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STUDY OF PARTICULATE EPISODES AT MONO LAKE

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PROJECT SUMMARY

The goals of this study were to --

1. Evaluate the frequency and severity of elevated dust (Total Supsended Particulates, TSP) episodes in the vicinity of Mono Lake,
2. Understand the physical and chemical nature of the particulate matter,
3. Determine the sources of the particulates and the suspension mechanisms responsible for elevated dust levels,
4. Establish the connection between particulate levels and local meteorology.

During the course of the work, adequate progress was made on these primary goals to allow us to develop a computer model to--

5. Predict changes in dust episodes as a function of the water level in Mono Lake, and
6. Discuss the nature and effectiveness of possible mitigation measures.

In order to achieve these goals, extensive measurements were made of particulate matter at two locations near Mono Lake that represent generally upwind and downwind sites with regard to strong (dust raising) wind conditions. Continuous 24 hour and 8 hour size-selective samplers were used for 8 months at these sites. Additionally, battery-and solar-powered units were developed at Davis and deployed during dust events to measure the spatial extent and magnitude of the dust clouds. Meteorological data were taken from monitors at the lake, and an intensive meteorological study was made at the Simis ranch in August and September, 1982. Elemental analyses were made of the particles by size catagory, and elemental and chemical studies were also made of local soils and playa materials. Data were also derived from the Great Basin Valleys APCD, our participation in the Lands Commision Owens Lake study, as well as photographs from the Los Angeles Department of Water and Power, the Mono Lake Committee, and our own work. The interpretation included in this study also draws upon the results of our two prior studies for the ARB at Owens and Mono Lakes. A semi-empirical computer model was developed and calibrated using dust levels measured at both lakes and at sites up to 75 miles downwind.

1. Frequency and severity of dust episodes

Two multi-year records of dust episodes near Mono Lake have been generated--data on total suspended particulates (TSP) taken with standard Hi-Vol samplers by The Great Basin Valley APCD, and a set of daily colored photographs taken by the Los Angeles Department of Water and Power.

Great Basin Valley's APCD (GBVAPCD) Particulate Monitoring. Table 3.2 shows the results of standard total suspended particulate measurements in the period from 1979 to 1983 at two sites near Mono Lake (Lee Vining and Binderup/Simis) and one near Owens Lake (Keeler). The TSP results show that particulate air quality at Mono Lake is among the very best in California when non-dust conditions occur; yet among the very worst during the relatively infrequent severe dust episodes. Sites downwind of Owens Lake (Keeler) and Mono Lake (Binderup/Simis) approximate or exceed the federal emergency level of 1000 ug/m^3 on 5% of all days--833 ug/m^3 at Mono and 1198 ug/m^3 at Keeler in the period 1979 - 1982. In most years, these two sites had the highest measured 24-hour TSP levels in California. Geometrical mean TSP values are not high, however, since TSP levels are very low in the far more common non-episode conditions.

Los Angeles Department of Water and Power photographic study. An extensive photographic record of Mono Lake, taken daily at a site near Lee Vining, has been generated by the Los Angeles Department of Water and Power (LADWP) for the period from February 22, 1980 through February 21, 1984. Of the photographs taken, 1,412 were of adequate quality to allow the LADWP to classify them into four catagories:

Clear	(89.4 % of all photos)
Faint Dust	(6 % of all photos)
Recognizable Dust	(3.3% of all photos)
Extensive Dust	(1.3% of all photos)

c) Correspondence between TSP and photographic catagories. The correspondence between these two statistically extensive data sets is given in Table 3.3. The district TSP measurements were made only on the standard one-day-in-six schedule, but adequate data exist to match the LADWP percentages of occurence for each visual dust catagory to district TSP measurements. These are given in Table 3.3, and graphed in Figure 3.2.

The "Clear" catagory, occurring 89% of all days, averages 17 ug/m^3 TSP, a level as low as the cleanest sites in California. The "Faint Dust" catagory, occurring 6% of all days, averaged 227 ug/m^3 TSP, or more than twice the state 24-hour TSP standard. The "Recognizable Dust" catagory, occurring 3.3% of all days, averaged 502 ug/m^3 TSP, or five times the state 24-hour TSP standard. Finally, the "Extensive Dust" catagory, occurring 1.3% of all days, corresponded to 1825 ug/m^3 TSP. The qualitatively greatest dust event of the past three years, November 29, 1980, included in the LADWP photographic survey, was not sampled by the district Hi-Vol, but our measurements gave an approximate value of 3300 $ug/m^3 \pm 400$ ug/m^3 for that day.

Since the "Recognizable Dust" and "Extensive Dust" catagories of the LADWP add up to 4.6% of all days, they can be compared directly to the "Highest 5% of all days" catagory of Table 3.2, giving an average value of 833 ug/m^3 TSP value in these conditions. The corresponding TSP value for the highest 5% of days at Owens Lake was 1198 ug/m^3.

2. Physical and chemical nature of particulate matter

Data on particulate size generated in this study show that fine particulate matter, below 2.5 um diameter, usually reaches only very modest levels, even in dust episodes. Fine mass at all sites near Mono Lake is dominated by sulfur-containing particles at levels similar to other Sierra sites, 0.48 ± 0.03 ug/m^3 of sulfur or about 1.5 ug/m^3 of sulfate (six month summer average of four sites). Little or no lake impact is seen in this fine mode. Coarse particle modes during non-episode conditions occur at low levels, and are dominated by local soils with some persistent but minor contribution from lake bed sources. Particles of the dust episodes, which in this study are between 2.5 and 15 um diameter and are thus inhalable, are dominated by materials from the lake playa areas, not the non-lake soils in the surrounding area. This conclusion is supported by:

1. Photographic evidence from the LADWP, Mono Lake Committee, our photographs, and the geological literature
2. Upwind-downwind ratios, normally between Lee Vining and eastern sites of the basin (Binderup/Simis) but occasionally the inverse, showing essentially all of the dust episodes are dominated by lake bed sources, with little transport into the basin or local soil impact
3. Size and compositional studies of dust episodes, which set upper limits to the non lake bed sources in the episodes
4. Meteorlogically correlated particulate sampling, showing the short term generation of dust particles from playas.

A summary of the photographs is included in Appendix B of the full report. The following table gives all simultaneously measured upwind-downwind ratios at Mono Lake, TSP > 120 ug/m^3.

Total Suspended Particulates

Date	Lee Vining	Binderup/Simis
August 19, 1979	17 ug/m^3	266 ug/m^3
October 24, 1979	15 ug/m^3	193 ug/m^3
November 17, 1979	7 ug/m^3	481 ug/m^3
June 2, 1980	1 ug/m^3	136 ug/m^3
November 29, 1980	6 ug/m^3	3300 $\pm$ 400* ug/m^3
But, also notice —		
March 28, 1980	131 ug/m^3	17 ug/m^3

* estimated from non Hi-Vol samplers and model

Studies of intensive episodes included measurements of both composition and downwind mass levels out to Cedar Hill, 8 miles northeast of Mono Lake and close to the Nevada state line. (Table 3.7) Studies were made of the possible chemical states of the dominant alkaline salts, including sodium sulfates, gypsum, trona, sylvite, and other minerals similar to those reported earlier of Owens Lake and Deep Springs Lake.

A number of potentially toxic elements were seen during the study, in both playa materials and dust episodes. These include selenium, arsenic, mercury, and lead. A special study was focused on arsenic content. Levels of arsenic in the playas were found in four separate studies to be in the range of 20 to 60 ppm, while dust episodes had measured arsenic levels of (30 $\pm$ 10) ng/m^3 at Keeler and (22 $\pm$ 10) ng/m^3 at Mono Lake. The precise chemical state of the arsenic in the highly basic alkaline salts was not determined.

3. Sources and suspension mechanisms for dust episodes

The dust problem involves the combination of an elevated wind threshold (25-3Ø mph) characteristic of large sand particles, and observations of fine dust particles (5-15 um) which, if lying on the ground, could be resuspended at wind velocities of only a few mph. A hypothesis was developed based on earlier work by this group and wind tunnel studies by Dale Gillett at Owens and other dry saline lake beds. It was found that the efflorescent crusts that grow above the briney mud, although fragile, are very hard to resuspend--even with strong winds. The answer appears to lie in the key role of saltating large particles that bounce along the ground breaking off and grinding up these fragile efflorescent crusts. This hypothesis is strongly supported by measurements made for the California Lands Commission and its subcontractor (Westec) on Owens Lake. During three severe 6-hour episodes, measurements of TSP at 2 meters above the lake averaged about 4Ø,ØØØ ug/m^3. The composition had far more coarse sand and large broken salt particles than measurements made away from the lake bed at Keeler and Lone Pine.

Thus, the mechanism for initiating a dust episode requires five conditions be met:

1. Wind velocity above some threshold, about 25 mph, generally associated with passage of a synoptic weather front and sudden change of barometric pressure;
2. High wind shear at the surface due to lack of obstructions and terrain relief;
3. Adequate fetch across the playas, since photographs show that it takes between 1 and 2 miles before dust events initiate;
4. Coarse particles must be present to grind up the efforescent salt crust which, by itself, can hardly be resuspended at any wind speed, and
5. The efforescent crust itself, easily broken into the 5 to 2Ø micron particles (alkaline-salt) observed in the dust (salt) plumes.

4. Connection between particulate levels and local meteorology

No strong association between synoptic weather and Mono dust episodes was found, other than they generally occur in strong westerly winds following a sharp drop in barometric pressure after passage of a front. More measurements are needed to determine the wind threshold for initiating dust events at Mono Lake; it appears to be slightlly higher than observed at Owens Lake, or around 25 mph. A micrometeorological intensive study documented the low zero-plane displacement paramenter Z_o, leading to high wind shear across the playas.

5. Computer modeling of changes in dust episodes as a function of water level

A computer model was developed using all the above information in order to predict dust levels at the lake and up to 150 miles downwind. This model, the Mono-Owens Davis Dust Model (MODDM), was applied to both Owens and Mono Lakes, and includes predictions of TSP values as a function of wind direction,length of playa, fetch, and lake elevation. This model was based on the known physics of blowing sand, calibrated in TSP magnitude against district Hi-Vol readings for the 5% highest days, and calibrated for fall-off of concentrations versus distance on four fully measured alkaline/saline dust events from Owens Lake to Bishop (75 miles) between 1979 and 1982. Thus, all predictions are based on data taken under similar or identical circumstances to those observed at Mono Lake. The predicted TSP mass contours for the worst 5% of dust episodes are shown in Figure 4.2, using the 1981 lake level. Using the stabilization level with diversions of 6330 feet, the predicted values for the 5% worst days rise by 180% (north playa), 480%, (Paoha Island transect), and 1090% (south playa), due to the rapidly increasing linear fetches and the decreasing water particulate sinks. (Figure 4.3)

6. Nature and effectiveness of possible mitigation measures

Since the causes of the dust episodes near Mono and Owens lake are clearly associated with the rapid lowering of lake levels, the most effective mitigation measures would be a raising of lake levels to cover playa areas. This, in fact, occurred to some degree at Mono Lake in 1982-1983, when the lake rose about nine feet. Owens Lake had very bad dust levels in 1982, worse than Mono, while in 1980, when Mono Lake was at its historically low level, Mono dust events were worse than Owens. Perhaps too few events were recorded to give statistical weight to these results, but it is in semiquantitative agreement with the model, since the higher 1982 Mono Lake level flooded a depression (marked "C" on Figure 4.2) and cut the major Mono dust fetch in two. For sake of argument, the MODDM model was also run for Owens, with two miles of water placed 2/3 of the way across the lake. Predicted dust levels at Keeler decrease by a factor of 2 for the 5% highest days. Emplacement of this water barrier may not be as difficult as it seems, if the laser-leveling techniques used in Northern California rice fields would be applied to making a series of shallow, alkaline ponds across Owens. The recent wet years have done almost half the job already.

Of the five conditions required for a dust episode, condition 1 (synoptic weather) is impossible to control; condition 5 (efflorescent crust) is very hard to control, since the wet alkaline muds beneath the surface would defeat all but the most expensive "paving" efforts, while fully drying the lake, an expensive proposition, would make matters far worse for decades before mitigation might occur, based on the Owens experience. Likewise, condition 3 (fetch) is hard to control except by adding water to the lake. Condition 2 (wind shear) can be lowered by placing obstructions such as snow fences, while condition 4 (coarse particles) could be controlled by either sand traps (fences or water barriers, or other such mechanisms) or by controling coarse particle sources at the edge of the playas. Controling coarse particles at Mono would be fairly easy if the lake is high since the fetches are long but narrow.

STUDY OF PARTICULATE EPISODES AT MONO LAKE

TABLE OF CONTENTS

List of Acronyms Used in this Report

Analytical Techniques

FAST = Forward Alpha Scattering Techniques (H to F)

LIPM = Laser Integrating Plate Method (C soot)

PIXE = Particle Induced X-ray Emission (Na to U)

XRF = X-Ray Fluorescence (Ca to U)

Sampler Systems

BPU = Battery Powered Unit

Multiday = Air Resources Board's Multiday Monitoring Impactor

SFU = Stack Filter Unit

SPASI = Solar Powered Air Sampling Impactor

Other

AQG = Air Quality Group

ARB = Air Resources Board

CNL = Crocker Nuclear Laboratory

GBVAPCD = Great Basin Valleys Air Pollution Control District

LADWP = Los Angeles Department of Water and Power

MODDM = Mono-Owens Davis Dust Model

TSP = Total Suspended Particulate Matter

LIST OF TABLES

LIST OF FIGURES

List of Appendices

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This study could not have been performed without the effective assistance of the personnel of the Great Basin Valley's Air Pollution Control District, especially Chuck Fryxell and Bill Cox, who handled most of the on-site labor. The APCD also provided us with their Hi-Vol particulate data. We would like to thank the Simis' and the Hansen's for providing secure sites and assistance. Steve Catton, Sam James and others performed much of the work of sampling the dust episodes. Bruce Kuebler of the Los Angeles Department of Water and Power was kind enough to provide data on their photographic summary at Mono Lake. Members of the U.C. Davis Air Quality Group provided invaluable assistance, especially Bob Eldred, head of Analytical Services at CNL, Dave Braaten, who coordinated the intensive meteorological data acquisition, Lowell Ashbaugh who handled synoptic meteorology, Kathleen Cortese who performed the chemical analysis of the lake bed playas and Joan Hancock who carefully prepared the manuscript. Finally we wish to acknowledge the continuing support of the Research Division of the California Air Resources Board, especially Jack Suder, who stayed with us through the Owen's and Mono Lake studies while we developed new instrumentation and a better understanding of the air quality in these important areas.

1. INTRODUCTION

Mono Lake is one of several saline lakes that exist along the arid eastern escarpment of the Sierra Nevada range. Located east of Tioga Pass near Yosemite National Park, Mono Lake is really an inland sea, because no rivers ever leave it, they only feed it. Several small streams have been depositing minerals in the Mono basin for at least 700,000 years, making the water so strongly alkaline that no fish can live in it. Over the last 40 years the lake's level has been dropping rapidly, due to the diversion of most of its tributaries, which uncovers more and more of the lake's ancient alkali bottom. On many occasions, alkaline dust is whipped into the air to the concern of residents of the basin and regulatory agencies.

In order to obtain quantitative data on air qualilty in the Mono Lake area, hundreds of air samples were taken and characterized by size, mass, and elemental composition over an 18 month period, from May 1, 1982 to Dec 15, 1983, as part of the present study. Surface materials were collected from the exposed lake bed and surrounding soils to establish the sources of the episodes. Data have also been generated as part of our prior studies of Mono Lake for the ARB, (MONO 1) and in two studies of dust episodes near Owens Lake, one we did for the ARB (OWENS), and one done by WESTEC for the State Lands Commision, in which we participated (WESTEC). Data from the Great Basin Valley's Air Pollution Control District's TSP data, and an extensive set of photographs from the Los Angeles Department of Water and Power were used to establish the frequency, severity, and extent of dust episodes, the sources of the observed dust, and its association with soils, terrain, and meteorology.

The task was made more complex by the nature of the problem and a number of apparent paradoxes. The infrequent nature of the episodes required a continuous sampling routine so that no event was missed, yet continuous electrical power was not available at some sites near the lake. Previous studies had shown that the playa was much harder to resuspend than the surrounding soils; however, chemical and photographic studies had shown that it was the playa and not the non-lake soils that caused the dust episodes, or "salt storms". The threshold wind velocity for initiating an episode was characteristic of a large (100 to 200 micron) diameter particle, but the measured size distributions in the dust peaked somewhere near 10 microns.

In this study we have tried to make those measurements that would complement the data from our two earlier reports at Owens and Mono Lake as well as several other important sources, in order to help solve some of these problems. Enough was learned about the specific requirements for Mono Lake's dust storms to generate a computer model that matches the data at Owens and Mono Lakes, and predicts dust levels under various meteorological and lake level conditions. Several mitigation measures were eveluated through the model.

2.0 DATA COLLECTION, SAMPLE ANALYSIS, and QUALITY ASSURANCE

Table 2.1 summarizes activities performed during this study. These activities and their full results are grouped in the Appendices, under the appropriate headings. Details of aerosol sampling, sample analysis, and quality assurance can be found in the Appendices and the relevant Air Quality Group publications listed in the bibliography.

