THE SAN JOAQUIN VALLEY

VOLUME 1 - EXECUTIVE SUMMARY

by

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ABSTRACT

A comprehensive field study was carried out in 1978-79 in the San Joaquin Valley to investigate the origin and fate of airborne pollutants in the valley. Specific objectives of the study were to determine the transport/dispersion characteristics and the ventilation budget of the valley together with its air quality and particulate aspects. The field programs which formed the observational base of the study consisted of 17 tracer releases in November-December 1978, July 1979 and September 1979. Each release was supported by special air quality and meteorological sampling. Two additional tracer releases were conducted in February-March 1979.

Air quality emissions in the valley are dominated by TSP and contributions from Kern County. Over 80 percent of the SO_2 in the valley and 40 percent of the TOG originate in Kern County. Particulate emissions from agricultural operations are greatest during planting, growing and harvest seasons. Particulate matter sampled during the study was dominated by soil dust, sulfate, nitrate and carbon.

Late fall and winter are characterized by near-stagnant conditions interrupted by occasional scouring events resulting from frontal passages. Residence time for pollutants released into the valley was estimated to be two to eight days during the winter, depending on release location and existing stability. Principal ventilation mechanisms are upslope flows and limited afternoon flow over the Tehachapi Mountains at the southeast end of the valley.

During summer and early fall, ventilation of the valley is characteristically good. Residence times for pollutants are estimated to be one to two days, depending mainly on release location. Primary mechanism for ventilating the valley is the daytime, northwest flow over the Tehachapi Mountains. Slope flow in the southern half of the valley contributes in a minor but significant manner. During the night this northwesterly flow continues into the northern end of the valley with only slight reductions in magnitude. This nocturnal influx of air is exhausted in the southern

part of the valley by a complex flow pattern in which the Fresno Eddy plays a major role. The northwest flow over the Tehachapis during the afternoon results in significant pollutant impact in the Mojave Desert.

Ozone occurrence in the valley is considered to be primarily an urban center problem rather than a valley-wide phenomenon. No evidence was found for a major ozone impact on the San Joaquin Valley from Bay area emissions although the trajectory of such emissions into the valley was verified.

Primary problems associated with further growth in the valley appear to be associated with the growth of urban centers, the downwind impact of these centers on the foothills of the Sierras and the significant present and future impact of the valley on the Mojave Desert. Sulfate formation during the winter months should receive further attention.

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1. Introduction

An extensive observational study was initiated in 1978 to investigate the origin and transport of pollutants in the San Joaquin Valley. Specific objectives of the study were:

- To investigate the transport and dispersion characteristics into and out of the valley
- To characterize the air quality and the particulate chemistry of the valley.
- To develop an aerometric data base for use in modeling

The program was divided into three intensive field periods: November-December 1978, July 1979 and September 1979.

Participants in the study were Meteorology Research, Inc., California Institute of Technology, Rockwell International, Environmental Research and Technology and the Atmospheric Testing Branch, California Air Resources Board.

The final report on the study comprises seven volumes and three appendices as follows:

Volume 1 - Executive Summary
Volume 2 - Extended Summary and Special Analysis Topics
Volume 3 - Winter Field Study
Volume 4 - Summer Field Study
Volume 5 - Fall Field Study
Volume 6 - Final Report - Rockwell International
Volume 7 - Final Report - Environmental Research and Technology
Appendix 1 - Data Volume - Winter Field Study
Appendix 2 - Data Volume - Summer Field Study
Appendix 3 - Data Volume - Fall Field Study

Surface and pibal wind data have been furnished to CARB on magnetic tape.

Summary material on particulate composition in Section 7 of this volume and the conclusions of particulate analyses in Section 8 were taken directly from the ERT Final Report.

2. Scope

Each intensive observational program included the following components:

- A surface wind network.
- A pibal wind network (3-4 locations during November-December 1978 and nine locations in July and September 1979).
- An acoustic sounder.
- An air quality and tracer sampling aircraft.
- Tracer releases supported by fixed and mobile samplers (five releases in November-December 1978, six releases each in July and in September 1979. A supplementary pair of releases were made in February and March 1979).
- Three air quality vans recording gaseous parameters and obtaining filter samples for particulate chemistry.
- Speciated hydrocarbon sampling (July and September 1979).

