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CLIMATOLOGY AND AIR QUALITY OF LONG VALLEY GEOTHERMAL RESOURCE AREA

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MASTER

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PREFACE

This report has been prepared as the climatology and air quality section of the Draft Environmental Impact Statement for geothermal development of the Long Valley Geothermal Resource Area. ✓

K. R. Peterson is the LLL Principal Investigator for the climatology and air quality assessment of Long Valley. His major contribution to this report has been the overall administration as well as evaluation of the expected distribution of surface air concentrations of the significant pollutants released during development and operation of the geothermal resource area.

T. Y. Palmer, formerly a research meteorologist with the U. S. Forest Service, is presently a private consultant and president of the Southwest Environmental Technology Laboratory, Inc., located in Fallbrook, California. His contributions to this report include description of the general climatology, temperatures and winds, air quality, and the general project impact on Long Valley.

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ABSTRACT

The Long Valley Known Geothermal Resource Area is one of the more promising regions for development of a large-scale geothermal energy center. This report discusses the climatology and air quality of the area. Details are given on the temperatures, temperature inversions, and winds. Estimates are presented for the present air quality and future air quality during and following development of the resource area. Also discussed are project impact from added pollutants, noise, and precipitation augmentation.

The major deleterious effects from development of the Long Valley Geothermal Resource Area appear to be due to increased dust loading during and following construction, and noise from production testing and potential well blowouts. Increased pollution from release of hydrogen sulfide and other pollutants associated with hot water geothermal wells seems to present no problems with regard to surrounding vegetation, potential contamination of Lake Crowley, and odor problems in nearby communities. Precipitation augmentation will probably increase the water level of Lake Crowley, at the expense of possible additional fogging and icing of nearby highways.

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CLIMATE

The Long Valley Geothermal Resource Area lies to the east of the Sierra Nevada Mountains and is located near the boundary between the Great Basin Desert to the north and the Mojave Desert to the South. The dryness of Long Valley is a result of both the "rain shadow" effect of the Sierra Nevada Mountains and the general sinking motion caused by the semi-permanent high pressure system off the Pacific Coast.

WINTER

During the winter season the oceanic high pressure system weakens and retreats to the southwest, allowing the storms moving around the semi-permanent Aleutian low pressure area to affect central California. Then a series of rapidly moving weather fronts move through the area, producing abundant rain or snow on the western slopes of both the Sierra Nevada and the higher elevations of the White Mountains. The valleys in the lee of the mountains, including Long Valley, receive little precipitation; however, strong winds do occur with these fronts. There are areas of particularly strong, jet-like winds through and below the passes along the Sierra Nevada crest. Fig. 1, taken in winter, shows clouds moving through Mammoth Pass being torn apart and evaporating on the lee slopes. The edges of these jets are sharp; at time the winds near the ground increase from a few metres per second to 25 or more metres per second (about 56 mph) in less than 100 metres (330 ft.) horizontal distance. These jets are extremely unstable since the momentum of the flow causes the air to become warmer than the surrounding air, often resulting in dust or snow whirlwinds. That portion of Long Valley north of Little Hot Creek and South of Casa Diablo is an area of such jet winds.

If the amplitude of the westerlies is large, occasionally an intense low pressure area will form to the east of Long Valley. Then strong northerly winds occur in the valleys along the eastern slopes of the Sierras with winds frequently in excess of 45 metres per second (100 mph), especially if the air aloft is cold and the terrain falls off toward the south. In the vicinity of Long Valley the most notable region of this kind is the Sherman Grade on Highway 395.

In between storms, the skies are usually clear and the out-going radiation is strong due to the dryness of the air. This cooling often produces a cold, continental high pressure area to the north and east of Long Valley. This is an area of pronounced low-level temperature inversions and extensive down-slope drainage of cold air which can persist not only during the night but also during several hours of the day. This cold high pressure area is shallow and is replaced by relatively weak westerlies about two kilometres above the ground.

SUMMER

In summer strong solar insolation over the western deserts heats the ground, thereby reducing the surface pressure and creating an inflow of air into the resultant area of lower pressure. This effect is responsible for mountain valley winds and the monsoonal-type flows which occasionally penetrate the lower passes of the Sierra Nevada. These flows are much stronger in Southern California because the passes are lower (1500 m or 5000 ft.). Occasionally these low-level flows from the Los Angeles Basin will move up the Owens Valley as far north as Independence. [1]

Upper level winds are dominated by a large high pressure system whose center is usually over Arizona, but wanders from day to day. When the upper level high moves sufficiently far northward (usually in late July and August) the resultant circulation brings in warm, moist air from the Gulf of Mexico or the Gulf of California. This often causes frequent thunderstorms over the mountains and ridges. Occasionally these thunderstorms drift over desert areas to leeward of the mountains.

TOPOGRAPHY

Normally a description of topography would not be interspersed between sections dealing with climatology. However, the altitudes of the various features near Long Valley have such a profound influence on the climate, topography is introduced at this point. Locations referred to in this section and elsewhere in the text are depicted in Fig. 2.

The Long Valley Geothermal area is at the headwaters of the Owens River on the eastern side of the Sierra Nevada Mountains. Major topographic features that tend to control air flows are the Mammoth Pass to the west, the Mono Basin to the north, the White Mountains to the east, and the Owens Valley to the south. Air flows in the valleys do not necessarily parallel river and stream flows, as is often true in less complex terrain. For example, major sources of cold air may be in areas where there is very sparse rainfall and consequently little or no runoff. The valleys and mountains are oriented north-northwest to south-southeast with elevations varying from below sea level in the south to 2100 m (7000 ft.) in the Bridgeport Valley to the north. The mountain ridges rise to 3200 m (10500 ft.) above the valley floor in the middle of the area, while topography averages 1800 m (6000 ft.) above the valley floor in the northern and southern ends. Mt. Whitney (4420 m, 14500 ft.) in the Sierra Nevada is the highest mountain in the contiguous United States. Boundary Peak in the White Mountains, on the eastern side of the valley is 4010 m (13150 ft.), while White Mountain is 4340 m (14240 ft.)

MONO BASIN

The Mono Basin, whose wind-borne particulates sometime affect Long Valley, is essentially a closed watershed. (See Appendix E.) The principal geographic feature is Mono Lake, with a water surface of more than 170 km^2 (65 sq. mi.) at an elevation of 1950 m (6400 ft.) The level of this alkaline lake is gradually lowering due to evaporation, thereby exposing large areas of bare clay and mineralized soil. The basin itself is approximately 19 km (12 mi.) by 37 km (23 mi.). The passes through which Mono Basin air moves are at 2400 m (8000 ft.) to the north, 2100 m (6900 ft.) to the east and 2400 m (8000 ft.) to the south. Passes in the Sierra Nevada Range vary from 2700 to 3000 m (9000 to 10000 ft.).