TABLE 2.1 Summary of Research Activities

A. Development of instrumentation

a) Battery Powered Unit (BPU)
Portable sizing sampler based on the stack filter unit (SFU)
Duration: 2 hours to 2 days per sample
Size cuts: 15 um to 2.5 um
2.5 um to 0 um

b) Solar Powered Air Sampling Impactor (SPASI)
Portable solar and battery powered
Duration: 30 days/revolution, 10 hour resolution (84 samples)
Size cuts: 15 um to 0.25 um

c) System to analyze SPASI strip samples by PIXE
5 to 10 hour resolution
PIXE analysis, sodium to uranium
Sensitivity (avg.) 0.1 ug/m^3

B. Aerosol sampling and analysis

a) Monitoring at Hansen's ranch 5/1/82 - 12/1/82
ARB Multiday Impactor
Duration: 7 months, 24 hour resolution (555 samples)
Size cuts: 15 um to 3.5 um
3.5 um to 0.5 um
0.5 um to 0 um

b) Monitoring at Simis' ranch 11/15/82 - 12/15/82
SPASI unit
Duration: 30 days, 10 hour resolution (72 samples)
Size cut: 15 um to 0.25 um

c) Dust episode sampling, 1982
5/08, 5/15, 5/31, 7/07, 7/18
8/28, 8/29, 8/30, 8/31, 9/01

Total Samples collected 627
Total Samples analyzed 338

C. <u>Onsite micrometerological study</u>

Simis ranch 8/28/82 - 9/01/82

Two-meter instrument tower
wind speed, wind direction, temperature, relative humidity

Ten-meter instrument tower
wind speed, wind direction, temperature

Acoustic sounder

Pilot balloons

D. <u>Analysis of soils and efflorescent crusts</u>

Chemical states of arsenic

Lake and non-lake dust sources

E. <u>Development of semi-emperical computer model for Owens and Mono Lake</u>

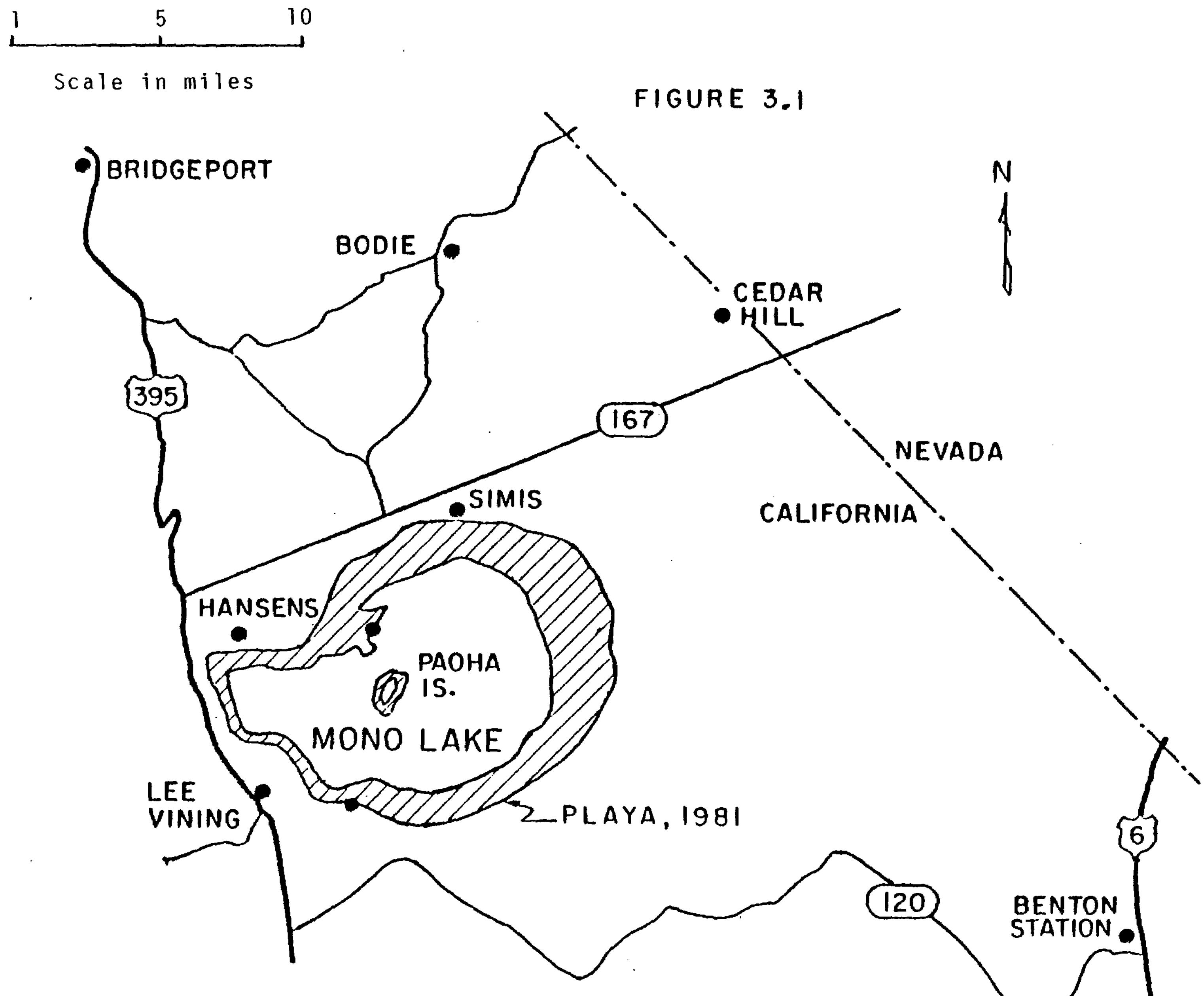
Mono-Owens Davis Dust Model (MODDM)

Spatial profiles calibrated to 75 miles downwind using three dust episodes, Owens Valley 4/79

Concentrations calibrated to Owens and Mono Lake values, worst 5/5 of days

Applied to Mono Lake for various wind directions, fetches and water levels

F. <u>Analysis of mitigation measures</u>



MONO LAKE AND VICINITY

FIGURE 3.1 Map of MonoLake and vicinity, with air sampling sites

3.0 RESULTS AND INTERPRETATION

3.1 Frequency and severity of particulate episodes

Statistical record of total suspended particulates The California Air Quality Data, 1979 through the first quarter of 1983, is the best statistically-valid summary of suspended particulate matter near Mono Lake. Table 3.1 summarizes the TSP values recorded by district Hi-vols's from 1979 through 1983. Included in this table are 78 measurements by high volume (Hi-vol) samplers downwind of Mono Lake (Simis ranch and nearby Binderup ranch), as well as 197 measurements made at Lee Vining (a site generally upwind of dust events). The 327 measurements at Keeler (downwind of Owens Lake) are included, since the effect of lowering Mono Lake is to increase the resemblance of Mono Lake to Owens (Dry) Lake. A summary of the frequency and severity of 24-hour TSP episodes at Mono and Owens Lake is given in Table 3.2. These data clearly indicate that both the frequency and severity of the dust episodes downwind of Owens and Mono Lakes are comparable, with Owens Lake having about 20% higher TSP levels. In most years the severity of these dust episodes has led to the highest recorded particulate levels in California, with values occasionally even exceeding the federal emergency level of 1000 ug/m^3, not to mention the California 24-hour TSP standard of 100 ug/m^3. (Appendix A)

Statistical record of visible dust episodes The frequency and severity of dust episodes near Mono Lake have also been studied by the Los Angeles Department of Water and Power (LADWP) by using a series of 1412 photographs that were taken daily at Lee Vining, facing east,

Table 3.1 Summary of 24-hour total suspended particulate values (TSP in ug/m^3) recorded by GBVAPCD Hi-volume samplers during 1979, through 1983 at Mono Lake (Lee Vining, Binderup ranch and Simis ranch) and Owens Lake (Keeler).

	Highest	Next Highest	Geometric Mean	Number of Observations >100	>150	>260	>375	Total
Mono Lake								
Lee Vining (upwind)*								
1979**	100	94	22	1	0	0	0	50
1980	131	73	15	1	0	0	0	38
1981	64	64	29	0	0	0	0	54
1982	60	57	21	0	0	0	0	53
1983***	61	33	45	0	0	0	0	2
								197
Binderup/Simis (downwind)*								
1979	481	266	102	4	4	2	1	11
1980	1825	352	44	5	3	3	1	24
1981	113	10	—	1	0	0	0	6
1982	673	34	16	1	1	1	1	34
1983	20	12	13	0	0	0	0	3
								78
Owens Dry Lake								
Keeler								
1979	1865	1247	39	9	8	6	5	91
1980	1244	1106	41	10	9	7	5	63
1981	983	871	43	9	7	7	5	67
1982	3295	2181	48	19	13	9	8	85
1983	919	455	32	2	2	2	2	21
								327

* Compared to most dust-raising wind conditions, defined photographically.

** Six months

*** Three months

(1) California Air Quality Data Vol. XI, XII, XIII, XIV, XV

(2) Arithmetic mean, Mono Lake, 1979-1983, = 65 ug/m^3, compared with 43 ug/m^3 geometric mean

Table 3.2 Frequency and severity of occurance of dust episodes near Mono and Owens Lakes, 1979-1983 (1)

	Mono Lake		Owens Lake
	Lee Vining (upwind)	Binderup/Simis (downwind)	Keeler (downwind)
1. Worst day measured 1979 to 1983	131 ug/m^3	3300 ug/m^3 *	3295 ug/m^3
2. Worst 1.3% of all days, 1979 to 1983	108 ug/m^3	1825 ug/m^3	2196 ug/m^3
3. Worst 5% of all days, 1979 to 1983	75 ug/m^3	833 ug/m^3	1198 ug/m^3
4. Worst 11% of all days, 1979 to 1983	58 ug/m^3	530 ug/m^3	630 ug/m^3
5. Remaining 89% of all days, 1979 to 1983	22 ug/m^3	17 ug/m^3	26 ug/m^3
Sampling days	197	78	327

(1) Based upon all 24-hour days measured by Great Basin Valley District Hi-Volume samplers, generally operated on a one-day-in six pattern

* Measured by Davis Sampler and corrected to equivalent Hi-Volume value. Estimated uncertainty, ± 400 ug/m^3. Not included in statistical summaries since it was not taken randomly

between February 22, 1980, and February 21, 1984. The photographs are classified by LADWP personnel into four categories:

Clear	89.4% of all days
Faint dust	6.0% of all days
Recognizable dust .	3.3% of all days
Extensive dust	1.3% of all days
	100 %

In Table 3.3 and Figure 3.2 these categories are matched by percentage of occurance to the corresponding particulate levels at the sites downwind of Mono and Owens Lakes. On those days that any dust at all was observed by the LADWP (extensive, recognizable, or faint), which occurred 11% of all days, the 24-hour mean particulate values averaged 530 ug/m^3, or more than five times the California 24 hour standard. For those days on which no dust was observed the TSP values averaged 17 ug/m^3, which is very clean air for California.

3.2 Sources of particulate matter at Mono Lake

Particulate matter at sites near Mono Lake could, in principle, be either generated locally or transported into the basin. Either of these, in turn, could be natural in origin or due to man's activity. In this and our previous reports, monitoring of particulate matter was done both at sites near Mono Lake and other sites well removed from the area, including Bridgeport, Bodie, and Benton, to help clarify the relative importance of these sources.

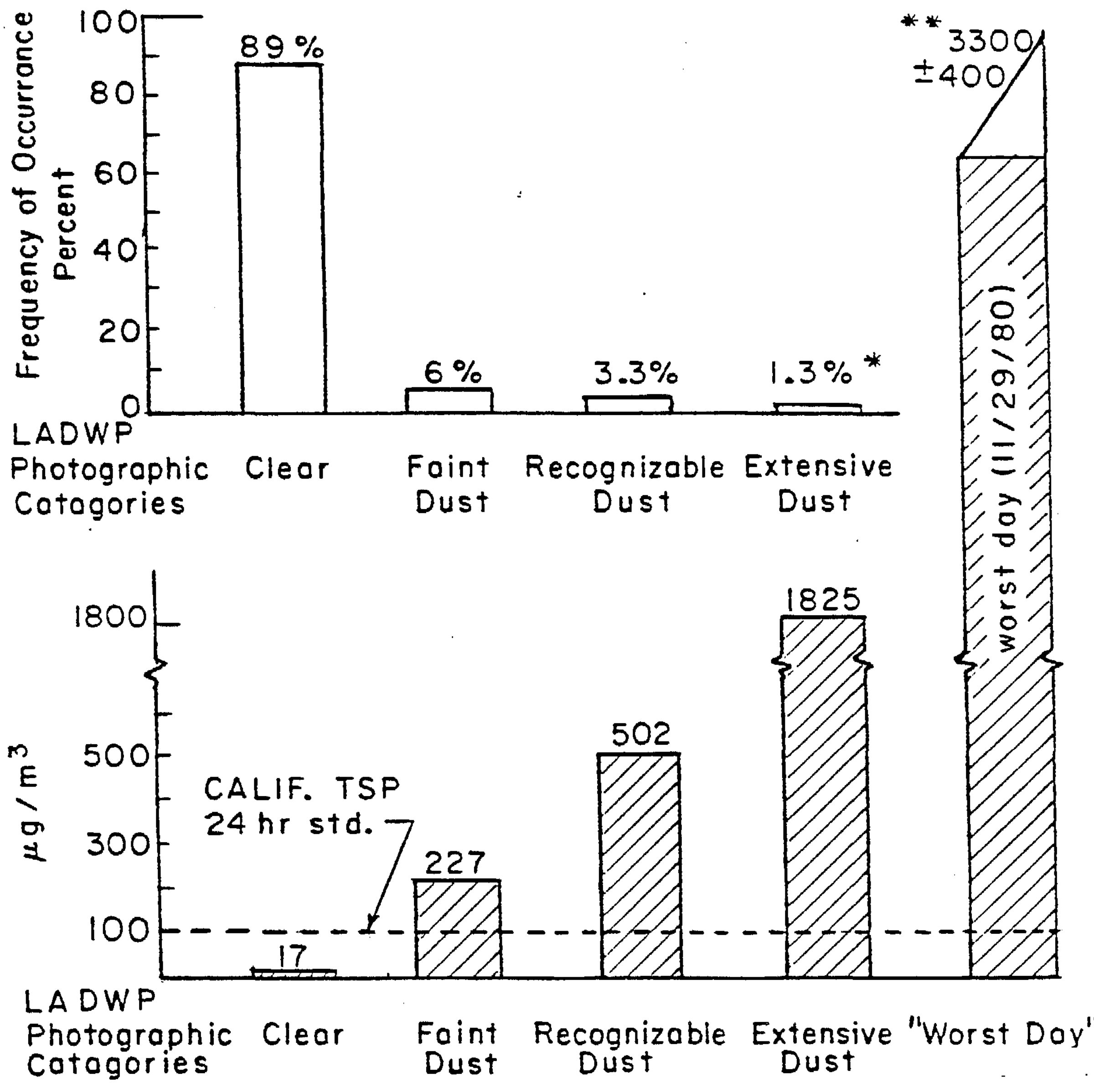
Data on particulates generated in these studies show that fine particulate matter, below 2.5 um diameter, usually reaches only very modest levels, even in dust episodes. (MONO 1;OWENS, Figs. 5-9) Fine mass at all sites near Mono Lake is marked by sulfur-containing particles at levels similar to other Sierra sites, 0.48 $\pm$ 0.03 ug/m^3 of sulfur or about 1.5 ug/m^3 of sulfate (six-month summer average of four

TABLE 3.3 Correspondence between photographic observations (LADWP) and dust (GBVAPCD) at Mono Lake

Los Angeles Dept. of Water and Power Photographic Categories		Frequency of Occurance	TSP Mass Loadings Mono/Simis	TSP Mass Loadings Keeler*
Extensive dust	[Worst]	1.3%	1825 (ug/m^3)	2196 (ug/m^3)
Recognizable dust	[Next]	3.3%	502 (ug/m^3)	836 (ug/m^3)
Faint dust	[Next]	6.0%	227 (ug/m^3)	269 (ug/m^3)
Clear		89.4%	17 (ug/m^3)	26 (ug/m^3)
		= 100.0%		
(Sum of Extensive and Recognizable categories)		4.6%	833 (ug/m^3)	1198 (ug/m^3)
(Sum of Extensive, Recognizable and Faint categories)		10.6%	530 (ug/m^3)	630 (ug/m^3)

* For comparison purposes; No equivalent photographic evidence is available at Keeler.

FIGURE 3.2 Correspondence between photographic record of dust episodes (LADWP) and total suspended particulate measurements (GBVAPCD)



* 18 days in 4 years

** Hi-vol equivalent from Davis sampler. Not included in statistical record since district sampler did not operate on this day.

sites). (MONO 1) Little or no lake impact is seen in this fine mode. The strong inference is that the finest particles are due to long range transport into the basin.

Particulate matter in episodes, both at Mono Lake and Owens Lake, is almost entirely in particles above 2.5 um, but mostly below 11 to 15 um diameter, as shown by size-segregated samples taken at Owens Lake in the WESTEC study (Appendix G), scanning electron microscopy of playa source materials by the U.S. Geological Service, and our laboratory studies of resuspended dusts in the first Mono report. These particles are generally local in orgin, since their settling velocities are large enough to remove them from the air in a matter of hours. Only in very strong winds is much transport possible, but this is exactly the condition that occurs in all major dust episodes at Mono Lake.