The cooperating organizations participating in the study had the following responsibilities:

Meteorology Research, Inc.

Meteorology and aircraft sampling

California Institute of Technology

Tracer release and sampling

Rockwell International

Gaseous air quality sampling

Environmental Research and Technology

Particulate sampling

Atmospheric Testing Branch, CARB

Speciated hydrocarbon sampling and analysis.

All participating organizations performed analyses of their own data and areas of interest.

3. Emissions

Emissions in the San Joaquin Valley total slightly less than generated in the nine Bay area counties. Exceptions are SO_2 and TSP, the latter being more than an order of magnitude larger due to the contributions of cultivated and uncultivated lands. Stationary sources therefore make up the overwhelming bulk of the TSP mass while mobile sources provide most of the CO emissions. In Kern County stationary sources predominate in all emissions with the exception of CO. In other counties the mobile vs. stationary contributions are better balanced. Petroleum processes in Kern County account for about 40 percent of the total organic gases (TOG) in the valley. NO_x emissions are about equally divided between mobile sources and combustion of fuel from stationary sources.

Emissions from stationary sources are not uniformly distributed throughout the valley. Over 80 percent of the SO_2 emissions are centered in the southern end of the valley near Bakersfield with a much smaller cluster of sources near Stockton. NO_2 point source emissions are distributed in a similar manner. Stationary TSP sources are more uniformly distributed within the valley but still cluster in the southern end.

Emissions in the valley show a strong seasonal dependence. Pesticide applications occur throughout the growing season but hydrocarbon emissions from cotton defoliants are a major source only during the winter harvest period. Organic particulate concentrations from agricultural burning occur mainly during the fall. Anthropogenic particulate emissions are largest during field preparation, planting and harvest periods. Fugitive particulate emissions are greatest during the winter season.

4. Winter Valley Characteristics

4.1 Meteorology

Late fall and early winter in the San Joaquin are characterized by stable periods punctuated by occasional cold frontal passages. During these incursions of cold air instability, strong winds tend to scour out the valley, removing most of the pollution which accumulates during the stable periods. Significant increases in visibility are a sensitive indicator of the occurrence of scouring and can be used to assess the typical duration of stagnation periods between scouring events.

During an 11-year period, the maximum duration of stagnation without a scouring event is given in Table 4.1.

Table 4.1

Maximum Duration of Stagnation Episodes
(1967-77)

Stockton	Number of Days
November	10
December	16
Fresno	
November	19
December	19
Bakersfield	
November	14
December	18

Surface winds during the stagnation periods are controlled mainly by local heating and cooling effects. During the night, a pronounced, low-level drainage flow occurs from the slopes into the center of the valley and thence northwestward. A zone of convergence is established in the valley which temporarily may impede the transport of surface layer pollutants across the valley. By mid-morning the downslope flow reverses and northwesterly and upslope winds are initiated. Mixing occurs throughout the valley by late morning.

4.2 Air Quality

Maximum hourly ozone concentrations did not exceed .08 ppm during the November-December field program. CO and NO_x concentrations showed the strong but local influence of urban centers. Pronounced low-level stability resulted in hourly CO concentrations as high as .18 ppm at Fresno. SO_2 concentrations were relatively low except at Fresno-Olive (.12 ppm) and at Oildale (.16 ppm).

4.3 Transport and Ventilation

Two afternoon tracer releases were made near the center of the valley (Chowchilla and Fresno). Tracer material drifted slowly within the valley in response to the light wind conditions. Most of the tracer remained in the valley on the following morning. Upward dilution through the lowest 500-800 m occurred on the second day.

Three afternoon releases were made near the edges of the valley (Bakersfield, Valley Acres and Lost Hills). In each case tracer material was transported toward the slopes of the valley but much of that material returned to the valley floor during the subsequent nocturnal drainage winds. Tracer material released on either side of the nighttime convergence zone appeared on the other side of the zone during the morning after release.

Two tracer tests were carried out from Lost Hills in February-March 1979 under more stable conditions than those encountered during November-December. Flow patterns were similar but weaker than observed in November-December. Ventilation of the valley was slower than in the early winter study. It was estimated that about half of the tracer was removed from the valley within 60 hours after the release.