LONG VALLEY

Long Valley topography ranges from 2066 m (6781 ft.) at Crowley Lake to 2400 to 4000 m (7900 to 13000 ft.) at mountains and along ridges. The divide between Long Valley and the Mono Lake Basin is a semi-circular ridge which begins south of June Lake Loop at Deadman's Pass, continues eastward to Bald Mountain (2755 m, 9046 ft.), then east-southeast to Glass Mountain (3390 m, 11123 ft.), southeast along Glass Mountain Ridge, and ends in the vicinity of Round Mountain (2348 m, 7625 ft.) which is near Lake Crowley. The Owen River Gorge drops 870 m (2850 ft.) from the south end of Lake Crowley to 16 km (10 mi.) downstream. On Highway 395, Sherman Summit, north of Bishop, is 2100 m (7000 ft.) in altitude. The most significant pass, in the Sierra Nevada Range to the west, is Mammoth Pass (2800 m or 9175 ft.). This pass lies at the headwaters of the San Joaquin River which flows westward from this point. In this area the Sierra Nevada

range averages more than 3300 m (11000 ft.), with many peaks exceeding 4000 m (13000 ft.). Near the Known Geothermal Resource Area lie the Little Antelope Hills whose peaks rise a short distance above the valley floor; Lookout Mountain (2545 m or 8352 ft.), the highest peak in the immediate area, lies in the northwestern portion of the Owens River Valley. Little Antelope Valley, which lies near the southern boundary of the Little Antelope Hills, is about 100 m (300 ft.) deep and 1.5 km (1 mi.) across. It is approximately circular with a flat bottom. Drainage is through a narrow canyon to the east, through which Little Hot Creek flows. Numerous narrow valleys with steep sides run out of this hill mass. The principal population center in this area is Mammoth Lakes Village; it has a permanent population of about 3000. In winter, sports enthusiasts increase the population to about 20000.

OWENS VALLEY

The Owens Valley is the principal valley in this region and as such sometimes influences Long Valley's climate. It is almost 200 km (120 mi.) long, and 24 to 48 km (15 to 30 mi.) wide. The logical northward extensions of the Owens Valley are the Chalfant, Hamil and Queens Valleys. Montgomery Pass, Nevada, at an elevation of 2200 m (7167 ft.), is the only broad pass through the White Mountains between Inyo County and the area north of the Mono Basin. The valley walls are precipitous on both sides of the valley. The Owens Valley is sparsely settled with small population centers at Bishop (8500), Big Pine (1200), Independence (900), Lone Pine (2000), and Benton (500). Owens Lake is a large, semi-dry lake with exposed areas of chemical and clay deposits.

TEMPERATURES AND TEMPERATURE INVERSIONS

GENERAL

Temperature records are available for a 34-year period from Long Valley Dam located at the south end of Lake Crowley.^[2] During the winter months, the USDA Forest Service maintains similar records at the Mammoth Ranger Station.^[3] Mean temperatures are below freezing at the dam from mid-November to the end of February. A summary of these data follows; further details are given in Appendix B. Freezing temperatures occur from November to mid-April at the Mammoth Ranger Station, which is only 300 m (1000 ft.) higher. The average maximum daily temperature is 18°C, occurring in July. The coldest months of the year are December and January when the temperature falls below -12°C at night about 25 percent of the time. Long Valley daytime temperatures rise above -12°C about 95 percent of the time during these months. Such cold nights persist into February and March 20 percent of the time. Cold air drainage during clear, relatively calm weather conditions is primarily off the colder nearby slopes, and is relatively slow, 1 metre per second (about 2 mph) or less. The temperature inversion depths are quite shallow over most of Long Valley because the steep slope south of Lake Crowley causes a rapid drainage of cold air down the Owens River Gorge. Observations with an acoustic sounder during the month of January 1976 indicate no evidence of temperature inversions between 60 and 600 m (200 and 2000 ft.), the range of the instrument. Visual observations of fog layers over the lake suggest that the nighttime temperature inversion is below 60 m.^[3] Temperature observations at the meteorological tower near Hot Creek during

the same period showed strong nighttime inversions, usually deeper than the height of the tower (15 m or 50 ft.). Visual observations (Palmer) of early morning steam plumes from geothermal springs near the Mammoth Fish Hatchery (see Fig. 3) indicate that the inversion is about 60 metres deep at that point. This estimate agrees well with the estimated depth of the fog layer which forms in the late fall and early winter.^[3] The inversion persists over Lake Crowley when the lake is frozen (from November to June). However, there is usually no fog during this time.

Radiosonde measurements of upper air temperatures east of Mono Lake, near the Glass Mountains in the Mono Lake Valley, during December 1965 showed a strong morning temperature inversion;^[4] the air at 335 m (1100 ft.) was 15°C (27°F) warmer than at the surface. During the day the inversion lifted about 120 metres (390 ft.) off the ground. Similar observations taken in June 1966^[4] show an early morning temperature inversion about 150 metres (490 ft.) deep. Observations taken in September 1967 at Montgomery Pass, Nevada^[4] show up-valley daytime winds extending to 500 metres (1600 ft.) and down-valley drainage nighttime winds about 300 metres (1000 ft.) deep. This flow is in the general air flow pattern developed in the Owens Valley and the desert areas of Nevada. In this case, the main river flow pattern of the Owens River does not coincide with air flow patterns since little rain or runoff occurs in the Chalfant-Hamil Valleys, which are a natural northward extension of the Owens Valley. Aircraft soundings at Independence in May and June 1972^[1] found inversions averaging 220 metres (700 ft.) deep.

EXCEPTIONAL LONG VALLEY TEMPERATURES AND INVERSIONS

Aside from the previously mentioned temperature inversions, the exceptional topographically-induced feature in the Long Valley area is the Little Antelope Valley. This valley is a natural circular bowl about 60 m (200 ft.) deep and 1600 m (1 mi.) across. The only exit is a narrow gorge through which a tributary of Little Hot Creek flows. Preliminary analysis of data from a meteorological tower located in this valley shows that extremely strong temperature inversions form at night. In winter, temperature increases of 20°C (36°F) have occurred between the surface and 30 metres (100 ft.).

WINDS IN LONG AND OWENS VALLEYS

Winds in the Long Valley Geothermal Area are strongly influenced by topography. Channeling of the wind through the valleys and the mountain-valley waves induced in the westerlies by the Sierra Nevada-White Mountain ranges for examples of these effects. Figures 4 and 5 show the prevailing wind flow during a typical afternoon and evening, respectively. Such wind flows can be classified into two major categories - synoptic winds and density winds.