The three potential sources of particulate matter that were studied in the Mono Lake basin are:

1. Alkaline/saline spray from the lake
2. Dusts from the alkaline/saline playas
3. Soil dusts from the surrounding basin

Alkaline/saline salt spray from the lake The waters of Mono Lake carry a heavy load of dissolved minerals with a composition indicated in Table 3.4. (Eugster, 1978;Clark, 1924) For comparison purposes, similar data are given for Owens Lake, Deep Springs Lake, and other local lakes. Although Owens Lake has a much larger burden of dissolved solids, it is quite similar to Mono Lake in relative composition.

TABLE 3.4 Analysis of water from several saline lakes in the eastern Sierras[1] for the relative proportion of dissolved minerals

Components	Mono Lake	Owens Lake	Deep Springs Lake	Searles Lake	Saline Lake
Na	38%	38%	33%	33%	36%
Cl	24%	25%	36%	36%	53%
CO_3+HCO_3	28%	24%	9%	8%	0.2%
SO4	13%	10%	17%	14%	8%
K	2.1%	1.6%	5.8%	7.7%	1.7%
Mg	0.06%	0.01%	<0.01%	---	0.7%
SiO_2	0.025%	0.14%	---	---	0.01%
Ca	<0.01%	0.02%	<0.01%	<0.01%	0.0%
Cl/S	5.5	7.5	6.4	7.7	19.9

[1] Eugster (1978); Clark (1924)

Particles derived from spray would thus have the elemental ratios to chlorine as follows:

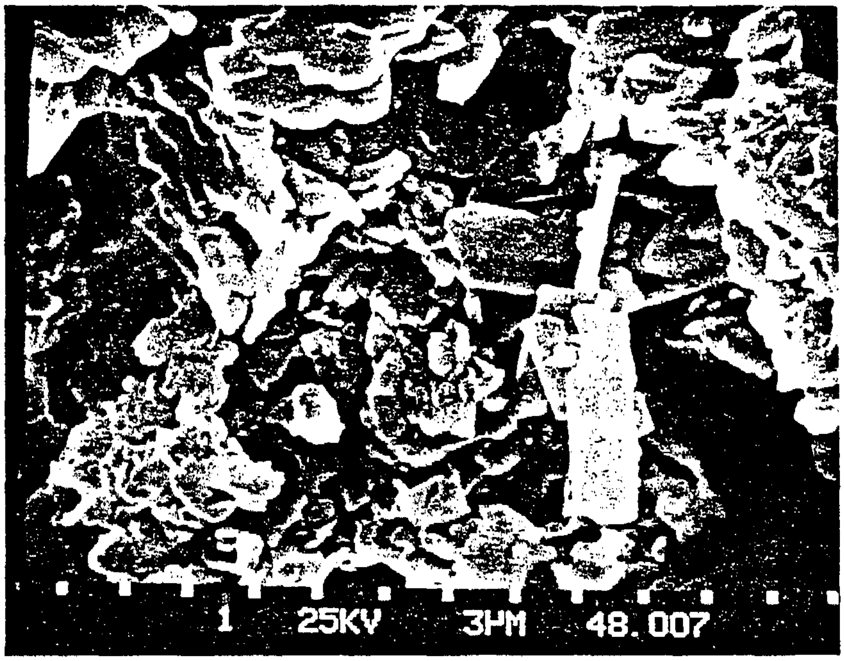
Chlorine	=	100	(by definition)
Sodium		158	
Sulfur		18	
Potassium		9	
Magnesium		0.2	
all other elements		<0.05	

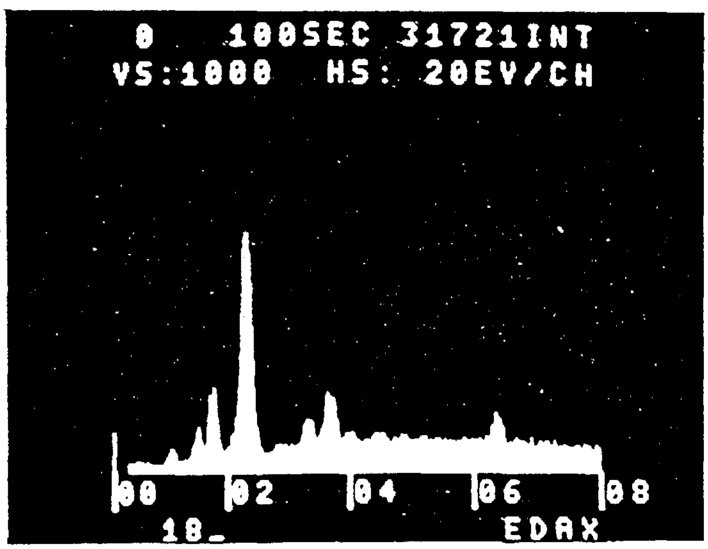
Such spray plumes have, in fact, been seen downwind of Mono Lake, but never in large amounts. (Appendix H.c)

Playa materials Samples of the crystalline crust were collected by C. Simis from the northeastern margin of the exposed lake bed. These were photographed using a scanning electron microscope (SEM) and analyzed by energy dispersive x-ray analysis by the U.S. Geological Survey. The results for one of the samples are included in this report, (Fig. 3.3) courtesy of Dr. Kenneth Lajoie of the U.S.Geological Service. Visually, the deposits show a crystalline nature, with structure as small as one micron (10^{-4} cm). Elemental analysis shows great similarities between the samples. Sulfur is the dominant element in all cases with major components of silicon and calcium. Chlorine was present in only minor amounts, but most prominently in the least crystalline sample. It is also interesting that elements such as silicon, calcium, and iron are present with sulfur, sodium, and chlorine in what appears to be a single, monolithic crystal in some pictures. Thus, the efflorescent white crusts are mixtures of chemical species.

Over 40 samples of Mono Lake basin materials were collected, representing potential particulate sources. Since the only particles of interest to this study were those less than about 15 um in diameter—the inlet cut point of all Davis sampling units—samples were resuspended in a air sampling device designed and built by the Air Quality Group staff to mimic the natural resuspension processes. This unit was calibrated against National Bureau of Standards reference materials, with excellent agreement. (Appendix E)

FIGURE 3.3 Scanning electron microscope photographs and energy dispersive x-ray analysis of alkaline/saline efflorescent crust, Mono Lake.





Si S Ca Fe

SEM Photograph and ED X-Ray Analysis of Lake Crust 2, USGS

Playa materials were broken up in a mortar and pestle prior to resuspension, since, as we and Gillette have both reported, the material is essentially a solid until fractured. No attempt was made to grind the crust, however. The results are shown in Table 3.5, and in more complete form in Table 7 of the first Mono report. Of particular interest are the very stable Cl/S ratios, 3.3 $\pm$ Ø.5 except for Paoha Island, Ø.48, the massive amounts of sodium, chlorine, and sulfur, and the almost total absence of aluminum. The tufa deposits are almost pure calcium, presumably $CaCO_3$ and its hydrated forms.

The SEM analyses differ from the "white lake crust" category of Table 3.5 in that the SEM results show far less sodium and chlorine. The Cl/S ratio was Ø.1, much closer to the ratio in lake waters, Ø.18, than playa materials. This shows a much higher degree of chemical variability at Mono Lake than at Owens Lake. It also supports the necessity for actually resuspending particles in airstreams in order to match particulate composition seen in the atmosphere.

<u>Soil dusts from the surrounding basin</u> Local non-playa soils were treated in a similar manner as the playa materials, with crusted materials broken up in a mortar and pestel prior to resuspension in the Davis resuspension and sizing system. (Appendix E) The results show that local soils are far easier to resuspend than playa materials, in agreement with earlier work. Examples of compositional data are shown in Table 3.6 for particles in the size range between 2.5 and 15 microns. Of particular interest are a universal lack of sulfur and chlorine at these relative compositions and the routine presence of aluminum. The expected amount of these materials in the Earth's crust is also given for comparison purposes, and they are comparable.

Table 3.5 Playa materials near Mono Lake
(resuspended, 2.5 to 15 um diameter)
(ratios to calcium)

	Na	Si	S	Cl	K	Ca	Fe	S+Cl/Ca
Soils (lake)								
Surface	95	228	<8	20	20	=100	16	0.28
sub-surface	<50	50	2.9	19	13	=100	16	0.22
Tufa Deposits	<10	3	<1	<1	0.6	=100	0.5	<0.02
White Lake Crusts								
Negit Is.	90	30	117	352	67	=100	6	4.1
Paoha Is.	1350	530	157	82	63	=100	51	2.4
beaches	2500	64	94	286	35	=100	9	3.8
beaches	11300	<60	296	1250	456	=100	<10	15.5
beaches	3600	36	111	420	52	=100	17	5.3
OWENS (bulk)	440	165	7	26	22	=100	25	0.33

Note: (1) Cl/S ratio, surface, except Paoha Is., 3.3 ± 0.5, when both present.
Paoha Is. Cl/S = 0.49; Owens Cl/S = 3.7
(2) Aluminium seen only once in all surface playa materials, with a value of Al/Ca x 100 = 14, near the Simis shoreline.

Table 3.6 Soils near Mono Lake
(Resuspended 2.5 t 15 um diameter)
(ratios to calcium)

	Al	Si	S	Cl	K	Ca	Fe	S+Cl/Ca
Silicon-rich soils								
Lee Vining H.S.	530	2140	<5	<5	185	=100	205	<0.10
Pine Grove (Hwy 120)	790	4710	<20	<20	398	=100	183	<0.40
Black Pt. Rd.	324	193	<20	<20	193	=100	220	<0.40
Calcium-rich soils								
Bodie	<23	251	<6	<6	106	=100	60	<0.12
South Tufa Rd.	26	378	<2	<2	62	=100	31	<0.04
Simis Ranch	43	264	<5	<5	24	=100	13	<0.10
Binderup Ranch	145	644	<4	<4	50	=100	63	<0.08
Earth's Crust (avg)	224	734	1.4	0.9	71	=100	138	<0.025

3.3 Size and composition of dust episode particles

Information on both the nature and sources of dust episode particles was gathered by photographic and personal observations of dust episodes, by sampling episode particles as a function of time and size, and by analyzing the collected particles for elemental and chemical composition.

Observations of dust episodes at Mono Lake, including photographs of several episodes taken during this study and examples from the extensive Los Angeles Department of Water and Power collection (Appendix B), show the episode particles to be white and coming off playa areas. Further, personal observations of Great Basin Valley APCD staff and others clearly separate the fine "Keeler fog"--type dusts from normal coarse sand storm particles that can sand-blast cars and windows.

Studies of the size-composition profile of episode and non-episode dusts was gathered in continuous 25-hour monitoring at Hansen's Ranch, north-west of the lake, and in the south tufa reserve area. (Appendix H.a) An example of the daily profiles for sulflur, chlorine, and sodium playa tracers, is shown in figure 3.4. Four minor episodes were recorded at this site, which is generally, upwind of the lake, but the largest probably did not amount to 100 ug/m^3, equivalent Hi-Vol 24-hour TSP. To be considered an episode, we required amounts in excess of the California 24-hour standard, 100 ug/m^3, Hi-Vol sampling. Since all Davis units had intake restrictions at a particle diameter of 15 um in still air, which dropped to about 11, um at 24 km/hr winds, the Davis units collected only a fraction of what a standard high volume sampler would have at the same location. (Appendix C) A correction factor of (x 1.5 $\pm$ 0.2) was applied when Hi-Vol equivalence was desired, based on two direct field intercomparisons in Charleston, West Virginia and at the Desert Research Institute, Reno Nevada. (Appendix C.a)

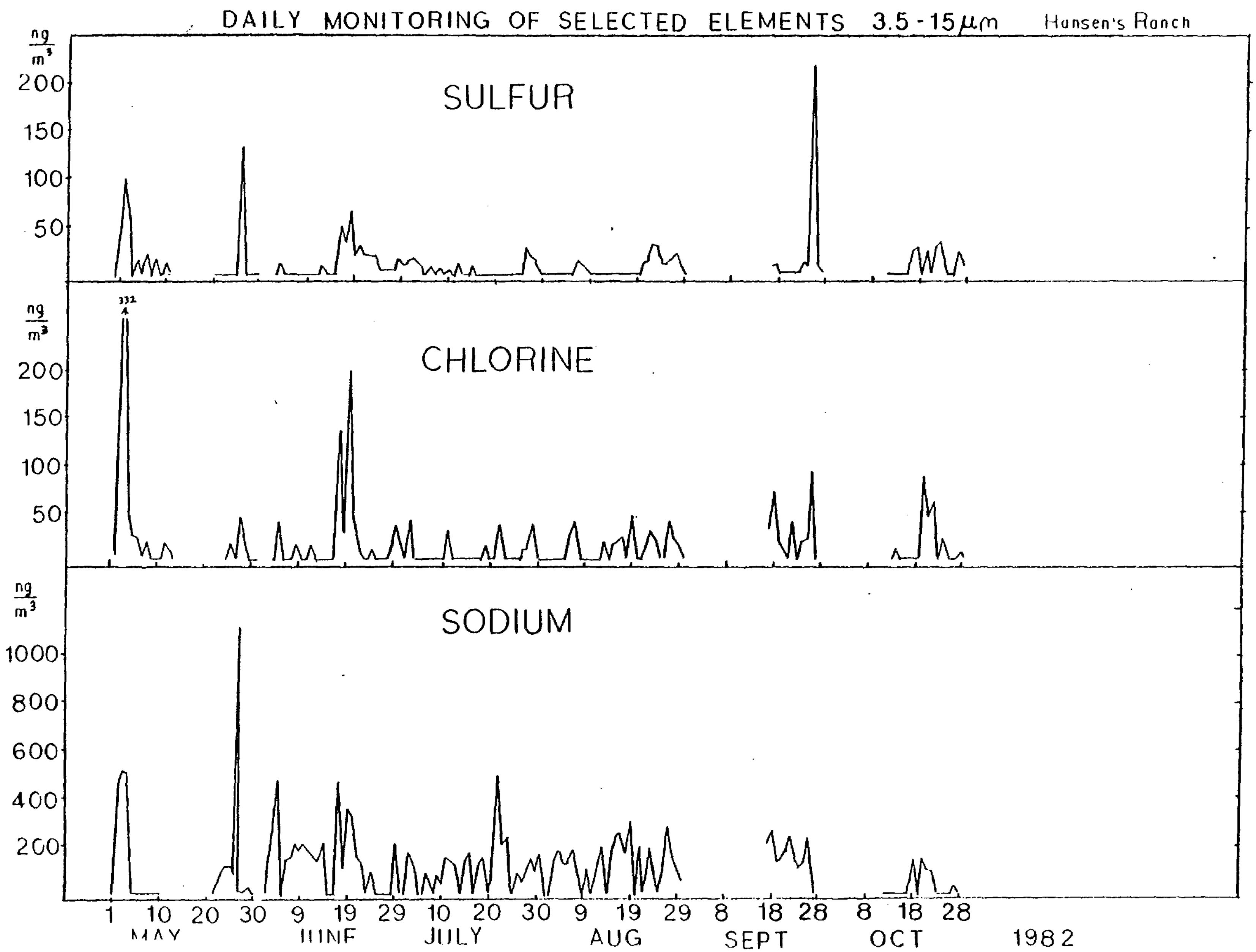

DAILY MONITORING OF SELECTED ELEMENTS 3.5-15μm
Hansen's Ranch
SULFUR
ng/m³
200
150
100
50
CHLORINE
ng/m³
332
200
150
100
50
SODIUM
ng/m³
1000
800
600
400
200
1 10 20 30 9 19 29 10 20 30 9 19 29 8 18 28 8 18 28
MAY
JUNE
JULY
AUG
SEPT
OCT
1982

FIGURE 3.4

On the basis of estimated mass greater than 100 ug/m^3, 24-hour TSP Hi-Vol equivalent, and visible dust plumes, 8 episodes were sampled during the 1980 and 1983 field studies, which lasted a total of 8 months in all. None of these coincided with district TSP monitoring downwind of the lake. Each had size-segregated samples collected, with chemical analysis and on-site photographs (Appendix C). An example of two such episodes, one probably the most intense in the 1979-1983 period, is given in Table 3.7. Also included for comparisons is one of the fully characterized Owens Lake dust episodes.