5. Summer Valley Characteristics

5.1 Meteorology

Intense surface heating characterizes the San Joaquin Valley during July. Mixing depths generally increase to about 1000 m (above ground level) during the afternoon even under episode conditions which are accompanied by warm temperatures aloft.

Wind flow in the valley is controlled primarily by diurnal variations in the surface pressure gradient between the coast and inland desert areas. The average wind flow during July is directed from Stockton to Bakersfield at all hours of the day. During the afternoon the principal outflow for this air is over the Tehachapi Mountains at the southeastern edge of the valley and up the slopes which ring the southern end of the valley. As the low-level air stabilizes in the valley during the evening a nocturnal jet frequently forms with velocities as high as 15 m/s at 300 m above ground level. This jet is an effective transport mechanism and serves to distribute pollutants throughout the valley at levels slightly above the immediate surface layers.

During the evening, low-level stability generally occurs in the southern end of the valley. Air moving rapidly southward is frequently unable to pass over the mountains to the southeast of Bakersfield. Under these conditions, a "Fresno Eddy" forms. Air is diverted cyclonically around the southern end of the valley and moves to the north along the eastern edge. The eddy averages about 1000 m in depth and gradually extends northward as far as Visalia and Fresno by 09 PDT. The eddy serves to transport pollutants from the southern end of the valley to the north.

5.2 Air Quality

Maximum hourly ozone concentrations ranged from .11 to .17 ppm during the July field study period. Lowest values occurred on the west side of the valley. Maximum CO and NO_x concentrations were 5 ppm and .32 ppm, respectively and reflected strong urban sources and peak traffic periods.

5.3 Transport and Ventilation

Two daytime tracer releases were carried out from Manteca during the July field program. In both cases the tracer moved rapidly down the west side of the valley and diluted to the extent that it did not have a significant impact on the following day.

Tracer was released during the late afternoon near Livermore to track the passage of Livermore Valley pollutants into the San Joaquin Valley. The tracer material was transported over and through Altamont Pass but stagnated during the night between Los Banos and Tracy as the evening winds subsided. This material was picked up in the northwest flow on the following day and transported southward.

Tracer material was released from Reedley during the afternoon to investigate upslope transport into the Sierras. The material was carried well up the slope but much of it returned in the subsequent evening drainage flow and stagnated near the foothills.

Tracer was released into the nocturnal jet at 300 m to study the effectiveness of the jet as a transport mechanism within the valley. The material was detected on the following morning at the southern end of the valley. Mixing to ground level did not occur effectively until surface heating developed later in the day.

6. Fall Valley Characteristics

6.1 Meteorology

September is a transitional month in the San Joaquin Valley between the intense surface heating conditions of summer and the more stable conditions of fall and early winter.

General wind flow conditions are very similar to summer but pressure gradients and low-level wind velocities are reduced. Average wind flows are directed from Stockton to Bakersfield at all hours of the day. A nocturnal jet forms on most nights. The Fresno Eddy is also usually present during the night and early morning hours in the southern half of the valley. Principal outflow regions from the valley are similar to summer, i.e., transport over the Tehachapis and up the mountain slopes.

6.2 Air Quality

Maximum hourly ozone concentrations observed during the field program were .17 ppm or less with Arvin frequently reporting the maximum value in the valley. Maximum CO and NO_x concentrations were 6 ppm and .39 ppm with strong urban influences.

NMHC concentrations were measured at Arvin and Lost Hills. Average 06-09 PDT concentrations were .3 ppm at Arvin and 2.9 ppm at Lost Hills. The latter was strongly influenced by proximity to the oil fields. Most of the high concentration at Lost Hills was attributable to paraffins. The more reactive species were present in very small concentrations.

6.3 Transport and Ventilation

Tracer releases during September were made along the edges of the valley at Oildale, Fellows and Lost Hills. During the first two releases from Oildale (07-12 PDT and 02-07 PDT) the tracer material initially moved to the northwest in response to the nocturnal drainage flow. By late forenoon the material was swept up in the daytime northwesterly flow and carried over the Tehachapis into the Mojave Desert. Most of the material could be accounted for in the desert by evening of the day following the release.