SYNOPTIC WINDS

Synoptic winds in Long Valley are associated with winter storms that affect the region. On the average, 38 storms affect Long Valley each year. Such storms usually last two to three days. The stormy season begins in September when, on the average, one or less storms occur. The storm frequency increases to six per month in January and decreases to two per month in May. See Appendix A for more details. During most of

the wet season, a two day interval of fair weather occurs between storms. Then northerly winds are frequent in Long Valley. In summer, large scale storms are very rare.

Wind measurements have been made in winter on Mammoth Mountain (3400 m or 11000 ft.) by the U. S. Forest Service during the testing of an automatic weather observing system. [3] These records show that storm winds primarily come from the southwest or north to northeast, with brief periods of northwesterly winds. These winds can be extremely strong and turbulent.

DENSITY OR MOUNTAIN-GAP WINDS

Density winds are usually produced by radiative heating and cooling of the surface. Such winds are associated with the drainage of cold air through passes in major mountain ranges that separate air mass source regions. For example, the Sierra Nevada Mountains separate the modified maritime Pacific Ocean air from the continental dry air of the interior of the United States. When this maritime air is about 3000 metres (10000 ft.) deep and surface heating in Nevada is sufficiently strong, westerly flow through Mammoth Pass will produce locally strong winds. These jet-like winds usually flow around the south end of the Little Antelope Hills and north of Hot Creek. The wind speeds are between 7 to 12 metres per second (16 to 27 mph) in the afternoon. A large counter-clockwise whirl is often observed in the Little Antelope Valley during periods of density winds.

COLD AIR DRAINAGE WINDS

The gravitational settling of cold air down slopes and out of valleys is caused by the cooling of air in contact with the ground. The ground is strongly cooled at the higher elevations of Long Valley and the nearby mountains since the air is thinner and contains less moisture than at lower elevations; consequently the radiation of heat from the ground is more efficient. Although this is usually a nighttime phenomenon, often down slope drainage winds occur in shaded areas during daytime. In summer, near the Little Antelope Hills, drainage winds typically begin shortly after local sunset and attain a speed of 2 to 3 metres per second (4 to 7 mph) from the west to northwest. Frequently in summer these winds occur with easterlies aloft at speeds of about 10 m/sec (18 mph). Such reversals are caused by downslope flow of cool air off the western slopes of the Sierra Nevada Range.

In winter, the drainage winds are stronger and are called "glacier" or "fall" winds. Speeds average about 5 to 10 metres per second (11 to 22 mph) near Highway 395. They are extremely gusty with typical horizontal speeds in gusts of 3 to 5 times the mean winds and strong downward motions of 1 to 2 metres per second (2 to 4 mph). The air is usually very dry because of heating during descent. As in summer, these winds typically start shortly after sunset on nearly calm, clear nights. As the surface temperature inversion in Long Valley deepens, the downslope wind maximum speed gradually moves aloft and is above 15 metres (50 ft.) by midnight. The areal extent of such winds spreads and they rapidly decrease in strength as they blow eastward. They are of little consequence by the time they reach the Owens River, where they usually turn south and merge with the

down-river flow. In the northern parts of Long Valley the cold air drainage winds are not as strong because the slope of the higher level terrain causes the fall winds to drain northward out of Long Valley.

WINDS PRODUCED BY LOCAL HEATING

The topography of Long Valley and the surrounding mountains is the determining factor in the strength and direction of the local thermally driven winds (winds produced by differences in heating). The vertical extent of "bumpiness" of the air associated with thermally driven winds are much greater than with cold air drainage winds. As a result the average speed of the thermally driven winds, due to strong mixing, is less than speeds in cold drainage winds.

The main valley winds in this area occur in the Owens Valley and the Chalfant, Hamil, and Queen Valleys to the north. The air moves north-eastward through Montgomery Pass into Nevada. The up-valley flow reaches its maximum strength (usually less than 5 m/sec or 11 mph) about 4:00 p.m. Pacific Standard Time. Next to the mountains there are upslope winds which tend to return to the center of the valley in a complex flow pattern and merge with the general up-valley flow.

The thermally driven winds in the Long Valley are relatively isolated from similar winds in the Owens Valley. A weak flow up the Owens River Gorge and the Sherman Grade is typical. The Sherman Grade up-slope winds turn to the west and flow up the Sierra Nevada slopes. The up-slope winds in the western part of Long Valley are easterly up the slopes and valleys of the Sierra Nevada mountains. They are very light, about 1 to 2 metres per second (2 to 4 mph). Even within the Mammoth Valley these

winds are less than 3 metres per second (7 mph). This pattern is similar to measurements made in the June Lake Loop area and is a result of the steep easterly slopes of the mountains (averaging 60°). This aspect results in much less solar heating of the slopes because of both the large angle of incidence and the greater depth of the atmosphere (which reduces the amount of incident heat). For example, the sun's rays fall perpendicularly on the eastern slopes at about 7:30 a.m. (PST) in June. Consequently, on the eastern slopes the easterlies do not start until about 9:00 a.m. and end about noon in the spring and fall and last only to about 3:00 p.m. in the summer.

In the eastern part of Long Valley, observations show that during a typical winter day the near-surface air mixes with air aloft to about 120 to 150 metres (400 to 500 ft.). Winds are from the south with little evidence of upslope mountain winds. In a typical summer day the near surface air mixes with air up to 4000 metres (13000 ft.) with light (1 to 3 m/sec or 2 to 7 mph) local winds. These winds are upslope over the dominant terrain near the surface and are replaced by light (1 to 3 m/s or 2 to 7 mph) easterly winds at the top of the layer. In general, both the cold drainage winds and the warm upslope winds dominate the flow except when the area is under the influence of a large-scale storm, or when it is very cloudy.

CURRENT AIR QUALITY

Air quality measurements in the Long Valley Geothermal Area have been intermittent and short term (see Appendix C). Measurements have been made primarily of the common air pollutants characteristic of automobile traffic and cities. A few short duration, special measurements of sulfur

and other compounds peculiar to geothermal sources have been made in the Long Valley Geothermal Area. The accumulated information nevertheless provides some insight into the environmental effects of development of the geothermal resource.