The similarity of the episode particulates is striking in several ways. First, the almost total absence of aluminium eliminates any significant sources in local, non-lake bed soils. Secondly, the (Cl + S)/Ca ratio, further strengthens the association with the playa materials. Recalling the results of Section 3.2,

Source	(Cl + S)/Ca
Non-Lake soils	0.025
Playa soils	0.28
Playa white crusts	5.5
Cedar Hill 11/29/80	2.0
Simis Ranch 11/30/80	3.2
All 8 Mono episodes	6.5

Using field measured equivalency factors and the most conservative estimates of the fraction of very light elements (C, O, N, H) not seen by x-ray methods, based on measured values at Owens Lake, one can calculate that the equivalent 24-hour Hi-Vol TSP reading at Cedar Hill, on the Nevada State line 8 miles from Mono Lake was 930 ug/m^3, of which 36 ug/m^3 was composed of particles less than 2.5 um diameter and 589 ug/m^3 resided in particles between 2.5 and 11 um in diameter. On November 30, 1980, a 24 hour TSP mass of 329 ug/m^3 was recorded at Simis ranch, of which 18 ug/m^3 lay below 2.5 um in diameter and 311 ug/m^3 lay between 2.5 and 11 um in diameter. A full photographic record of the 11/29/80 event was recorded, an example of which is in Appendix B. The

TABLE 3.7 Analysis of episodes 11/29/80 and 11/30/80, Mono Lake, and Owens Lake, 4/16/79

Major Elements	Cedar Hill 11/29/80			Simis Ranch 11/30/80			Keeler 4/16/79		
	Coarse	Fine	Total	Coarse	Fine	Total	Coarse	Fine	Total
Sodium	69.0	4.0	73.0	50.3	<3	50.3	91.0	<5	91.0
Aluminum	<2	0.6	0.6	<2	<1	<2	<0.7	<2	<1
Silicon	52.7	1.6	54.3	18.9	1.8	20.7	39.3	0.4	39.7
Phosphorus	<1	<1	<1	<1	<1	<1	<1	<1	<1
Sulfur	6.8	1.9	8.7	5.2	2.1	7.3	16.5	0.3	16.8
Chlorine	7.4	0.7	8.1	2.2	0.9	3.1	15.5	0.3	15.8
Potassium	5.6	0.2	5.8	1.5	<0.3	1.5	5.7	0.15	5.8
Calcium	7.0	0.4	7.4	2.3	<0.2	2.3	11.3	0.16	11.5
Iron	6.4	0.15	6.5	1.4	<0.15	1.4	4.9	0.23	5.1
	155	9.6	164	81.8	4.8	86.6	185	1.5	186.5
% fine*		6%			7%			3%	
HI-VOL MASS ESTIMATES									
1. Inclusion of elements lighter than Na (mostly carbonates)	589	36	625	311	18	329	1056**	10.6**	1067**
2. Correction for equivalent Hi-Vol intake	894	36	930	472	18	490	1600	10.6	1611

* Adding 1/2 of Na Lower Limit — ** Measured

clear association of the episode plume with the playas, and especially the Negit Island land bridge, is evident in the colored original.

Additional evidence on the central role played by the playas of Mono Lake in total suspended particulate measurements near the lake is shown by the comparison between Lee Vining (usually upwind) and the Binderup/Simis sites (generally downwind) from GBVAPCD TSP measurements.

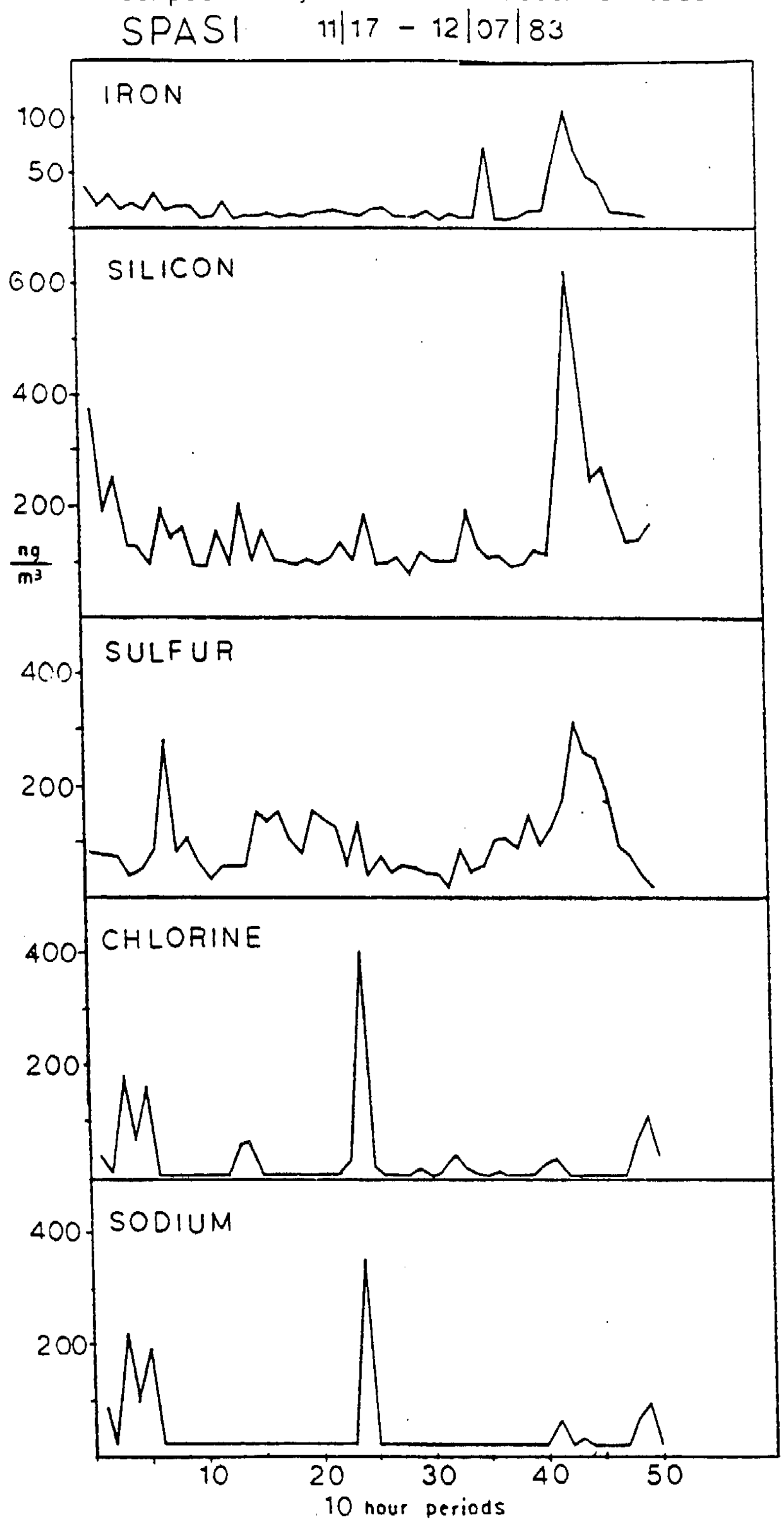
Total Suspended Particulates

Date	Lee Vining	Binderup/Simis
August 19, 1979	17 ug/m^3	266 ug/m^3
October 24, 1979	15 ug/m^3	193 ug/m^3
November 17, 1979	7 ug/m^3	481 ug/m^3
June 2, 1980	1 ug/m^3	136 ug/m^3
But, also notice —		
March 28, 1980	131 ug/m^3	17 ug/m^3

These readings are the only ones in which simultaneous readings are available at both sites for the 10 worst episodes at Binderup/Simis and the worst episode Lee Vining. In all cases, high levels on one side of Mono Lake had corresponding low levels on the other side, thus eliminating both aerosols transport into the basin and basin non-lake bed soils as significant factors in the worst episodes. This is illustrated most strongly by the very low TSP reading of 6 ug/m^3 at Lee Vining during the 24 hours of what was perhaps the worst particulate episode in four years, November 29, 1980, for which the down wind sites had an estimated 3300 $\pm$400 ug/m^3. It also indicates how few of the really major dust episodes downwind of Mono Lake were sampled by the district.

Recent availability of the Solar Powered Aerosol Sampling Impactor (SPASI) has allowed short time-resolution particulate measurements even at remote sites. An example taken at Simis ranch—Nov. 15, 1983 to Dec. 15, 1983—shows sporadic dust events of lake origin

FIGURE 3.5 Particulates at Simis ranch as a function of time and composition, November - December 1983



including several relatively pure sodium chloride salt episodes, and a sulfur-rich episode near Dec. 8 which closely resembles the playas around Paoha Island. (Figure 3.5)

In summary, all photographic, size, compositional, and meteorological factors support the conclusion that virtually all of the material in the dust episodes comes from the recently exposed playa areas of Mono Lake, with only very modest contributions from Paoha Island, lake spray, and local soils.

Toxic components of playas and dusts

Measurements made in this study have shown the presence of potentially toxic elements such as selenium, mercury, lead, and arsenic in the playa meterials and dust plumes of Owens and Mono Lakes. This is not suprising in light of early studies of the geochemistry of playa lakes and the presence of arsenic-rich springs in the area, but it does require an evaluation of the amount present in inhalable particles at inhabited sites near these lakes.

At Owens Lake, mean arsenic levels at Keeler were (30 $\pm$ 10) ng/m^3 in particles smaller than 11 um diameter during the three dust storms of April 1979 (Owens Report, Fig. 10, reanalyzed to correct for lead interference). This amounted to about 45 ppm arsenic in the dust plumes, which is in approximate agreement with the 63 ppm arsenic in the 2 to 5 um, and 34 ppm arsenic in the 5 to 15 um diameter dust events sampled on Owens Lake in 1983 as part of the Westec study. (Westec Air Quality Appendix, 1983).

At Mono Lake, arsenic was detected by x-ray fluorescence and PIXE in 28 out of 37 playa samples, with a median level of about 50 ppm arsenic, by weight, similar to that of Owens Lake. (Mono Report #1, this work). Direct measurements were made of arsenic in Mono dust episodes of 5/18/83 (27 $\pm$ 6 ng/m^3) and 5/13/83 (18 $\pm$ 4 ng/m^3)

Using the value of 5Ø ppm arsenic for Mono dust episodes, one can estimate that there would be an average of about 25 ng/m^3 of arsenic present in inhalable particles less than 11 um diameter during 11% of all days downwind of Mono Lake. The equivalent value for Keeler, downwind of Owens Lake, would be about 3Ø ng/m^3, due to the somewhat lower arsenic fraction in the dusts but higher dust levels.

A study was initiated to find out the chemical states of the arsenic, since the x-ray analysis only gives the presence of elements, not their compounds. A number of techniques were attempted to isolate the state of arsenic in the strongly basic alkaline salts, without a clear isolation of which compounds dominate. Techniques were developed that allowed separation of the arsenic-containing fraction from the bulk of the salts. (Appendix C)

Generation of particles from playas

The question still remains as to how an efflorescent alkaline/saline crust can be turned into 5 to 15 micron particles. Gillette (Gillette et al 1982) showed that this crust could not by itself be suspended under any realistic wind conditions, a result confirmed at Davis in our resuspension studies. Another aspect of this problem is that the suspension threshold of about 25 mi/hr is characteristic of the suspension of a large 1ØØ to 2ØØ micron particles, while all measurements show that downwind plumes are dominated by particles in the 5 to 15 micron range.

A good deal of insight into these problems was developed during the State Lands Commission--WESTEC studies on Owens Lake, in which we participated. Measurements made with a 4 stage Lundgren rotating drum impactor during three episodes of about 6 hours each in spring, 1983 (Appendix G). (See Appendix E for another use of this unit). The unit could be faced into the wind, and was approximately, isokinetic at 6 m/sec or 13 mi/hr.

The mean dust collected during these episodes was about 40,000 ug/m^3 at a height of 2 meters above the playa. The fraction of particles collected in the first two size ranges can not be trusted too far, since the rotating greased surfaces were soon totally covered with particles and bounce-off doubtlessly occurred.

Nevertheless, the fractional collection values were as follows for the particle diameter.

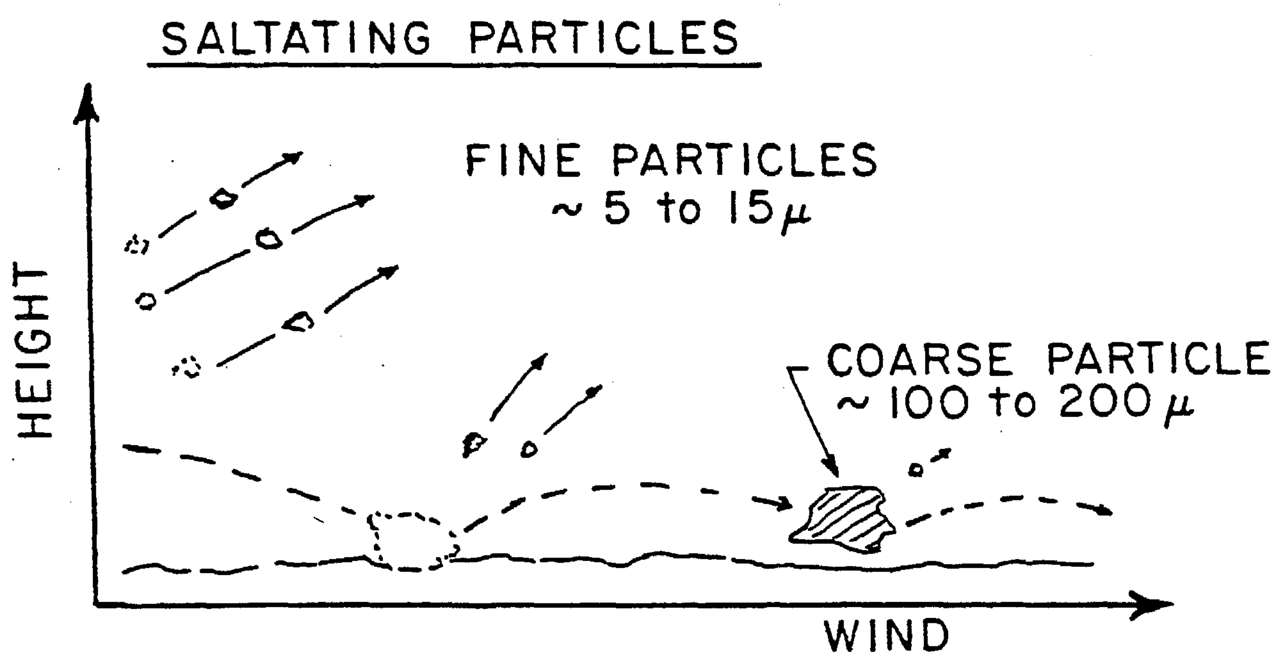
D_p = 15 to ~ 200 micron	(40%)
D_p = 5 to ~ 15 micron	48%
D_p = 2 to ~ 5 micron	10%
D_p = 0.5 to ~ 2 micron	2%
	100%

Particles below 0.5 um were not collected, but our other SFU samplers indicate negligible contributions to this mass.

The chemical composition of the collected particles varied with size, with the playa materials associated with the efflorescent crust becoming a larger fraction of the finer size ranges. Excellent agreement is seen between typical dust episodes at Keeler and the Owens lake bed study in terms of the Cl/S, but the (Cl+S)/Ca ratio is depressed by a factor of 10, with large soil particles and crustal materials present.

Thus, it appears that not only must one have strong winds and an efflorescent crust, there must also be abundant coarse particles to grind up the otherwise solid playa minerals. This process is most likely dominated by saltation, illustrated schematically in figure 3.6, (after Gillette, et. al, 1980). Such a process explains both the high wind threshold and the fine particles seen in the plumes, since both mechanical and optical studies show that crust fractures into micron-sized particles.

FIGURE 3.6 Representation of a saltation process (after Gillette, 1980)



While this mechanism fits very well the data on alkaline/saline dust plumes from the playas, it still leaves unresolved the question of why the generally more easily resuspended local soils do not contribute in any major fashion to Mono dust episodes. This question involves a consideration of wind shear and momentum transfer, and requires a close study of the meteorological conditions around Mono Lake.

Meteorological studies: Synoptic No consistent synoptic weather pattern is associated with dust events. At Bishop, 50 miles to the southeast, wind speeds are generally higher than average during dust events and peak gust winds are also high. A brief description of the synoptic situation for several dust episodes follows. (Table 3.8)

3.3.1 On August 19, 1980 a low pressure system was centered over Idaho. Wind speeds over Mono Lake at the 500 mb level were approximately 40 knots from the NNW. A surface low was located near Las Vegas. The station pressure at Bishop was 0.16 inches higher than the previous day.

3.3.2 On November 29, 1980 an upper level low was located northwest of Washingtion. The 500 mb flow was from the west at approximately 50 knots over Mono Lake. Station pressure at Bishop had dropped 0.23 inches from the previous day. Winds at Bishop were quite gusty, with a peak gust of 37 mph. These conditions resulted in the most extensive dust episode seen in the past 3 years. (Fig. 3.7)

3.3.3 On May 18, 1981, an upper level trough was located off the west coast. Winds at the 500 mb level over Mono Lake were 30-35 knots from the southwest. During the day, the trough developed into a cutoff low which later moved SE across northern California. Station pressure at Bishop was 0.16 inches lower than the previous day, and continued to drop the following day. The peak gust at Bishop was 28 mph, with mean winds during the day of 12-20 mph.