Two tracer studies were made from Fellows (07-12 PDT and 01-06 PDT). Material from the first release was transported upslope to the west of Fellows and had minimum ground level impact within the valley. Tracer released earlier in the morning was carried into the valley by the nocturnal drainage flow and transported southeastward over the Tehachapis during the afternoon.

An early morning release from Oildale (22-03 PDT) was carried northward to Delano in the drainage flow and thence moved eastward upslope.

A final release from Manteca (09-14 PDT) was carried rapidly southward along the west side of the valley in agreement with the July releases from Manteca. A significant tracer plume was observed in Bakersfield around mid-day of the day after release.

7. Summary of Results

Primary objectives of the study are listed in the Introduction. In terms of these objectives the following results were obtained:

1. Identify Transport Routes

   The primary transport route into the valley is through the northwestern portion in the vicinity of Stockton. Net 24-hour transport is directed from Stockton to Bakersfield on a mean basis for all months except January and February. During the summer the flux into the valley is directed from the northwest at all hours of the day.

   The primary transport route out of the valley is over the Tehachapi Mountains to the southeast of Bakersfield. This flow contributes significantly to the pollutant burden in the Mojave Desert. The flow over the Tehachapis is most effective during the summer but may be totally ineffective during stagnant winter periods.

   Upslope flow operates during the afternoons throughout the year and is effective in removing pollutants from the edge of the valley. A portion of this material is returned to the valley by the nocturnal drainage winds.

   Ventilation of the valley during the summer leads to a typical residence time of one to two days, depending on release location, for pollutants released into the valley. During the winter, in stagnation periods, typical residence times of two to eight days may be experienced.

2. Particulate Composition

The results of the aerosol study indicate that the particulate matter sampled during short periods of the winter 1978 and summer and fall 1979 were dominated by soil dust, sulfate, nitrate and carbon. This was true of both the particles $\lesssim 20\ \mu m$ aerodynamic diameter, and $\lesssim 2.5\ \mu m$ aerodynamic diameter. Fine particles made up half or less of the material sampled. Sulfate concentrations and carbon were reasonably uniform through the months and locations sampled, but there was significantly more nitrate found in winter than in the summer. Some evidence for enrichment in ammonium was found in the aircraft data. The source contributions of particle samples were estimated by the chemical element balance method. Blowing dust from cultivated and uncultivated land, unidentified carbon sources, and material from atmospheric chemical reactions (ammonium sulfate and nitrate) accounted for most of the material collected.

3. Data Base

An extensive data base has been generated for use in the development of air quality models for the San Joaquin Valley. This base includes the following:

a. Tracer releases - A total of 17 releases were carried out supported by air quality and meteorological sampling. These releases covered the period of November-December 1978 (5), July 1979 (6) and September 1979 (6).

b. Air Quality Observations - In addition to the standard air quality network, three air quality vans were used to obtain hourly observations of SO_2, O_3, NO-NO_x, THC and CO as well as meteorological parameters. 12-hour filter samples were also taken at each site and analyzed for chemical composition.

c. Aircraft Air Quality Observations - An air quality sampling aircraft was used to measure SO_2, O_3, NO_x, NO, b_{scat}, CN as well as turbulence, temperature and dew point meteorological parameters. Flights were made in conjunction with each of the 17 tracer releases to define the vertical and horizontal air quality structure. Both vertical soundings and horizontal traverses were made on each flight.

d. Pibal Wind Observations - Single theodolite pibal observations were made at two-hour intervals during each test for about 36 hours beginning near release time. For the November-December program, observations were made at four locations. During the July and September programs pibal winds were obtained at nine locations on a two-hourly basis.

e. Surface Wind Observations - Surface wind data from 30-35 locations were obtained from a number of different public agencies and private interests. These sources included the National Weather Service, FAA, Getty Oil Company, Arvin Edison Water Storage District, U.S. Forest Service, Shell Oil Company, Belridge Oil Company, Cal Trans, California Division of Forestry, Merced County Fire Department, Lebec Fire Station, Westside Fire District and California Department of Water Resources.

f. Speciated Hydrocarbon Sampling - several locations during July and September.