URBAN SOURCES

The principal data for urban sources consists of measurements made by the California Air Resources Board (ARB), using its mobile Air Quality Surveillance Van, in June and July 1974.^[5] In addition, data are available from the California Department of Transportation (CALTRANS)^[6] (Appendix C) in the form of whole air samples of carbon monoxide in December 1974, and ozone measurements made by the U. S. Forest Service in 1976.^[3]

These data show that state air quality standards were exceeded in Mammoth Lakes in June and July 1974 in the total hydrocarbons (THC), oxidant and total suspended particulates (TSP). There are no winter data for these parameters; however, comparison of the ARB 1974 carbon monoxide (CO) data and the December 1974 Caltrans data shows ten to twenty-fold increase in carbon monoxide in winter. Since vehicular traffic increases by only about 25% in Mammoth Lakes during the winter skiing season, this large increase in average CO concentrations is undoubtedly due in large part to the strong wintertime low temperature inversions and the resultant poorer mixing, caused by the fall winds generated on the nearby mountain slopes.

Correlations of THC, oxidant, and TSP with CO are weak; consequently it is difficult to draw valid estimates of wintertime levels of these pollutants. Concentrations will probably be higher, except for TSP. Since there is usually widespread snow cover in winter, airborne particulate concentrations of pollutants will be lower in the winter. The Forest Service

Visitor Center, 2 km (1.5 mi.) east of Mammoth Lakes Village, showed only background levels (0.04 to 0.08 ppm) of ozone in 1976. This indicates that the rural areas have only background levels of ozone. However, significant (but below state standards) amounts of NO_x were measured^[7] both at Mammoth Lakes and within the Long Valley Geothermal Area at the meteorological tower southeast of the Little Antelope Hills.

TOTAL SUSPENDED PARTICULATES

TSP measurements tend to consistently exceed air quality standards in Long Valley.^[1] The frequent moderate to high winds and the loose, sandy, sparsely vegetated nature of the soil determine a region which is highly susceptible to large values of total suspended particulates. The dried-up areas of Mono Lake also produce airborne particulates that are sometimes blown to Long Valley. In addition, there have been occasions in the June Lake Loop when local stagnant nighttime inversions have trapped wood smoke from campers' fireplaces and produced heavy concentrations of TSP.^[8] Similar conditions can trap local emissions in Long Valley.

GEO THERMAL EMISSIONS

Local sources of characteristic natural geothermal emissions are confined to the Casa Diablo area as hot springs and ponds of water (Appendix C). Sulfur background levels for this area are given by a series of observations from the Rovana area (20 mi. west of Bishop) taken once a month for one year.^[1] They show levels of 0.008 ppm SO_2 and 0.0095 ppm H_2S . USGS measurements of H_2S and SO_2 , taken in April and August 1976,^[7] indicate that the steam at Casa Diablo has 8 to 9.5 ppm of H_2S . Measurement 9 metres (30 ft.) upwind show a level of 0.15 ppm of H_2S . Maximum

values near Hot Creek were from 0.1 to 0.15 ppm where H_2S was detected; these samples were immediately adjacent to Hot Springs. All of these USGS measurements were above the 0.03 ppm California standard for H_2S . However the powerful dispersive action of the Long Valley atmosphere rapidly dilutes the gases in short distances to undetectable levels. No amounts of SO_2 were measured at detector thresholds of 0.01 ppm. Intermittent NO_x levels from 0.068 to 0.104 ppm were found at various sites in the Long Valley Geothermal area.^[7] It is not possible to identify the source as natural or manmade. Large values of ammonia (NH_3) were found at the sewage plant (0.143 ppm), while levels of 0.024 ppm were measured during light winds at the Forest Service meteorological tower southeast of the Little Antelope Hills.

Heavy metals, such as mercury, have been found in the soil near the local geothermal sources and probably occur in locally small concentrations in the wind-raised dust.

SUMMARY

The principal air pollution factor under current conditions in the Long Valley Geothermal Area is wind-raised dust (see Appendix E). Oxidant and total hydrocarbon concentrations are occasionally exceeded for 24 hours exposures in Mammoth Lakes.^[1] Levels of carbon monoxide are currently near the maximum 24-hour exposure when stagnant, stable weather conditions occur in Mammoth Lakes.

PROJECT IMPACT

There are four factors related to air quality that may be affected by the development of the Mammoth-Long Valley Geothermal Resource. They

are:

1. Increased dust loads and total suspended particulates (TSP) in the atmosphere due to construction and alteration of the already sparse vegetative cover.
2. Increased releases of sulfur compounds into the atmosphere.
3. Increased noise due to well operations, production testing, and potential blow-outs.
4. Increased clouds, fog, or precipitation due to cooling tower operation wherein moisture and particulates are released. Such particulates are capable of causing ice and snow to form in the cooling tower plume at below freezing temperatures.

DUST LOADING

Windborne and wind-raised dust have been problems in the Long Valley area for many years. Construction and drilling operations will disturb the highly mobile soil and, in some cases, remove or alter vegetation patterns. The present soil conditions are a result of near-equilibrium conditions which have been achieved over many years. Altering this equilibrium reduces the wind threshold for movement by as much as 50% until a new equilibrium is established. [9] The strength of the winds at times during the day will cause TSP standards to be exceeded on an average of about 30% of the days during construction operations. This condition will return to current levels over a period of years as the ground surface returns to equilibrium. Estimates of the dust loading within Long Valley are given in Appendix E.

INCREASED SULFUR RELEASE

Sulfur compounds can harm sensitive plant life, in particular evergreens such as Ponderosa Pine (*pinus radiata*) and Jeffery Pine (*pinus jeffreyi*).^[10] From estimates of projected releases, it is predicted there will be little measurable effect on vegetation because (1) concentrations of sulfur compounds in the steam are low (about 8 ppm), (2) mixing of the near-surface air in Long Valley is vigorous during the day, and (3) during stable atmospheric conditions, when dispersion of the surface air is at a minimum, the temperature inversions are shallow and the steam plumes from production testing and possible blow-outs would penetrate the inversions and diffuse at heights where the dispersion is faster. In addition, except in the Little Antelope Valley, air drainage under stable conditions is toward the center of Long Valley where there is little vegetation to affect. Consequently any materials released below the temperature inversion will usually move away from forested areas sensitive to sulfur compounds. Pollutants released above the temperature inversion during summer evenings will usually move toward Mammoth Lakes. However, average winds of 10 m/sec (18 mph) will greatly reduce the concentrations downwind. (See Appendix D.)

The possible exceptions to a prediction of little or no impact of the release of sulfur compounds would occur if the steam jets form a layer of fog and supplement the cold fogs that form naturally over Lake Crowley in September, October, and November. This is considered to be unlikely since the glacier or fall winds from the mountains have very low humidity and there would be insufficient steam from isolated operations to form an

extensive saturated fog or stratus layer if the temperatures are above -12°C . Effects at lower temperatures will be discussed below. Even if a fog layer were formed, an active drizzle could occur near Lake Crowley only if the two fog layers were in direct contact. Estimates of concentrations of hydrogen sulfides and other significant pollutants are given in Appendix C.