3.3.4 On May 31, 1983 a weak trough was located off the Pacific Northwest coast. The 500 mb flow was westerly over Mono Lake, however, at

TABLE: 3.8 Surface wind summary, Bishop, California

SURFACE WIND SUMMARY
Bishop, California
(Inyo County)

Average Wind

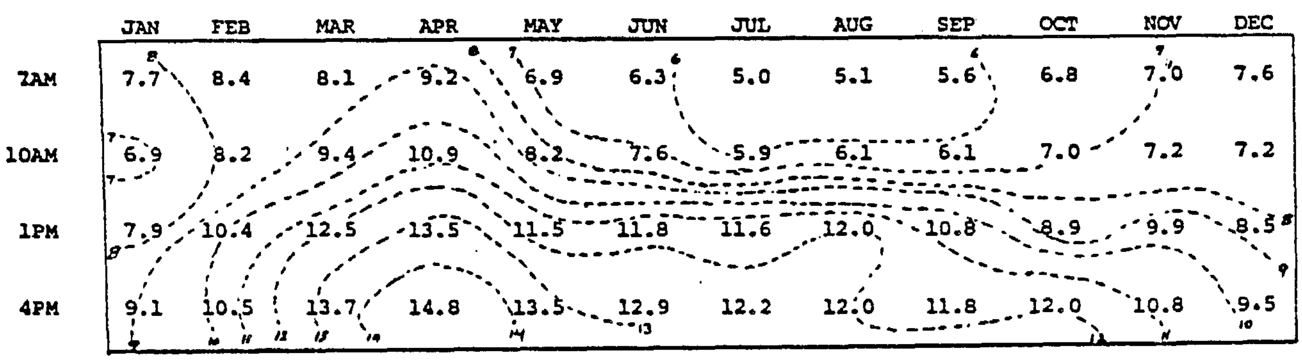
Month (Jan 1965 to Oct 1974)

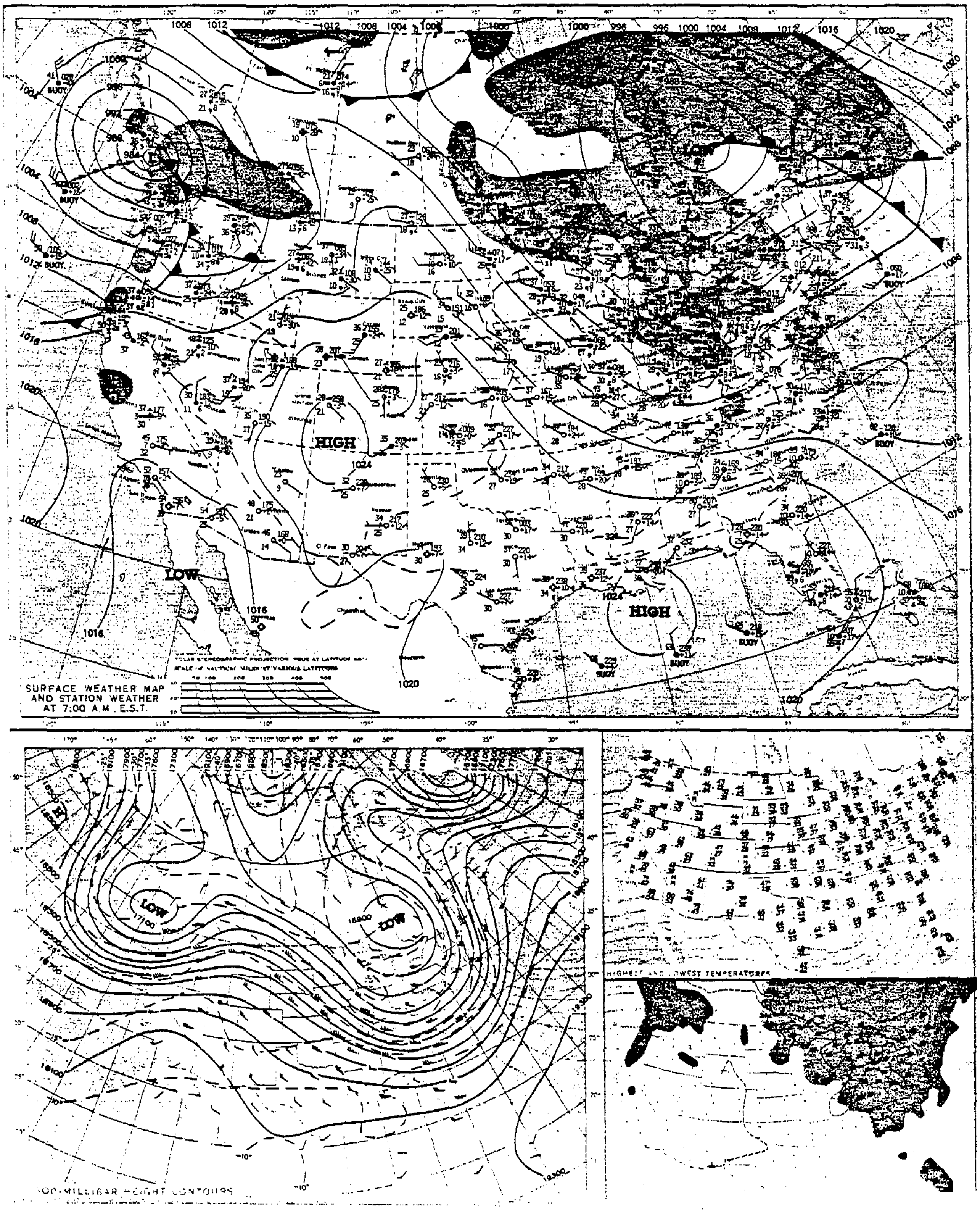
Time PST	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual Mean
7AM	34/4.7	33/5.2	34/5.1	35/6.0	35/5.4	34/4.9	33/3.5	33/4.1	35/4.6	34/5.3	33/4.1	34/5.0	34/4.8
10AM	35/3.5	35/9.3	34/2.8	34/1.1	34/0.6	23/0.7	19/2.2	20/2.2	30/1.0	35/2.6	34/1.5	35/3.8	34/2.0
1PM	34/1.7	36/1.7	19/1.0	24/1.3	20/3.1	17/3.0	17/8.6	18/9.3	18/5.7	19/2.9	17/2.0	33/1.8	18/2.6
4PM	28/1.0	29/0.9	24/1.7	25/3.1	24/3.7	22/3.6	17/3.8	19/6.7	19/6.1	19/4.5	34/4.2	31/0.9	22/2.3
Mean*	34/2.6	34/4.1	32/1.8	31/1.9	28/1.4	25/1.1	18/2.9	20/3.8	20/1.8	27/0.9	33/2.0	34/2.8	30/1.1

* Mean value of 4 reported winds per day.

NOTE: 34/4.7 denotes a mean wind speed of 4.7 mph and from an average direction of 340°. These values represent a vector mean of the monthly winds reported in Local Climatological Data for Bishop, California.

AVERAGE WIND SPEED




SURFACE WEATHER MAP
AND STATION WEATHER
AT 7:00 A.M. E.S.T.
HIGH
LOW
HIGH
LOW
1024
1016
1020
LOW
LOW
HIGHEST AND LOWEST TEMPERATURES

2Ø-3Ø knots. The station pressure at Bishop showed a drop of Ø.19 inches from the previous day. Mean wind speeds at Bishop exceeded 1Ø mph most of the day, with a peak gust of 23 mph. (Appendix I.a)

Micrometeorological intensive From August 28, 1982 to September 1, 1982 aerosol sampling was conducted simultaneously with meteorological data collection near Simis' ranch. Aerosol monitoring was done with two battery-powered SFU's, one located at Simis' ranch, the other one at South Tufa--as well as the ARB multiday sampler at Hansen's ranch.

The meteorological equipment consisted of a 1Ø-meter tower which recorded wind speed, wind direction, and temperature; a 2-meter tower which recorded wind speed, wind direction, temperature, and relative humidity; and an acoustic sounder which provided information on the temperature structure of the atmosphere up to 1ØØØ feet. In addition, pilot balloons were released periodically during the day and night. The balloons were tracked for 2Ø-25 minutes providing wind profiles up to 1Ø,ØØØ feet above the lake level. (Figure 3.8) (Appendix I.b)

From the above data friction velocity values [u*] were developed; a necessary measurement for episode modeling. The surface roughness height Z_o in the sage brush areas is one order of magnitude larger than that on playa areas, greatly reducing wind shear on non-playa soils and thus supressing soil resuspension. (Fig. 3.9) These measurements helped explain the dominant playa origins of all major dust episodes. The measurements also detailed a ground-based radiation inversion that would protect the playa surfaces from winds at higher levels. Only after this stable layer goes away can the wind shear initiate saltation processes. This may explain the inactive areas of playa upwind of the point of dust episode initiation seen in the photographs.

FIGURE 3.8 Wind data for Mono Lake, meteorological intensive study, August, 1983.

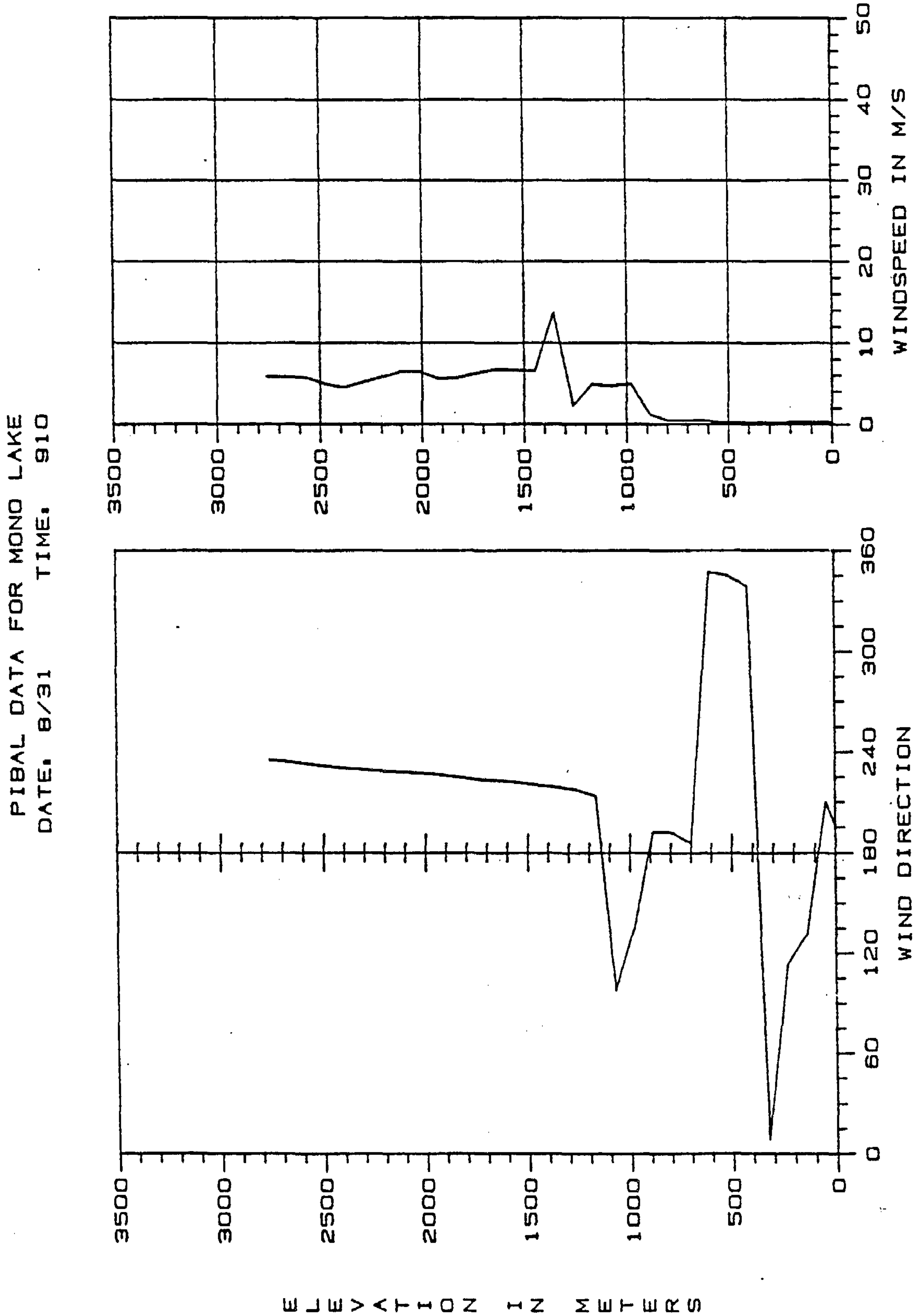
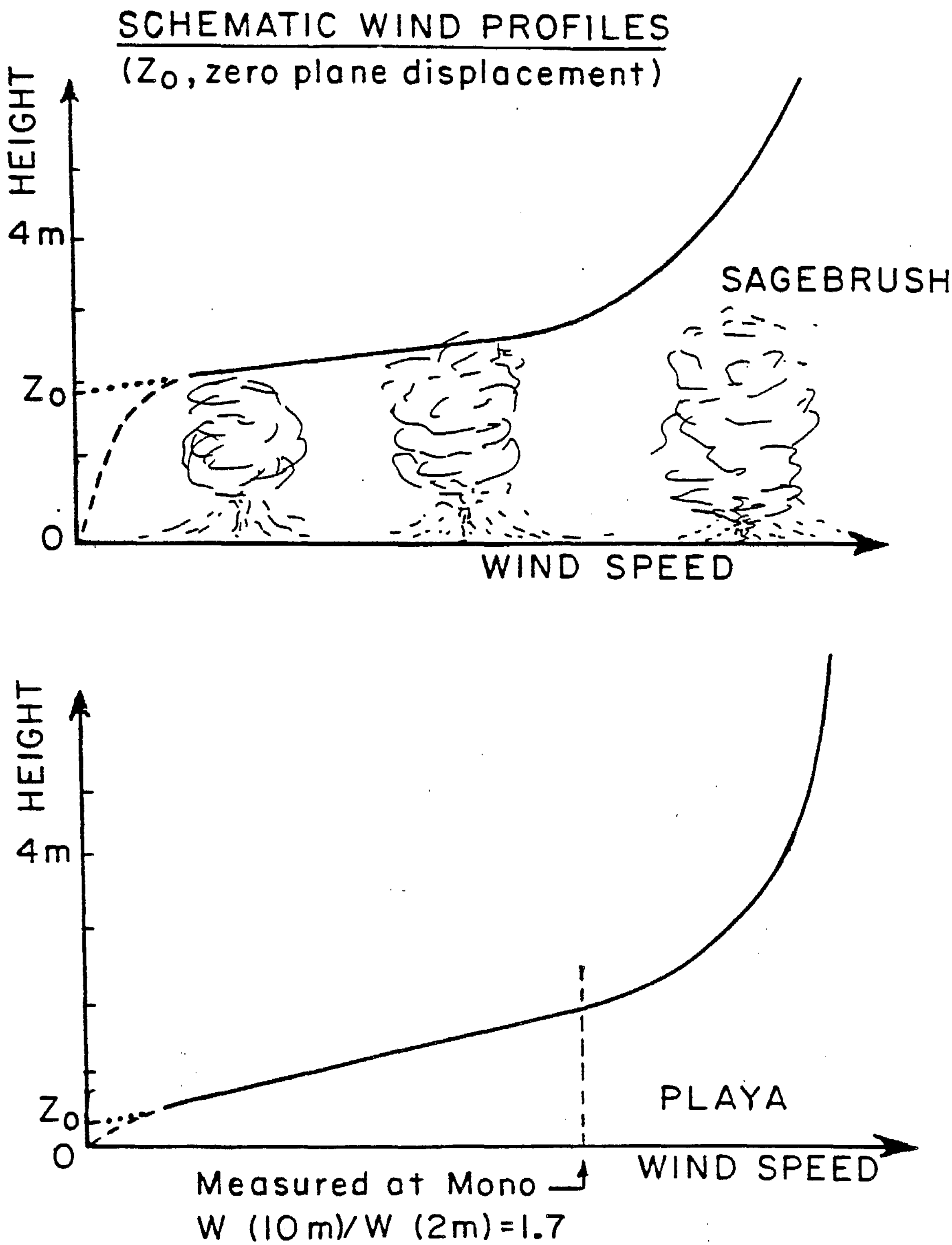


FIGURE 3.9 Representation of the effect of surface roughness on wind shear via an increase in Z_0, the zero plane displacement.



4.Ø SEMI-EMPIRICAL MODEL OF DUST EPISODE EXTENT

Findings from this and earlier studies indicate that once the wind threshold is reached, a saltation process is begun that rapidly escalates into a general dust-event generated from all locations downwind of the point of initiation. Five conditions must occur simultaneously to generate the alkaline/saline storms typical at Owens and Mono Lakes:

a. Threshold wind velocity, about 25 mph at Owens, perhaps somewhat higher at Mono Lake
b. High wind shear at the flat surface due to lack of obstructions (small Z_o parameter)
c. Adequate fetch across the playas; at least one mile (from photographs at Mono)
d. Coarse particles to initiate saltation process, Dp > 1ØØ um; (sand)
e. Efflorescent alkaline/saline crust, to generate fine particles, Dp $\leq$1Ø um

From these data--and the measurements made by the Davis group in 1979 in the Owens Valley--a semi-empirical model was developed to predict dust levels downwind of a dry lake like Owens or Mono. The Mono Owens Davis Dust Model (MODDM) has two component growth and settling-factors (coarse and fine). The model has for sources two variable fetches of local soils and three variable playa areas, and sinks which include these areas and two regions of water of arbitrary width. Once wind threshold is reached, dust generation proceeds according to Bagnold's $(u^*)^3$ relationship. Two component aerosols, settling and exponential re-establishment of background soil aerosols can be computed as far as 15Ø miles downwind of the lake, with the percentage of lake bed material calculated at each point. (Appendix J)

The main reason that a semi-empirical model was chosen was that existing diffusion models with particle fall-out could not duplicate the lofting of dust to high altitude clearly shown in photographs. Thus, the down wind values of TSP decrease more due to an ever increasing volume of clean air entrapped in the dust episode than to particle settling. (Fig. 4.1)

4.1 Calibration of the model

The model was matched to existing mass data in two ways:

a. Values for 24-hour TSP readings by district Hi-Vols were used to set the absolute amounts seen on the highest 5% of all days, 1979-1983, and

b. Down wind profiles were calibrated with an array an Davis SFU samplers deployed in April, 1979, in 3 dust episodes. This calibration was confirmed by one fortuitous measurement from Lone Pine to Bishop by district Hi-Vols. The resulting parameter set is called MODDM (M), for mass. (Table 4.1)

This procedure, however, does not take into account the chemical data in our first Owens report, showing little playa materials (Na, S, Cl) at sites beyond 25 miles. According to these specific components, clearly of playa origin, falloff is far more rapid beyond 30 miles than for all mass. This set of parameters is denoted by MODDM (P), for playa.