During the course of the study, a number of potential problem areas were identified which should be considered during the development of control strategies for the San Joaquin Valley:

1. The ozone concentrations in the valley are primarily associated with urban areas and their downwind influences. Only under extreme conditions do they appear to be a valley-wide problem. Evidence was not found of significant impact of Bay area or Delta precursors

on the development of ozone in the valley. Both of these conclusions relate to the large areal extent of the valley and the consequent dilution of the ozone or precursor contaminants.

2. Ozone concentrations in the Sierra foothills are already comparable to values observed in the urban centers. Further growth in the urban areas on the east side of the valley may lead to a disproportionate increase in ozone concentrations along the Sierra slopes due to the time-dependent, reactive nature of the ozone formation process.
3. In the same vein, increased growth in the southern part of the valley will impact significantly on the Mojave Desert due to the photochemical processes which will occur as well as the generally good air quality which the desert now enjoys.
4. Cross-valley mixing from the west side to the east can occur frequently within 24 hours or less in the southern part of the valley. Transport from the east to the west is usually limited by the initiation of northwesterly winds which begin during the day throughout the valley and transport pollutants back toward the southeast.
5. Sulfate formation during winter in the southern part of the valley appears to be associated with stagnant conditions and high moisture content. Low pH values should also be expected in the fog. There was no opportunity in the present program to investigate the sulfate episodes but an increasing problem can be expected in view of the current oil field developments.

6. Regional modeling of the valley for the purpose of developing a control strategy may be very difficult. During the summer a complex, dynamic flow pattern develops in the southern part of the valley which will be difficult to describe computationally. During the winter, the principal problem will be meandering winds and a lack of organized flow during the stagnant episodes when the modeling results are of most interest.

8. Conclusions

8.1 Winter

1. During the winter, near-stagnation conditions may exist as a result of extreme stability in the valley. These periods of relatively stagnant conditions are interrupted only by the occasional passage of low pressure frontal systems through the valley.
2. The stagnant atmospheric conditions observed during the winter can lead to significant carryover of pollutants into days subsequent to their release. Under the most stable conditions encountered during the test program, about one-half of the tracer material remained in the valley 60 hours after the start of a 12 hour release.
3. The predominance of nighttime drainage flows compared to slope flows limits the surface level ventilation of the valley. The drainage flows also serve to enhance the cross-valley mixing of pollutants.
4. Significant horizontal and vertical variations in the generally light winds can spread pollutants over wide areas, and even cause bifurcation of individual pollutant plumes. Light winds, often below typical measurement threshold velocities, can serve to mix pollutants rather uniformly over wide areas.
5. Rainfall and irrigation sources contribute to extensive and persistent fogs in the valley during the winter months. The chemistry of these fogs was not examined but may lead to considerable sulfate and/or sulfuric acid production in view of the long residence times associated with stagnant conditions.
6. Maximum ozone concentrations measured during the November-December field program did not exceed 0.08 ppm. Timing and distribution of CO and NO_x peaks indicated that these pollutants primarily resulted from local mobile sources. Peak SO_2 concentrations were generally observed in locations downwind of known stationary sources.

8.2 Summer and Early Fall

1. During the summer and early fall, the air flow within the valley is directed from Stockton to Bakersfield at all hours of the day.
2. Pollutants transported from the northern boundary of the valley preferentially impact the western side during transport to the southern end.
3. In the daytime, the influx of air at the northern end of the valley is balanced by the efflux of air passing upslope over the ridges at the southern end of the valley.
4. The afternoon flow over the mountains that form the southern boundary of the valley results in a significant impact of valley pollutants upon the air quality in the Mojave Desert. The transport of valley pollutants into this receptor region is a cause of the rapid decrease in visibility in the northern Mojave Desert near nightfall.
5. The afternoon upslope flows on both sides of the northern valley also serve to remove pollution from the edges of the valley. However, some of the material carried upslope may be returned in the subsequent drainage flow. This may give rise to an effective stagnation condition in the valley or foothills and a resulting increase in the total dosage of pollutants.
6. During the evening, stabilization in the surface layer of the valley, frequently leads to the formation of a nocturnal wind jet with winds as high as 15 mps at 300 m altitude near Fresno/Los Banos. The nocturnal jet can transport pollutants that have mixed upward during the previous day to the southern end of the valley by the following morning. The ground-level impact of these pollutants is limited, however, until fumigation occurs as the mixing height grows during the subsequent afternoon.