NOISE

A geothermal well operating as an open well during a blowout or during production testing produces a noise level of 118 to 120 absolute decibels [db(A)] about seven metres (23 ft.) from the well.^[10] Experience at the Geysers Geothermal Area indicates that rock mufflers can lower these sound levels by about 25 percent. However, the shallow temperature inversions and nighttime westerly winds in the western part of the Long Valley Geothermal Area will duct and on occasion focus well and operation noise into the populated areas along the eastern slopes of the Sierra Nevada. Atmospheric variability in this area makes it difficult to accurately predict levels and precise location of excessive noise. It is probably feasible to manage this noise with sound barriers of nominal height because of the shallowness of the temperature inversion.

COOLING TOWERS AND STEAM OPERATIONS

Atmospheric water vapor will be significantly increased by geothermal operations of cooling towers and steam wells if natural rain or snow is occurring or if temperatures are below -12°C .^[11,12] Measurements of enhanced snowfall downwind from large cooling towers elsewhere have indicated increases of about 7 mm (0.3 in.) of fluffy snow per hour when the temperature was -12°C (10.4°F). (See Appendix F.) This snow was observed to

start 13 km (8 mi.) from the cooling towers and continue to 43 km (27 mi.). Visibilities were reduced to 1600 metres (1 mi.) by the snow. The indicated impact area is from the Owens River or the Glass Mountains (depending upon siting of the cooling towers) then east to the White Mountains and north to Mono Lake. There will undoubtedly be terrain effects on amounts or rates of snowfall. The proper conditions occur 26% of the time at night in December and January and 19% of the time during February and March. Twenty-four hour periods when the temperature is below -12°C occur 4% of the time in December, 2% of the time in January and 1% in February. These values indicate enhanced snowfall estimates of between 250 mm (10 in.) and 1950 mm (77 in.). These amounts will not be deposited in the same area but will depend upon the variability of the wind. During the evening, if the air temperature is sufficiently cold, it is possible for supercooled fog, instead of snow, to form downwind of the cooling towers. Such fog would follow the downslope air currents, forming a shallow layer of reduced visibility.

In addition, many of the trace minerals in geothermal waters are effective in changing cloud vapor into snowflakes. For example, small amounts of silver iodide, lead iodide, and aluminum oxide may be present in sufficient quantity to affect natural clouds both during localized summer thunderstorms and large-scale winter storms. In either case, rain or snow that might otherwise form and evaporate before reaching the ground will likely fall on the surface in the presence of these trace substances and increased water vapor. If only the water evaporated from cooling towers under the planned full development (200 MW) of the Long Valley Geothermal Area reaches Mono Lake, further reduction in the lake level by evaporation would stop.

A third possible effect of cooling towers and steam wells is to create large, intense dust devils. A large, persistent whirl has been observed in the Little Antelope Valley. This is probably caused by the jet-like winds flowing through Moommoth Pass. Large sources of heat could cause this whirl to migrate or form a new whirl.

MITIGATING ACTIONS

Blowing dust and sand can be decreased by appropriate treatment of disturbed areas. Technology being developed for the Geysers Geothermal Resource Area for removing sulfur from steam can probably be applied to the Long Valley Geothermal Area.^[10] Noise can probably be controlled to acceptable levels by baffles, walls, and absorbent materials. It would probably be desirable to augment precipitation.

FIG. 1 (top picture). Looking to the west toward Mammoth Pass in winter. Shows storm clouds from a Pacific weather front. Note how clouds are dispersed and evaporated as the winds blow them through the Pass.

FIG. 3 (bottom picture). Taken shortly after sunrise, this picture shows a natural geothermal steam plume. Note how the plume spreads horizontally due to the strong low-level temperature inversion.

FIGURE 1

FIGURE 3

FIG. 2. Locations of geographic and topographic features mentioned in text. The Long Valley Geothermal Area is within the boundaries of the Owens River north of Lake Crowley, the western shore of Lake Crowley, and Route 395.

FIG. 4. Typical afternoon wind flow in vicinity of Long Valley

FIG. 5. Typical nighttime wind flow (mostly drainage winds) in vicinity of Long Valley.

REFERENCES

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APPENDIX A

LONG VALLEY WINTER STORMS

The Long Valley Geothermal Area lacks comprehensive meteorological observations over long periods of time. Intermitent observations, made at a number of sites, are not long enough to reliably establish the climatology of the area with precision.

The formation, frequency of occurrence, and intensity of temperature inversions is important to a study of the environmental impact of the development of geothermal power on air quality and climate. Dispersion of emissions and the effects of local weather modification depend upon the frequency of occurrence of temperature inversions, which in turn usually require periods of clear, relatively calm weather. Consequently, lacking long term observations, determination of periods of clear weather must be developed from other considerations.

We have chosen the recurrence interval of storm systems as an implicit measure of the frequency and intensity of temperature inversions in the Long Valley Geothermal Area. The storm systems over the central and southern Sierra Nevada have been tabulated and classified by Rowland et al. [A1] for the period 1929 to 1954. A statistical study of the successive days between storms must have an upper and lower bound; the bounds lie between the upper bound zero and the number of days in the month.

From these considerations and an examination of accumulative distribution probability curves drawn to the data for the months October through March (Fig. A7), it appears that the distributions are of a bounded lognormal type.

The four parameter lognormal distribution has been treated by Aitchison and Brown [A2], Johnson [A3] and Moshman [A4]. The general properties of a lognormal distribution may be considered in terms of the number of parameters involved. A parameter here means the number of quantities that are necessary to describe the distribution. The minimum number of parameters is two - the mean, μ , and the variance. The variate cannot assume zero values since the transformation $y = \log(x)$ is defined only for $x > 0$.

If there are physical reasons to believe that a lower or upper bound ($\pm \gamma$) exists, then the three parameter lognormal distribution $y = \log(x \pm \gamma)$ is appropriate. This transformation yields three parameters - the mean, the variance and the upper or lower bound, γ , as appropriate. If there are physical reasons to believe that an upper bound and lower bound exist (whose average is not the mean), then the appropriate transformation of the data is $y = \log((x - \gamma)/(\theta - x))$ which has the four parameters the mean, the variance, the upper bound, γ , and the lower bound, θ .

Higher order lognormal distributions are difficult to analyze, particularly when the upper or the lower bounds are not known. The difficulty becomes even greater when there are mixed distributions with several almost equal peaks, such as occur during the month of October. Aitchison and Brown [A2] recommend that the upper and lower bounds be estimated from a cumulative plot on logarithmic probability paper.