Since the upwind mass data is very low, one can not argue for material transported into Owens Valley. Yet, Hi-Vol readings at Bishop are high. The conclusion we foresee is that there are non-playa soil-derived particles resuspended in the Owens Valley itself, downwind of the lake, in wind conditions that cause the alkaline/saline storms from the playas. For this reason, we will choose the MODDM (P) set for all calculations at Mono Lake, except for one extrapolation for which MODDM (M) gives a lower, more conservative TSP value. (Table 4.2)

TABLE 4.1 Dust profiles in the Owens Valley, south winds, relative to Keeler. Profiles are derived from data on playa elements (sodium, chlorine, sulfur), silicon, which occurs in both playas and non-playa soils, and mass

	Three Episodes, April, 1979 (UCD SFU's)			Episode 12/20 to 12/21/82 (GBVAPCD Hi-Vols)
Site	Na, Cl, S	Silicon	Mass	Mass
Upwind (far)				
Little Lake	2.5%	1.5%	0.7%	NA
Upwind (close)				
Cartago	5.3%	9.3%	4.4%	NA
Owens Lake				
Keeler	= 100%	= 100%	= 100%	= 100%
Lone Pine	26%	43%	27%	30%
Independence	8%	16%	10%	18%
Big Pine	1%	14%	5.6%	NA
Bishop	<1%	19%	6.4%	7%

NA = not Available

TABLE 4.2 Calibration of Mono-Owens Davis Dust Model (MODDM) for Owens Valley dust episodes

Site	Distance (Miles)	Data (Mass)	MODDM (M)	Data (Na, Cl, S)	MODDM (P)
Upwind (far)					
Little Lake	(27)	0.7%	1.2%	2.5%	1.2%
Upwind (close)					
Cartago	—	4.4%	1.2%	5.3%	1.2%
Owens Lake	—	NA	123%	NA	125%
Keeler	1	=100%	=100%	=100%	=100%
Lone Pine	8	27%	27%	26%	26%
Independence	25	10%	9%	8%	7%
Big Pine	50	5.6%	6%	1%	2%
Bishop	75	6.4%	4%	<1%	1%

NA = Not Available

Table 4.3 Example of MODDM results fit to the worst 5% of all days, down wind of Owens Lake

MONO-OWENS DUST MODEL
(DODDM)

Ver. 3, 11/84

Wind Velocity and Threshold (mi/hr) 35 25

Threshold Length and Playas (mi) 1 14 Ø Ø

Water Lengths (mi) Ø Ø

Mass Factors: Bkgd, Threshold, Rate, Total (1Ø-6g.M3) 15 13Ø Ø 13Ø
Coarse/fine fall-off rates and fractions 4.2 65 .9 .1

Length From Upwind edge 14 mi Mass at End of First Playa 1483.3
Lake fraction 99.9%

Mass at Distances X Downwind of Last Water of Playa (1Ø-6g/M3)

Distance (miles)	Mass (TSP)	Ratio to M(O)	Lake Fraction
Ø	1483	1ØØ%	1ØØ%
1	12Ø1	81%	1ØØ%
2	979	66%	99%
3	8Ø3	54%	99%
4	664	44%	99%
5	554	37%	98%
6	467	31%	98%
8	343	22%	96%
1Ø	264	17%	95%
15	17Ø	1Ø%	91%
2Ø	135	8%	89%
3Ø	11Ø	6%	86%
4Ø	95	5%	84%
5Ø	84	5%	82%
75	62	3%	76%
1ØØ	47	2%	68%
125	37	1%	59%
15Ø	3Ø	1%	5Ø%

While use of a semi-empirical model makes it more difficult to clarify basic physical processes, the model is inherently representative of the field data. Thus, it has the statistical weight of its source data, which is considerable, and provides a sound way to calculate trends. (Table 4.3)

Magnitudes of dust episodes were variable, but each model was calibrated to measure suspended particulates at Mono (Simis) and Owens (Keeler) for the 5% worst days. The source generation rate (ug/m^3 per km of playa) was 2.7 times greater at Mono than Owens, possibly because the alkaline salt beds at Mono were more recently exposed. (Table 4.4)

4.2 <u>Predictions of the model versus the level of Mono Lake</u>

<u>Effect of Mono Lake level</u> The establishment of calibrated dust episode models based on statistically sound TSP measurements allowed the spatial extent of dust episodes to be predicted (Figure 4.2).

The representation of dust episode extent is based upon GBVAPCD Hi-vol TSP values for the worst 5% of all days roughly corresponding to the sum of the LADWP photographic catagories "Recognizable dust" and "Extensive dust". Approximately 40 transects were made across the lake and playas as they existed around January 8, 1981 (6373 ft) (Mann et al 1982). Transects were made parallel to the typical dust episode westerlies, matched in this example to the direction of the November 29, 1980 episode that has been photographically documented both along the wind (LADWP) and at right angles to the wind (Mono Lake Committee). (Appendix B). A lateral variability of $\pm$ 15° in direction was estimated from the photographs, as was the lofting angle. Both measured mean backgrounds (Lee Vining) and playa alkaline/saline particles were considered.

Table 4.4 Summary of Owens Lake MODDM Predictions

Note: Points of calibration to measured particulate most for the profiles are underlined twice, while other measurements are underlined once.

Total Suspended Particles, 24hr Hi-Vol (mg/m^3)

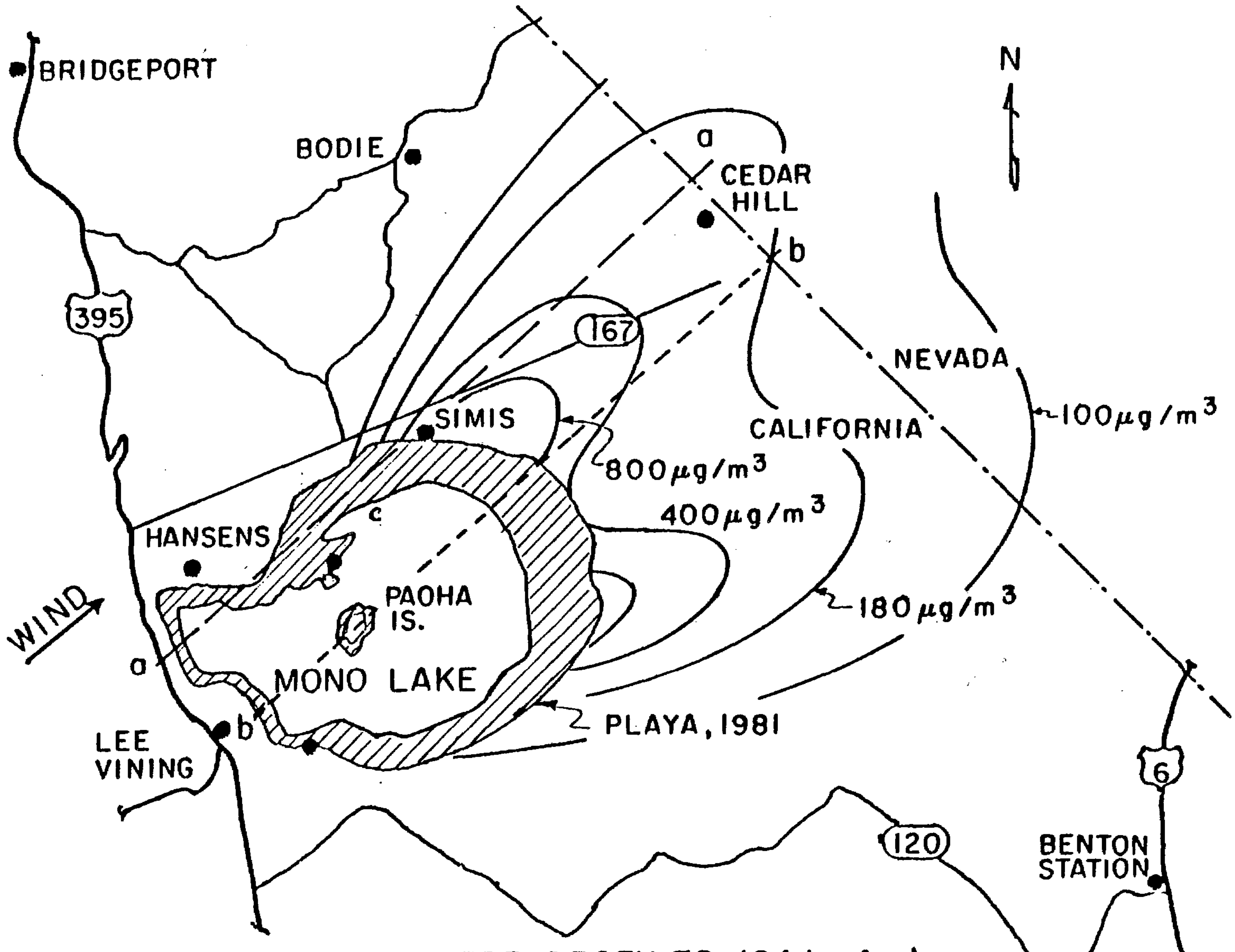
Distance (mi) (downwind edge of lake bed)	"Mean" Episodes (5% of all days) Parameter Set M	"Mean" Episodes (5% of all days) Parameter set P	Episode (4/16/79) Parameter Set M	Severe Episode (12/20/82) Parameter Set P
0	1483	1490	1711	4072
1 Keeler	1201	1202	1386/1570	3295
2	979	975	1128	2677
3	803	795	925	2191
4	664	653	764	1806
5	554	540	637	1502
6	467	451	537	1261
8 Lone Pine	343	323	393/324	918
10	264	242	303	702
15	170	143	194	441
20	135	106	154	346
25 Independence	120	92	136	311
30	110	77	124	275
40	95	62	108	235
50 Big Pine	84	51	94/37	204
75 Bishop	62	34	69/130	143
100	47	25	52	102
125 Mono Lake	37	20	40	75
150	30	18	32	56

The model also allows variations of Mono Lake water level, giving predictions of the dust near Mono Lake under such conditions. (Table 4.5) These are shown in Figure 4.3. Notice the effect of bodies of water in supressing dust formation by acting as a sink for coarse particles. The model was run for the lake as it was, Summer 1984, when it had risen 9 feet. (Stine et al. 1984; NASA Landsat photo, Science, 1982). Dust levels down wind were sharply reduced due to a small water embayment, (Table 4.6) marked "C" in Figure 2. Loss of such water bodies has a dramatic effect on TSP levels, as shown by the Paoha Island transect. The ratio of TSP values of the lake as it was 1981 (6373 ft.) to the projected stabilization level with diversions (6323 ft) increases by 180% for the north playa transect, 480% for the Paoha Island transect, and 1,090% for the south playa transect. (Table 4.7) Establishment of 8 to 10 mile playa fetches at Mono Lake will result in particulate levels similar to or greater than those at Keeler, due to the higher salt aerosol generation rate.

4.3 Mitigation Measures

An obvious mitigation measure is to place the playa areas under water. An unscheduled but invaluable experiment along these lines occured in 1982 and 1983 at Mono Lake, when two wet winters and reduction of diversions allowed Mono Lake to rise about 9 feet, reaching its 1973 level. Owens Lake had the worst dust episodes in recorded history in 1982, and since Owens episodes often occur in conditions that also give dust episodes at Mono Lake (OWENS, Fig. 7), one would have anticipated a series of severe episodes at Mono Lake. In fact, these did not occur (Appendix A, Figure A and Table A.2). In 1980, the worst recorded Mono episode was 50% larger than the worst recorded Keeler episode, with standard GBVAPCD one-day-in-six Hi-vol sampling. In 1982, the worst Owens episode was five times greater than the worst Mono episode. MODDM predicts a reduction of about a factor of two (Table 4.6), based upon the severing of the dominant north playa fetch (marked transect 'a' at point 'C'; Figure 4.2).

FIGURE 4.2



MEAN EPISODE TSP PROFILES (24 hr Av.)
MONO-OWENS DAVIS DUST MODEL (HIGHEST 5% OF ALL DAYS)

FIGURE 4.2 Mean episode TSP profiles (24 hour average)
Mono-Owens Davis Dust Model (Highest 5% of all days)

TABLE 4.5 Summary of Mono Lake MODDM Predictions

Note: Points of calibration to measure particulate mass for the profiles are underlined twice.

Distance (mi) (downwind edge of lake)	"Mean" Episodes (5% of all days) North Playa Transect (a) Lake level 6373 ft (1/8/81)	Lake level 6330 ft (Predicted)	Severe Episodes (11/29/80) Parameter set M	Parameter set P
0	1030	1621	4110	4400
1 Simis Ranch	833	1310	3323	3543
2	675	1060	2702	2867
3	553	863	2211	2332
4	454	708	1822	1909
5	376	586	1515	1574
6	315	488	1274	1308
8 Cedar Hill	227	348	930	930
10 Nevada St. Line	17	260	710	688
15	13	152	445	394
20	77	112	348	283
25	67	95	312	240
30	58	81	277	198
40 Hawthorne, NV	47	65	237	153
50	40	53	205	121
75	28	38	145	70
100	22	27	103	43
125	18	21	75	30
150	17	18	56	23

FIGURE 4.3 Profiles across Owens and Mono Lakes from Mono-Owens Davis Dust Model as a function of lake levels

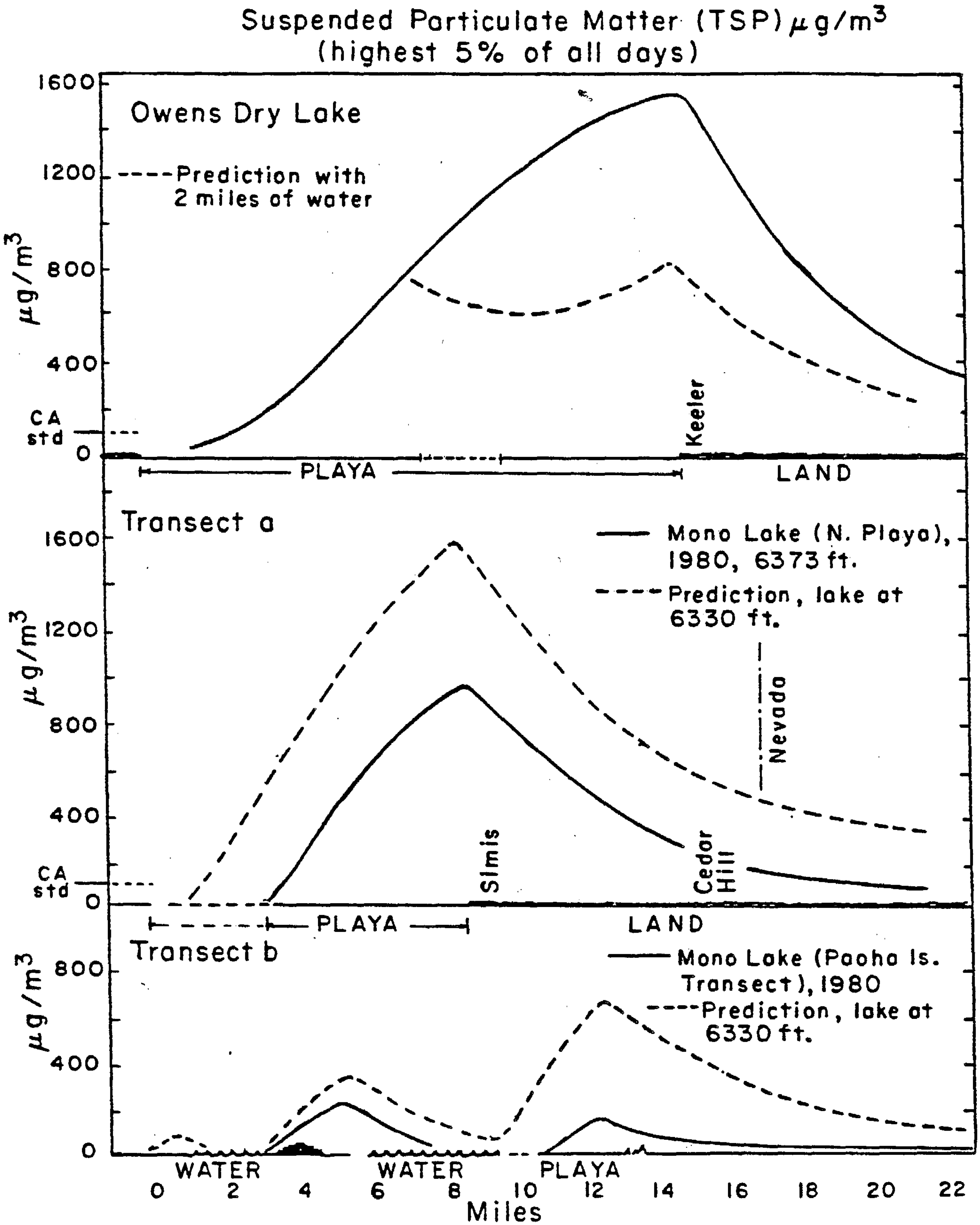


Table 4.6: MODDM prediction, Mono Lake at 6382 ft (1983)