7. The afternoon flow over the southern boundary of the valley is cut off in the low levels during the night. As a result, a cyclonic eddy forms in order to balance the influx of air at the mouth of the valley. The eddy extends northward during the night and becomes the "Fresno Eddy." During the night and morning hours, the Fresno Eddy can effectively distribute pollutants from the southern part of the San Joaquin Valley to the north.
8. The Fresno Eddy and the nighttime drainage flows contribute to cross-valley mixing. Transport from the west side of the valley to the east was observed by mid-morning in spite of a convergence zone in the center of the valley during most of the night.
9. Maximum ozone concentrations detected during the July and September field programs were 0.17 ppm, with Arvin frequently reporting the highest values within the valley. Maximum CO concentrations ranged from 1 to 6 ppm while from .17 to .39 ppm NO_x were observed. NMHC concentrations varied depending on the proximity and strength of a source area, from .3 ppm at Arvin to 2.9 ppm at Lost Hills during September. The concentration of reactive hydrocarbons was quite low throughout the valley.

8.3 Particulates

1. Concentrations, composition and sources of the particles vary more with time of year than with location.
2. Total particle (aerodynamic diameter below ~20 μm) mass concentrations measured in the lower half of the San Joaquin Valley were about the same during the winter (November-December 1978) and fall (September 1979) sampling periods. Concentrations measured in the northern half of the valley during the summer sampling period (July 1979) were lower than those measured in the southern half of the valley during the fall and winter.

3. The major sources of the total particle mass varied from one season to another. During the winter, sources of carbon, ammonium nitrate, ammonium sulfate and fugitive emissions of dust accounted for most of the measured mass, on the average. During the fall, the contribution from fugitive dust emissions increased substantially while the contribution from sources of ammonium nitrate decreased. Sources of ammonium sulfate and carbon also contributed substantially to the fall samples. Major contributors to the samples collected during the summer month were similar to the contributors to the fall samples.
4. Direct emissions of particles from motor vehicles and from oil combustion were always minor in their contributions to total particle mass concentrations given available data and emission composition. The contributions of nitrogen oxide and sulfur dioxide emissions from these sources to particulate nitrate and sulfate were not assessed.
5. Fine particles (aerodynamic diameter below $\sim 2.5\ \mu m$) comprised about 45 percent of the total particle mass during the winter, and about 30 percent of the total particle mass during the other seasons.
6. During the winter period, the major contributors to fine particle mass were sources of ammonium nitrate, ammonium sulfate and carbon. Fugitive dust emissions contributed little to the fine particle mass. During the other two seasons, sources of ammonium sulfate and carbon and fugitive dust emissions contributed substantial amounts to the fine particles. Direct emissions of particles from motor vehicles and oil combustion contributed only minor amounts to the fine particle mass. Contributions of nitrogen oxides and sulfur dioxide emissions from motor vehicles and oil combustion to sulfate and nitrate were not assessed.
7. A substantial fraction of the fine particle mass (30 to 50%) was not accounted for by the sources included in the calculations made in this study. This fraction may be comprised partly of water in the particles.

Additional efforts to better identify the sources of the suspended particles should include:

1. More extensive characterization of the chemical composition of fugitive dust emissions in terms of spatial variations and seasonal variations throughout the valley. Important factors to be considered in this characterization are variations in land use and fertilizer application.
2. An attempt to identify the sources of carbon in the particles. These efforts should include investigations of atmospheric conversion of gases to particulate-phase organic compounds in the San Joaquin Valley and an attempt to better determine contributions of vegetative burning, fossil fuel combustion and diesel vehicle emissions to carbon concentrations. Since carbon represents a major unidentified contribution to the particle concentration, special investigations to determine the emission composition for oil combustion sources under operating conditions in the San Joaquin Valley should be undertaken. These studies should be planned to separate elemental carbon vs organic material for future use in visibility studies.
3. Obtain more extensive data about the chemical composition of the suspended particles to allow more reliable determination of seasonal averages.
4. Further investigation of the formation of secondary sulfate and nitrate in the San Joaquin Valley should be carried out. Such an investigation should be directed at quantifying the contributions of sources of sulfur dioxide and nitrogen oxides to particulate sulfate and nitrate.