The data for October (Fig. A1) appears to be multi-modal with three probable maxima at 3, 6 and 10 days. November is more of a winter month; more than 20% of the clear intervals are two days in length. The November peak at 6 days is of approximately the same amplitude (11%) as in October,

but the maximum at 10 days has decreased almost 50% from 13 to 7 percent. In December the same relationships hold approximately, except that the maximum at 2 days has broadened considerably. These relations also hold in January (Fig. A4). However, in February there is a marked increase in preference for the peak near 2 day clear periods (Fig. A5), which occurs almost one-third of the time. A secondary peak also occurs for clear periods 5 days in length. In March (Fig. A6) the mode at two days is by far the strongest, while the secondary peak for clear intervals 6 days in length is strongly suppressed. The months of March and February (Figs. A8 and A9) have the more nearly single logarithmic distribution. The upper bound in March was 31 days which indicates that occasionally the whole month can be storm-free. The apparent upper bound in February is for clear periods 18 days in length. January is a composite of two distributions, with no clear upper bound in the length of clear periods (analysis not shown). The other months were not analyzed because of their multi-modal distributions. Spatial coherence and partial coherence between temperatures, temperature lapse rates and storm occurrence were not performed because of a lack of a coherent set of records.

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A-4

FIG. A-1

SUCCESSIVE DAYS OF CLEAR SKIES

A-5

FIG. A-2

SUCCESSIVE DAYS OF CLEAR SKIES

FIG. A-3

SUCCESSIVE DAYS OF CLEAR SKIES.

A-7

FIG. A-4

SUCCESSIVE DAYS OF CLEAR SKIES

FIG. A-5

SUCCESSIVE DAYS OF CLEAR SKIES

FIG. A-6

SUCCESSIVE DAYS OF CLEAR SKIES

Figure A7. Two parameter analysis (mean and variance) of cumulative distributions of successive clear days during winter months, 1929-1954.

Figure A8. Determination of upper bound of successive clear days in March during 1929-1954.

Figure A9. Determination of upper bound of successive clear days in February during 1929-1954.

APPENDIX B

LONG VALLEY CLIMATOLOGICAL DATA

The principal data available for formulating the synoptic climatology of the Long Valley are the storm data described in Appendix A and the sets of observations of various lengths and completeness in and near the area. These include daily wind measurements from the Mammoth Lakes Ranger Station, micrometeorological measurements of wind, temperature, temperature difference and humidity in the flat area east of the fish hatchery, a period of micrometeorological data in the Little Antelope Valley, a 34 year record of monthly temperature and precipitation averages from the dam on Lake Crowley, a few upper air soundings on the eastern side of the Owens Valley, and the climatological data from Bishop (50 km to the southeast), and Gem Lake (30 km to the northwest).

WIND ANALYSES

Wind speed and direction have a natural angular characteristic. [B1]
Conventional displays of such data use wind roses or tables showing the percentages of the time winds occur in defined directional intervals. These depictions range from the relatively crude to the sophisticated composite wind rose of Napier Shaw. [B2]

The mean hourly wind data for the two micrometeorological towers in Long Valley have been used to prepare such wind roses, shown in Figs. B1 to B6 for Hot Springs Creek and B7 to B12 for Little Antelope Valley. The measurement period for the first site is approximately one year; six months

of data are available at Little Antelope Valley. These wind roses show by months the annual course of the frequency of three classes of wind speed from 24 directions. For both sites a chart is shown for every four hours of the day.

The flags in each circular segment, represent the wind in classes that have been chosen to represent winds which are: (1) very light (1 to 2.5 m/sec), (2) light (2.5 to 5 m/sec), (3) moderate (5 to 10 m/sec), and (4) strong (greater than 10 m/sec). The bars in each segment represent the data from each month, progressing clockwise from January. The distributions are scaled from the maximum value which is identified by an asterisk located inside the circles for both the lower level (5 m) and upper level (15 m) plots on the chart. This value is assigned a length of 3.5 inches on the original computer plot. The distribution of calm winds, which is displayed in the center of the "wind star", is by month. Each value is given in terms of the percent of the total number of calm winds. The indicated directions are the same as in conventional wind roses.

The graphical depictions are not usually accompanied by a statistical analysis. The methods given by Mardia^[B1] permit statistical analysis in terms of multi-modal distributions, the means and variances.

The resultant wind direction, $\bar{R}$, for a set of wind observations in a given angular interval is determined from

$$\bar{\theta} = \arctan \left(\frac{\bar{S}}{\bar{C}} \right)$$

$$\bar{R} = (\bar{C}^2 + \bar{S}^2)^{1/2}$$

where

$$\bar{S} = \frac{1}{n} \sum f_i \sin \theta_i$$

$$\bar{C} = \frac{1}{n} \sum f_i \cos \theta_i$$

$$n = \sum f_i$$

The term f_i is the sum of occurrences in a given angular increment whose central value is θ_i . The variance S_0^2 , transformed to range $(0, \infty)$ is given by

$$S_0^2 = -\ln(\bar{C}^2 + \bar{S}^2)$$

Bimodal distributions can be studied by extending the unimodal range within a segment on $(0, 2\pi/\ell)$ to $(0, 2\pi)$. The variable ℓ represents the number of modes. The bimodal distributions in Table B2 were considered to be in the range $(0$ to π, π to $2\pi)$. This kind of analysis clearly indicates the integrated influence of terrain upon the airflows. The data presented in Table B1 shows the following:

1. Wind speeds 8 mph (3.6 metres/sec) or greater are from the west through southwest. The standard deviation in direction is small (less than 36°) except during the spring months. Only 33% of the stronger winds are from the east.
2. Winds less than 8 mph (3.6 m/s) rarely blow from the east in the spring months. During the night the winds are predominantly westerly (260° to 290°) with standard deviations ranging from 40° to 70° . The more southerly the wind, the greater the standard deviation.

3. Except during March, April and May, the (1800-0500) night time winds less than 3.6 m/sec (8 mph) are about equally divided between east and southwesterly winds. The standard deviation in the easterly winds increases almost linearly from 14.8° at 105° direction to 36.4° from 78° direction. This probably is caused by eddy effects about the mountain ridge to the northeast. There is no apparent directional dependence of the standard deviation in the winds from the west, which range from 17.7° to 41.2°.

TEMPERATURE

Temperatures and temperature inversions are important in the Long Valley Geothermal Area because (1) cold temperatures will preserve the winter snow cover, thereby reducing blowing dust, (2) snowfall has been observed downwind from cooling towers at temperatures less than - 12°C, [B3] and (3) excessively cold temperatures will affect operations of geothermal plants. There are two data sources for temperatures: (1) the Los Angeles Water and Power weather observations at the Long Valley Dam on Lake Crowley (see Table B2) and (2) the Mammoth Ranger Station of the USFS (see Table B3). In winter, the Lake Crowley average temperatures are slightly warmer than those at the Mammoth Ranger Station (see Fig. B13). Since there is an elevation difference of 330 metres (1000 ft), this indicates that air descending from Mammoth to the lower Lake Crowley level would be warmed 3.3°C. This implies that a temperature inversion usually occurs over Long Valley during the winter.