MONO-OWENS DAVIS DUST MODEL
(MODDM)

Ver. 3, 11/84

Wind Velocity and Threshold (mi/hr) 35 25

Threshold Length and Playas (mi) 1 3 2.2 0

Water Lengths (mi) .5 0

Mass Factors: Bkgd, Threshold, Rate, Total (10-6g/M3) 15 350 0 350
Coarse/fine fall-off rates and fractions 4.2 38 .91 0.09

Length From Upwind Edge 3mi Mass at End of First Playa 251.9
Lake Fraction 97.1%

Length From Upwind Edge 3.5 Mass at End of First Water 225.8
Lake Fraction 97.1%

Length From Upwind Edge 5.7 Mass at End of Second Playa 512.7
Lake Fraction 98.7%

Mass at Distances X Downwind of Last Water or Playa (10-6g/M3)

Distance (miles)	Mass (TSP)	Ratio to M(O)	Lake Fraction
0	513	100%	99%
1	416	80%	99%
2	339	65%	98%
3	279	53%	97%
4	231	43%	95%
5	193	36%	94%
6	162	29%	92%
8	119	21%	89%
10	92	15%	85%
15	59	9%	75%
20	46	6%	68%
30	36	4%	59%
40	31	3%	52%
50	27	2%	45%
75	21	1%	30%
100	18	1%	18%
125	17	0%	10%
150	16	0%	6%

A similar water barrier was added conceptually to the MODDM predictions for Owens Lake (Table 4.8 and Figure 4.3), with a barrier 2 miles wide by about 6 miles long. A sharp reduction in dust episode levels is predicted for Keeler, Lone Pine, and Independence, about a factor of 2. This barrier, a total of less than 8,000 acres, could use the technology of rice farming to maintain shallow lagoons of salty water, much like ones presently used in Owens Lake for mineral recovery. The annual water requirement would be about 1/2% to 1% of that used every year in rice farming, depending on evaporation rates. Based on the experience of the WESTEC study, these lagoons would collect large amounts of coarse particles, and here the experience of the mineral collection ponds near Keeler and Olancha would be valuable.

The Davis dust model also raises the possibility of estimating the effect of possible mitigation measures other than covering the playas with water. Of the 5 essential conditions for triggering large salt storms, only two are capable of amelioration:

a. The wind shear at the surface caused by the very flat playas,
b. The existence of loose, coarse particles.

The role of the wind shear is clearly seen in studies done as part of this program measuring the resuspendability of Mono area soils. Dirt from non-lake areas is easily blown into the air, far more easily than playa materials. Yet, such dusts rarely contribute any significant fraction of the observed particulate matter in the TSP—dominating salt storms. This is shown both chemically, morphologically, and by regional photographs. The resolution of this dilemma is found through the greatly reduced wind shear and much larger roughness parameter Z_o found in vegetated areas around the lake. The wind is forced up above the sagebrush and other vegetation. If the lake were slowly falling, the sagebrush, saltbush, and grasses would continually follow the shoreline,

Table 4.7: MODDM predictions, Owens Lake, with 2 miles of water

MONO-OWENS DAVIS DUST MODEL
(MODDM)

Ver. 3, 11/84

Wind Velocity and Threshold (mi/hr) 35 25

Threshold Length and Playas (mi) 1 7 5 Ø

Water Lengths (mi) 2 Ø

Mass Factors: Bkgd, Threshold, Rate, Total (1Ø-6g.M3) 15 128 Ø 128

Coarse/fine fall-off rates and fractions 4.2 38 .91 Ø.Ø9

Length From Upwind Edge 7 mi Mass at End of First Playa 544.3
Lake Fraction 99.5%

Length From Upwind Edge 9 Mass at End of First Water 354.1
Lake Fraction 99.5%

Length From Upwin Edge 14 Mass at End of Second Playa 765.2
Lake Fraction 99.7%

Mass at Distances X Downwind of Last Water of Playa (1Ø-6g/M3)

Distance (miles)	Mass (TSP)	Ratio to M(O)	Lake Fraction
Ø	765	1ØØ%	1ØØ%
1	619	8Ø%	99%
2	5Ø4	65%	99%
3	412	53%	98%
4	34Ø	43%	97%
5	283	36%	96%
6	237	29%	95%
8	172	21%	93%
1Ø	131	15%	9Ø%
15	81	9%	82%
2Ø	61	6%	76%
3Ø	47	4%	68%
4Ø	39	3%	62%
5Ø	33	2%	55%
75	25	1%	39%
1ØØ	2Ø	1%	25%
125	18	Ø%	15%
15Ø	16	Ø%	8%

Table 4.8: MODDM prediction, Mono Lake at stabilization level (6330 ft), Paoha Island transect (b)

MONO-OWENS DUST MODEL (MODDM) VER. 3, 11/84

Wind Velocity and Threshold (mi/hr) 35 25
Threshold Length and Playas (mi) 1 1.7 2.4 3.2
Water Lengths (mi) 2 3.9

Mass Factors: Bkgd, Threshold, Rate, Total (10-6g/M3) 15 350 0 350
Coarse/fine fall-off rates and fractions 4.2 38 .91 0.09

Length From Upwind Edge 1.7 mi Mass at End of First Playa 44.6
Lake Fraction 77.6%

Length From Upwind Edge 3.7 Mass at End of First Water 28.7
Lake Fraction 78.4%

Length From Unwind Edge 6.1 Mass at End of Second Playa 363.4
Lake Fraction 98.3%

Length From Upwind Edge 10 Mass at End of Second Water 160.0
Lake Fraction 99.1%

Length From Upwind Edge 13.2 Mass at End of Third Playa 710.8
Lake Fraction 99.9%

Mass at Distances X Downwind of Last Water of Playa (10-6g/M3)

Distance (miles)	Mass (TSP)	Ratio to M(O)	Lake Fraction
0	711	100%	100%
1	575	80%	99%
2	468	65%	99%
3	383	53%	98%
4	316	43%	97%
5	263	36%	96%
6	221	29%	95%
8	161	21%	92%
10	123	15%	89%
15	76	9%	81%
20	58	6%	74%
30	45	4%	66%
40	37	3%	6-%
50	32	2%	53%
75	24	1%	37%
100	20	1%	23%
125	17	0%	14%
150	16	0%	8%

limiting the size of the playas and, consequently, airborne dust. The rapid reduction of lake levels at Owens and Mono through anthropogenic intervention, and the rapid natural fluctuations of some shallow lakes such as Deep Springs Lake, expose large areas of playa and hence allow salt storms. (Jones, 1965)

The existence of massive amounts of loose, large particles was observed directly through isokinetic sampling on the Owens lake bed in 1982 as our part of the Lands Commission/Westec study. Mean TSP values in three 6 hour salt storms averaged 40,000 ug/m^3 at 2 m above the lake bed. Unlike the Keeler results, major amounts of sand were present along with large pieces of efflorescent crust, ground up in the event. A snow fence placed at the site rapidly generated a major sand dune, confirming the transmigration of sand across the lake bed. Large dunes also exist east of Mono Lake, and many salt storms are triggered just below Black Butte, near Negit Island. This area is a ready source of coarse particles, and it may be implicated in the remarkable salt storms east of that location.

Control of wind shear and coarse particles could be done with snow fence type structures, placed across the prevailing winds from permanent shore lines to near the water. The separation would have to be fairly close to control Z_o and wind shear, every 30 meters or so, but coarse particle control could allow placement much farther apart, at several hundred meters (WESTEC). Quasi-permanent dunes would result, potentially capable of supporting salt-tolerant vegetation since winter rains would naturally leach the salts away while the sand would provide a barrier to the sharp humidity gradient that drives growth of the efforescent crusts. A wood fence would erode rather rapidly unless protected by a wear resistant (plastic?) surface. Nevertheless, especially at Mono, some significant mitigation appears possible since the important fetches, north and south, are long but narrow. At Owens, the scale of such an effort is far greater, but in principle such a program is possible.

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APPENDIX A

Total Suspended Partculates 1979

	Lee Vining Mean	Max	Day	Mono Lake Mean	Max	Day	Keeler Mean	Max	Day
July	42	94	(7)	-	-	-	51	84	(10)
Aug	25	36	(4)	110	266	(19)	45	82	(28)
Sept	51	100	(15)	-	75	(1)	41	128	(30)
Oct	26	93	(12)	-	193	(24)	123	1247	(28)
Nov	7	9	(7)	-	481	(17)	71	537	(19)
Dec	15	18	(11)	88	185	(23)	146	1865	(26)
Year (avg.)	28	58		142	200		79	657	
Year (max)		100			481			1865	

Total Suspended Partculates 1980

	Lee Vining Mean	Max	Day	Mono Lake Mean	Max	Day	Keeler Mean	Max	Day
Jan	14	21	(8)	16	24	(4)	53	668	(19)
Feb	13	17	(3)	30	40	(15)	99	587	(7)
Mar	56	131	(28)	17	19	(10)	172	310	(16)
Apr	-	-	(28)	336	1825	(21)	92	154	(9)
May	10	16	(3)	32	52	(9)	53	85	(15)
June	25	52	(20)	132	264	(12)	43	80	(20)
July	45	73	(8)	205	352	(14)	44	56	(26)
Aug	16	17	(10)	-	-	-	39	45	(1)
Sept	-	-	-	-	-	-	-	-	-
Oct	-	-	-	-	-	-	-	-	-
Nov	18	37	(7)	-	-	-	-	-	-
Dec	6	8	(17)	-	-	-	-	-	-
Year (avg.)	22	41		110	368		74	248	
Year (max)		131			1825			668	

Total Suspended Partculates 1981

	Lee Vining			Mono Lake			Keeler		
	Mean	Max	Day	Mean	Max	Day	Mean	Max	Day
Jan	38	44	(10)	-	-	-	48	49	(22)
Feb	5	5	(27)	-	-	-	20	41	(21)
Mar	24	28	(11)	113	113	(29(1))	31	65	(17)
Apr	21	24	(16)	-	-	-	111	389	(10)
May	38	54	(16)	-	-	-	103	373	(16)
June	28	50	(27)	-	-	-	36	60	(27)
July	37	43	(15)	-	-	-	47	63	(15)
Aug	43	62	(8)	-	-	-	47	77	(14)
Sept	35	64	(1)	-	-	-	38	47	(1)
Oct	32	39	(7)	-	-	-	154	474	(7)
Nov	41	64	(12)	10	10	(21(1))	214	871	(24)
Dec	18	22	(18)	6	8	(19)	54	280	(21)
Year (avg.)	30	42		43	44		75	232	
Year (max)		64			113			871	

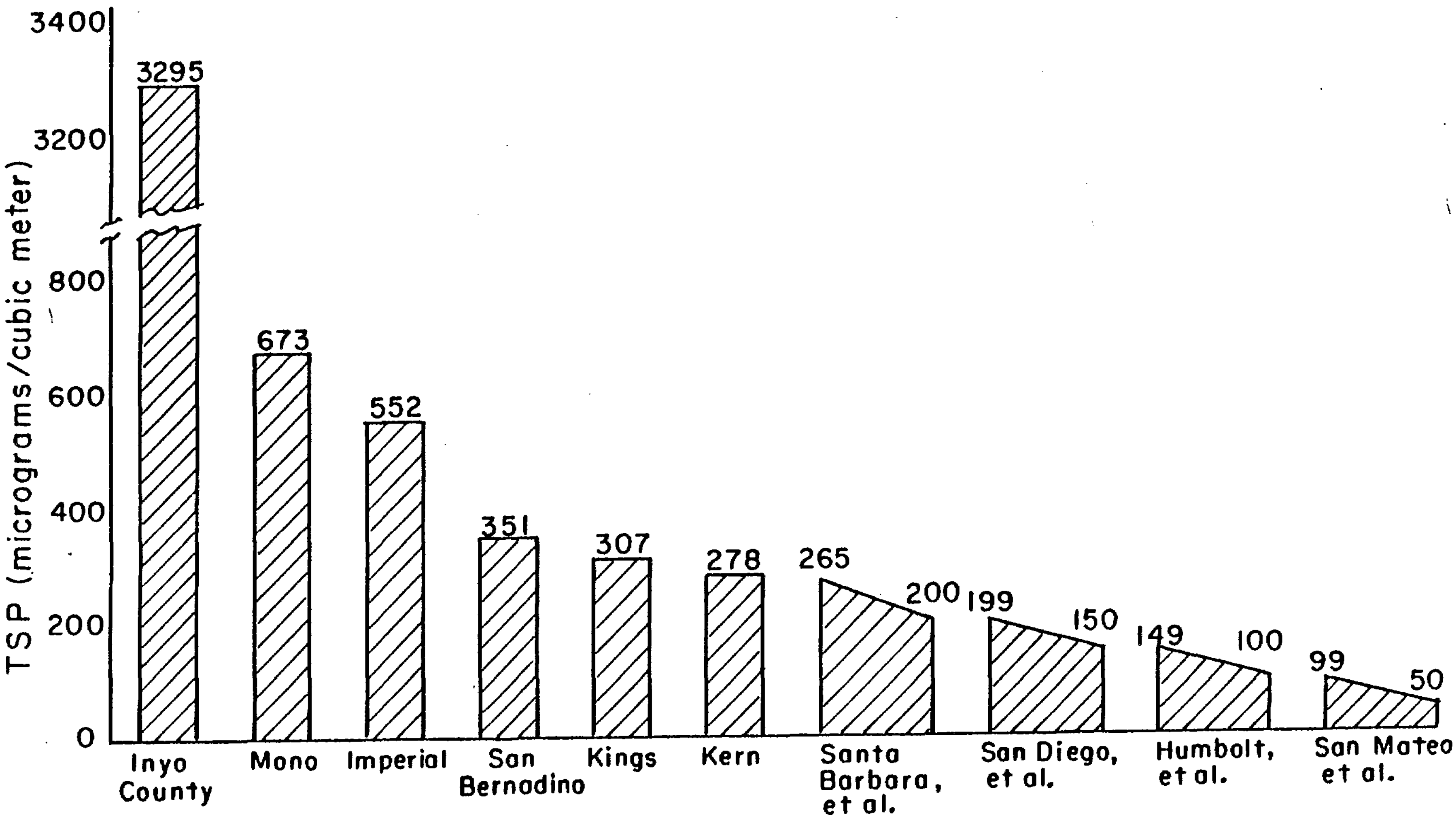
Total Suspended Partculates 1982

	Lee Vining			Mono Lake			Keeler		
	Mean	Max	Day	Mean	Max	Day	Mean	Max	Day
Jan	25	46	(29)	7	7	(2(s))	301	1442	(28)
Feb	29	53	(10)	9	13	(27)	91	818	(1)
Mar	22	32	(24)	173	673	(25)	267	2181	(2)
Apr	21	30	(17)	23	27	(25)	73	210	(29)
May	19	25	(23)	17	21	(8)	99	256	(4)
June	28	60	(4)	24	34	(27)	36	52	(4)
July	26	34	(22)	25	31	(19)	42	58	(22)
Aug	22	29	(9)	21	24	(25)	50	99	(21)
Sept	17	32	(14)	20	21	(6)	205	633	(29)
Oct	25	38	(2)	27	27	(18)	27	47	(7)
Nov	25	41	(25)	9	14	(6)	30	121	(18)
Dec	43	57	(2)	8	18	(12)	487	3295	(20)
Year (avg.)	25	40		30	76		142	768	
Year (max)		60			673			3295	

Total Suspended Partculates 1983

	Lee Vining			Mono Lake			Keeler		
	Mean	Max	Day	Mean	Max	Day	Mean	Max	Day
Jan	47	61	(12)	14	20	(15)	22	33	(22)
Feb	-	-	-	-	-	-	134	455	(18)
Mar	-	-	-	-	-	-	169	919	(31)

Worst 24 period by county during 1982, total suspended particulates (TSP) in micrograms/cubic meter.



Description of the Mono-Owens Davis Dust Model, MODDM

The MONO-OWENS DAVIS DUST MODEL is a semiempirical model of dust generation and transport based upon data from studies of the Owens Valley and Mono Lake. The generation of the dust is based on observations of dust generation, mostly personal and photographic, combined with the theory of the generation of dust from Bagnold, Gillette, and other workers in the field. The transport and fall-out is based on some observations of the Owens and Mono areas, but mostly on the measured dust profiles seen during three dust events in the Owens Valley in spring, 1979. Calibration of the model is discussed in the body of this report, along with an independent confirmation derived from district Hi-Vol readings. In this appendix, the model itself will be described.

A few words might be in order as to why the present form of the model was generated. The present model was developed because no other model available to us, including diffusion models with particulate fall-out previously used by us in freeway studies, was able to even qualitatively reproduce the lofting of the dust clearly observed and measured at both sites. Further, the chemical fractionization of the Owens Valley dust, and the two different fall-off rates needed to describe the ground level was clear that the decrease in ground level concentrations versus distance was due more to the admixture of clean air into the plume than fall-out to the ground versus distance. No parameter was added to the model without observational support for it. For instance, the up-wind playa "dead region" was clearly seen at both Owens Lake (from Navy high altitude photographs) and Mono (reproduced in the appendices).

Finally, by calibrating the model against actual and well documented dust events, the results are forced to be relevant to the local areas. There are uncertainties, however, in scaling the results from the Owens Valley to the Mono Lake area. Terrain effects are less pronounced east of Mono Lake than they are in the Owens Valley, so that one might expect a somewhat faster fall-off versus distance downwind of Mono Lake. However, the largest event was measured at the Nevada state line, so that if the fall-off is faster, it raises even further the dust value seen immediately downwind of Mono Lake. The secondary source of dust seen in the Owens Valley, not associated with the lake bed, is most likely absent downwind of Mono Lake, since no linear river bottom fetch is present east of Mono Lake and that may be associated with the Owens non-lake dust. One parameter that has not been used is the relationship between the wind velocity and downwind dust level.

The primary equation used in the model for generation of labeled dusts is:

Mass (TSP) = constant x fetch

where the fetch is the uninterrupted length that the wind blows over playa areas, corrected for the upwind "dead" region.

The primary equation used to calculate the fall off downwind of the lake is:

$$\text{Mass} = \text{const} \times A_c e^{-x/xc} + A_f e^{-x/xF}$$

where A_c = fraction of coarse mass, whose fall-off is exponential with constant X_c, and

A_f = fraction of fine mass, whose fall-off is exponential with constant X_f.

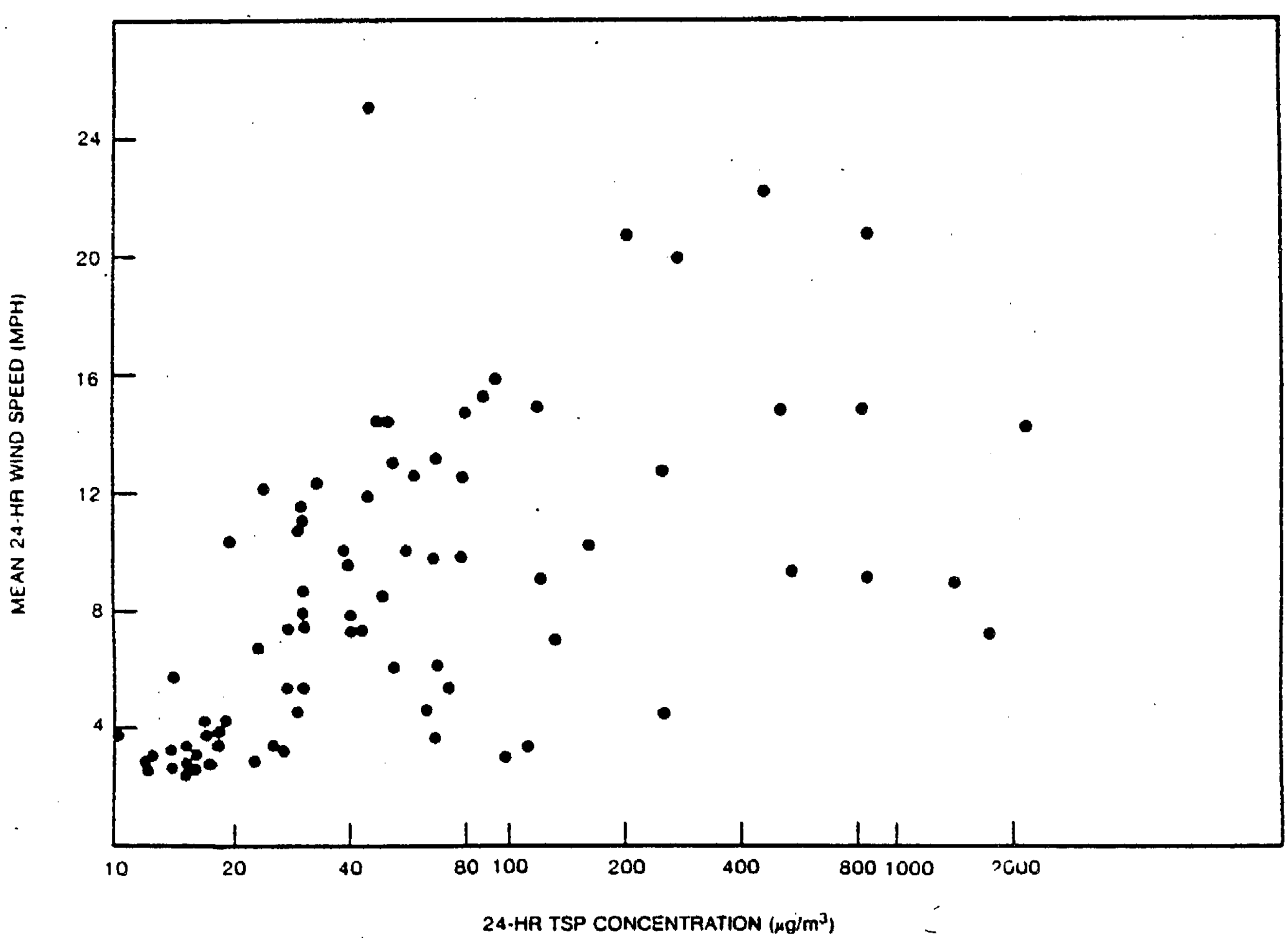
$A_c + A_f = 1$

```
2 SCREEN 2
5 PRINT "                    MONO-OWENS DAVIS DUST MODEL"
10 PRINT
12 PRINT "                              (MODDM)          "
15 PRINT  "                                                11/84, VER.3"
16 REM "  WRITTEN BY TOM CAHILL, 1984,FOR THE AIR QUALITY GROUP, CROCKER NUCLEA
R LABORATORY AND THE DEPARTMENT OF PHYSICS. IT IS BASED ON THE REPORTS WRITTEN F
OR THE CALIFORNIA AIR RESOURCES BOARD ON OWENS AND MONO LAKES (3)"
17 PRINT
18 PRINT
20 INPUT "   WIND VELOCITY (MI/HR)  "; VW
21 INPUT "   WIND THRESHOLD VELOCITY  "; VW0
22 INPUT "   UPWIND DISTANCE THRESHOLD  "; LP0
23 INPUT "   LENGTH OF FIRST PLAYA (MI) "; LP1
24 INPUT "   LENGTH OF SECOND PLAYA "; LP2
25 INPUT "   LENGTH OF THIRD PLAYA "; LP3
26 INPUT "   LENGTH OF FIRST WATER "; LW1
27 INPUT "   LENGTH OF SECOND WATER "; LW2
28 INPUT "   BACKGROUND TOTAL SUSPENDED PARTICULATES (10-6 G/M3)"; MB0
29 INPUT "   MASS GENERATION FACTOR  "; MR0
30 INPUT "   MASS GENERATION RATE  "; MRV
31 INPUT " Coarse particle fall off rate "; XC
32 INPUT " Fine particle fall off rate "; XF
33 INPUT " Coarse particle fraction "; AC
34 INPUT " Fine particle fraction "; AF
35 IF XC = 0 THEN XC = 4.2
36 IF XF = 0 THEN XF = 65
37 IF AC = 0 THEN AC = .9
38 IF AF = 0 THEN AF = .1
```

This fraction of the code sets all the default values to match the measurements made in the Owens Valley. The upwind distance threshold, LPO, represents the playa area upwind of the point of initiation of the dust event. Note that the coarse and fine fractions are not individually measured, since even the fine particles lie above 2.5 microns and no size resolution was available between 2.5 microns and 11 to 15 microns, the inlet cut-off. However, such a parameter and its associated fall-off rate is required to match the data.

```
46 PRINT "BACKGROUND MASS, MASS GENERATION FACTOR, RATE";MB0;MR0;MRV
50 IF LP0 = 0 THEN LP0 = 1
60 IF MB0 = 0 THEN MB0 = 15
80 IF MR0= 0 THEN MR0 = 120
82 MR = MR0
83 IF MRV = 0 GOTO 95
85 IF (VW - VW0)<0 GOTO 95
90 MR = MR0 + .3*MRV*(VW - VW0)^3
```

The data of the WESTEC Owens Lake study clearly show that no simple relationship exists between wind velocity and dust level. (Figure 4.10). Thus, levels are calibrated against the nearest downwind site, not by wind velocity.



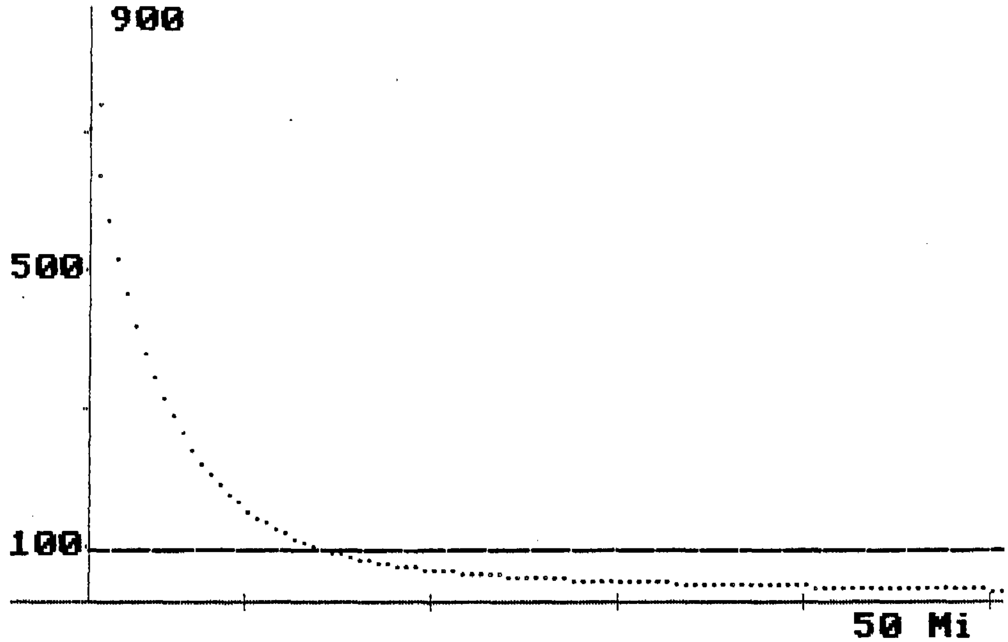
```
100 MB1 = MB0*EXP(-LP1/XC)
110 IF LP1 < LP0 GOTO 130
119 LR = (LP1 - LP0)
120 MP1 = MR*LR*( 1 - (AC*EXP(-LR/XC) + AF*EXP(-LR/XF)))
125 GOTO 140
130 MP1 = 0
140 M = MB1 + MP1
142 F =(MP1/M)*100
145 PRINT
150 PRINT "MASS AT END OF FIRST PLAYA ";M; "  LAKE FRACTION  ";F;" % "
155 IF LW1 = 0 GOTO 300
160 MB2 = MB1*EXP(-LW1/XC)
170 MW1 = MP1*(AC*EXP(-LW1/XC) + AF*EXP(-LW1/XF))
180 M = MB2 + MW1
182 F =(MW1/M)*100
185 PRINT
186 PRINT "MASS AT END OF FIRST WATER ";M; "  LAKE FRACTION  ";F;" %"
190 IF LP2 = 0 GOTO 300
200 MB3 = MB2*EXP(-LP2/XC)
210 MP2 = MW1 + MR*LP2*(1 - (AC*EXP(-LP2/XC) + AF*EXP(-LP2/XF)))
220 M = MB3 + MP2
222 F =(MP2/M)*100
230 PRINT
231 PRINT " MASS AT END OF SECOND PLAYA "; M; "  LAKE FRACTION  ";F;" % "
235 IF LW2 = 0 GOTO 300
240 MB4 = MB3*EXP(-LW2/XC)
250 MW2 = MP2*(AC*EXP(-LW2/XC) + AF*EXP(-LW2/XF))
260 M = MB4 + MW2
261 PRINT
262 F =(MW2/M)*100
265 IF LP3 = 0 GOTO 300
270 MB5 = MB4*EXP(-LP3/XC)
275 MP3 = MW2 + MR*LP3*(1 - (AC*EXP(-LP3/XC) + AF*EXP(-LP3/XF)))
280 M = MB5 + MP3
282 F =(MP3/M)*100
```

This section of the code calculated the generation of the dust under the assumption that the background is all coarse particles, with the average level measured in high wind conditions at Owens Lake, about 15 micrograms per cubic meter. The playa acts as source, beyond the threshold length LPO, and the water acts as a sink. Fall-off across the playas and lake areas follows the same parameters measured downwind of the last playa in the Owens Valley.

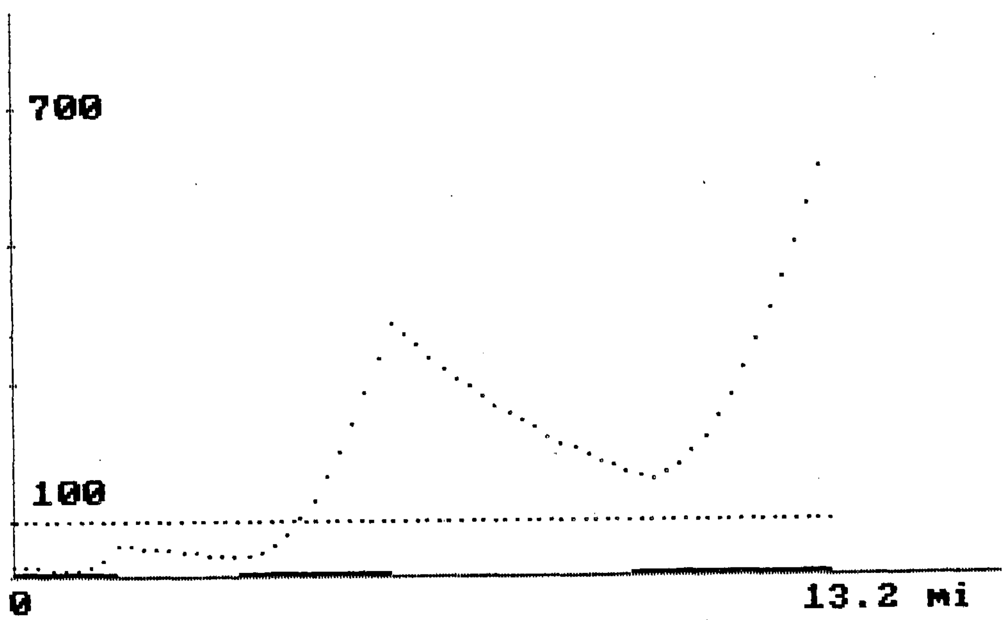
```
310 PRINT "MASS AT DISTANCES X DOWNWIND OF LAST PLAYA OR WATER "
311 PRINT
312 PRINT "DISTANCE";TAB(15) "MASS";TAB(25) "Ratio to ";TAB(35)"Lake Fraction"
313 PRINT TAB(25)"M(0)"
314 DIM R1(150)
315 DIM X(150)
316 DIM MB(150)
317 DIM M(150)
318 DIM MT(150)
319 DIM R(150)
320 READ X
330 DATA  0,1,2,3,4,5,6,8,10,15,20,30,40,50,75,100,125,150
340 MB(X) = MB0*(1 - EXP(-X/XC))+ (1 -.01* F)*M*EXP(-X/XC)
350 M(X) =.01*F* M*(AC*EXP(-X/XC) + AF*EXP(-X/XF))
355 MT(X) = MB(X) + M(X)
358 R(X) =(M(X)/MT(X))* 100
359 R1(X) = (M(X)/M(0))*100
```

This section handles the falloff of ground level concentration, 24 hour arithmetic mean values, TSP equivalent, for distances up to 150 miles. The last calibration point was, however, 75 miles, so that beyond this point is an extrapolation. The fraction due to the lake is found by comparing the lake contribution to the background, which is reestablishing itself once the last playa is passed. However, the background found downwind of Owens Lake is greater than that found upwind of Owens Lake, probably due to loose soil in the Owens River bed. Photographs show clearly, however, that a great deal of white lake dust is present in the air above Bishop, 75 miles downwind, in major dust episodes. The data, however show that there is only modest contributions to Bishop TSP due to the lake, since the lake dust is by this distance highly diluted by great volumes of cleaner air. Thus, the parametrization based to the chemical data represents the true playa contribution versus distance as measured at the ground.

The remainder of the model has options for printing, color graphics in the source generation region and the downwind fall-off region. An example of the output is given below.



Downwind particulate concentrations. The dashed line is 100 ug/m^3, TSP, the California 24-hour standard.



Particulate concentrations across Mono Lake-Paoha Island transect. Playa regions are indicated with solid lines; between the playa regions is water. The 100 ug/m^3 TSP line is included.