Although no long range measurements of temperature and precipitation have been made in the immediate geothermal area, the Long Valley Dam data are the most relevant, even though the geothermal area is about 300 m higher. Long range climatological data are also available for Gem Lake, about 30 km to the northwest and for Bishop, 70 km to the southeast. Tables B4 and B5 give tabulations of data for these two sites.

A series of daily aircraft soundings were made at Independence in May and June 1972. These data are shown in Table B6.

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TABLE B1. Directional analysis of Mammoth Ranger Station winds for 12-hour periods. Some of the angular data are bimodal, reflecting the effects of local terrain

		WIND SPEED RANGE - m/sec										
		0 - 3.5				3.6 - 8.0				Greater than 8.0		
Season	Time Interval (LST)	0-3.5 (%)	Total (%)	Mean Direction	Standard Deviation	3.6-8.0 (%)	Total (%)	Mean Direction	Standard Deviation	> 8.0 (%)	Mean Direction	Standard Deviation
WINTER												
(Dec-Feb)	0600-1700	42.7	27.3	77.8	36.4	*	27.3	242.5	38.5	8.8	245.5	28.6
	1800-0500	*	77.2	281.1	55.6	*	13.6	274.3	32.0	9.3	264.6	16.9
	24 hrs.	57.3	36.6	228.9	39.6							
SPRING												
(Mar-May)	0600-1700	*	46.5	284.7	104.7	*	44.1	247.9	51.4	9.4	269.6	27.4
	1800-0500	*	54.8	290.4	70.0	*	37.0	268.2	44.9	8.2	236.1	56.1
	24 hrs.	*										
SUMMER												
(Jun-Aug)	0600-1700	49.5	19.7	104.8	14.8	*	53.4	247.5	30.1	6.9	255.0	22.9
	1800-0500	*	48.8	287.8	36.2	*	45.3	266.0	24.4	5.9	280.6	20.2
	24 hrs.	50.5	20.0	283.8	41.2							
FALL												
(Sep-Nov)	0600-1700	49.4	25.5	86.6	21.2	8.5	3.3	84.1	21.6	9.1	236.8	20.2
	1800-0500	8.2	5.6	104.8	39.7	*	22.7	257.1	20.1	9.1	255.0	22.9
	24 hrs.	50.6	26.2	241.7	17.7	91.5	35.9	240.1	10.6			
ANNUAL	All hrs.	39.6	62.6	261.7	41.2							

* Single mode distributions

TABLE B2. Analysis of Mammoth Ranger Station maximum and minimum temperatures, including estimates of the length of time temperature is below -12°C.

Month	Mean Maximum Temperature °C	Standard Deviation °C	Standard Error of Mean °C	Mean Minimum Temperature °C	Standard Deviation °C	Standard Error of Mean °C	% of Nights Below -12°C	% of Whole Days Below -12°C	Mean Temperature
Nov.	3.7	5.7	0.6	-4.6	4.9	0.5	7	0.3	-0.45
Dec.	-2.0	5.8	0.4	-8.1	5.9	0.4	26	4.0	-5.05
Jan.	0.7	6.2	0.4	-7.1	7.4	0.5	26	2.0	-3.2
Feb.	-0.1	5.3	0.4	-7.8	4.9	0.3	19	1.0	-4.0
Mar.	0.8	5.6	0.4	-7.3	5.3	0.3	19	1.1	-3.25
Apr.	1.9	5.9	0.4	-6.4	5.2	0.4	14	1.0	-2.25
May	8.5	5.4	0.6	.9	4.4	0.5	< 1	< 1.0	4.7

TABLE B3. Climatological Data for Long Valley Dam (at Lake Crowley), Elevation 2070 Metres (6800 feet), 34 Years of Records.

Month	Average Temperature		Average Precipitation		Average Daily Wind Speed		Average Transpiration	
	(°C)	(°F)	(mm)	(in.)	(m/s)	(m/hr)	(mm)	(in.)
January	-4.8	23.3	46.5	1.83	1.7	3.7		
February	-3.6	25.5	37.3	1.47	1.8	4.0		
March	-0.2	31.7	27.4	1.08	2.2	5.0		
April	4.6	40.2	14.0	.55	2.5	5.7		
May	9.4	48.9	12.2	.48	2.6	5.9		
June	13.7	56.6	5.3	.21	2.4	5.4		
July	17.6	63.7	9.9	.39	2.1	4.6	193.0	7.61
August	16.4	61.6	6.1	.24	2.0	4.4	177.0	6.98
September	12.9	55.2	6.6	.26	1.9	4.3	132.0	5.19
October	7.6	45.6	9.1	.36	1.9	4.2		
November	2.0	35.6	31.0	1.22	1.7	3.9		
December	-2.8	27.7	45.2	1.78	1.6	3.6		
Annual	6.1	43.0	250.7	9.87	2.1	4.6		

The diurnal range of temperature on clear days ranges from 17°C (30°F) in July to 8°C (15°F) in January.

TABLE B4. Climatological summary for Gem Lake, California, elevation 2780 m (9120 ft).

Temperature Summary (°F)													
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Highest	67	70	71	75	80	89	91	88	82	74	68	61	91
Average Max.	38.1	38.6	43.6	49.7	56.8	63.3	71.7	70.7	64.3	54.8	46.1	39.0	53.1
Average Min.	14.4	14.1	18.1	24.2	31.4	38.9	46.4	46.8	40.1	32.8	25.5	18.9	29.3
Record Mean	26.2	27.4	30.7	36.9	44.1	51.2	59.0	58.8	52.2	43.8	35.8	29.0	41.0
Lowest	-20	-16	-12	-2	5	16	22	18	14	6	-3	-15	-20

Precipitation Summary (in)													
Record Mean	4.13	4.61	3.13	2.14	0.57	0.56	0.43	0.52	0.47	1.52	1.93	4.07	24.48
Mean Snowfall	39.0	46.9	32.6	20.3	5.1	1.8	T	T	0.8	7.8	18.0	41.4	214.0

Avg. number of days with .01 or more precip. 60. Average growing season: 87 days.

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Month	Temperature °F							Normal heating degree-days (Base 65°)	Precipitation - in.										Relative humidity %				Wind - mph				Pct. of possible sunshine	Mean sky cover	Mean number of days												Average daily solar radiation, lampless																																																																																																																																																																																																																																																																																																																																																																																			
	Normal				Extremes				Normal total	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hrs.	Year	Snow, ice pellets				Hour	Hour	Hour	Hour	Mean speed	Prevailing direction	Fastest mile			Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, ice pellets 1.0 inch or more	Thunderstorms	Fog	Ice	Temperatures																																																																																																																																																																																																																																																																																																																																																																																							
	Daily maximum	Daily minimum	Monthly	Record highest	Year	Record lowest	Year									Maximum monthly	Year	Minimum monthly	Year							Maximum in 24 hrs.											Year	Mean total	Maximum monthly	Year		Maximum in 24 hrs.	Year	Hour	Hour	Hour	Hour	Mean speed	Prevailing direction	Speed	Direction	Year	Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, ice pellets 1.0 inch or more	Thunderstorms	Fog	Ice	Max.	Min.																																																																																																																																																																																																																																																																																																																																																														
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(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)	(o)	(p)	(q)	(r)	(s)	(t)	(u)	(v)	(w)	(x)	(y)	(z)	(aa)	(ab)	(ac)	(ad)	(ae)	(af)	(ag)	(ah)	(ai)	(aj)	(ak)	(al)	(am)	(an)	(ao)	(ap)	(aq)	(ar)	(as)	(at)	(au)	(av)	(aw)	(ax)	(ay)	(az)	(ba)	(bb)	(bc)	(bd)	(be)	(bf)	(bg)	(bh)	(bi)	(bj)	(bk)	(bl)	(bm)	(bn)	(bo)	(bp)	(bq)	(br)	(bs)	(bt)	(bu)	(bv)	(bw)	(bx)	(by)	(bz)	(ca)	(cb)	(cc)	(cd)	(ce)	(cf)	(cg)	(ch)	(ci)	(cj)	(ck)	(cl)	(cm)	(cn)	(co)	(cp)	(cq)	(cr)	(cs)	(ct)	(cu)	(cv)	(cw)	(cx)	(cy)	(cz)	(da)	(db)	(dc)	(dd)	(de)	(df)	(dg)	(dh)	(di)	(dj)	(dk)	(dl)	(dm)	(dn)	(do)	(dp)	(dq)	(dr)	(ds)	(dt)	(du)	(dv)	(dw)	(dx)	(dy)	(dz)	(ea)	(eb)	(ec)	(ed)	(ee)	(ef)	(eg)	(eh)	(ei)	(ej)	(ek)	(el)	(em)	(en)	(eo)	(ep)	(eq)	(er)	(es)	(et)	(eu)	(ev)	(ew)	(ex)	(ey)	(ez)	(fa)	(fb)	(fc)	(fd)	(fe)	(ff)	(fg)	(fh)	(fi)	(fj)	(fk)	(fl)	(fm)	(fn)	(fo)	(fp)	(fq)	(fr)	(fs)	(ft)	(fu)	(fv)	(fw)	(fx)	(fy)	(fz)	(ga)	(gb)	(gc)	(gd)	(ge)	(gf)	(gg)	(gh)	(gi)	(gj)	(gk)	(gl)	(gm)	(gn)	(go)	(gp)	(gq)	(gr)	(gs)	(gt)	(gu)	(gv)	(gw)	(gx)	(gy)	(gz)	(ha)	(hb)	(hc)	(hd)	(he)	(hf)	(hg)	(hh)	(hi)	(hj)	(hk)	(hl)	(hm)	(hn)	(ho)	(hp)	(hq)	(hr)	(hs)	(ht)	(hu)	(hv)	(hw)	(hx)	(hy)	(hz)	(ia)	(ib)	(ic)	(id)	(ie)	(if)	(ig)	(ih)	(ii)	(ij)	(ik)	(il)	(im)	(in)	(io)	(ip)	(iq)	(ir)	(is)	(it)	(iu)	(iv)	(iw)	(ix)	(iy)	(iz)	(ja)	(jb)	(jc)	(jd)	(je)	(jf)	(jg)	(jh)	(ji)	(jj)	(jk)	(jl)	(jm)	(jn)	(jo)	(jp)	(jq)	(jr)	(js)	(jt)	(ju)	(jv)	(jw)	(jx)	(jy)	(jz)	(ka)	(kb)	(kc)	(kd)	(ke)	(kf)	(kg)	(kh)	(ki)	(kj)	(kl)	(km)	(kn)	(ko)	(kp)	(kq)	(kr)	(ks)	(kt)	(ku)	(kv)	(kw)	(kx)	(ky)	(kz)	(la)	(lb)	(lc)	(ld)	(le)	(lf)	(lg)	(lh)	(li)	(lj)	(lk)	(ll)	(lm)	(ln)	(lo)	(lp)	(lq)	(lr)	(ls)	(lt)	(lu)	(lv)	(lw)	(lx)	(ly)	(lz)	(ma)	(mb)	(mc)	(md)	(me)	(mf)	(mg)	(mh)	(mi)	(mj)	(mk)	(ml)	(mn)	(mo)	(mp)	(mq)	(mr)	(ms)	(mt)	(mu)	(mv)	(mw)	(mx)	(my)	(mz)	(na)	(nb)	(nc)	(nd)	(ne)	(nf)	(ng)	(nh)	(ni)	(nj)	(nk)	(nl)	(nm)	(nn)	(no)	(np)	(nq)	(nr)	(ns)	(nt)	(nu)	(nv)	(nw)	(nx)	(ny)	(nz)	(oa)	(ob)	(oc)	(od)	(oe)	(of)	(og)	(oh)	(oi)	(oj)	(ok)	(ol)	(om)	(on)	(oo)	(op)	(oq)	(or)	(os)	(ot)	(ou)	(ov)	(ow)	(ox)	(oy)

Means and extremes above are from existing and comparable exposures. Annual extremes have been exceeded at other sites in the locality as follows: lowest temperature -15 in January 1916; maximum monthly precipitation, 9.67 in January 1914; maximum monthly snowfall, 59.0 in January 1914.

TABLE B6
SUMMARY OF
VERTICAL TEMPERATURE SOUNDINGS
(MEASURED BY AIRCRAFT)
Independence, Inyo County
May 15 - June 23, 1972

MAY	Surface Temperature	Top of Inversion	Inversion Strength	3000 ft Temp less Sfc Temp	JUN	Surface Temperature	Top of Inversion	Inversion Strength	3000 ft Temp less Sfc Temp
15	50°F	1300 ft	15	9	1	68	500	5	-4
16	53	1000	13	6	2	68	500	4	-7
17	54	500	10	0	3	66	700	2	-4
18	55	500	0	-8	4	64	500	5	-2
19	48	500	1	-7	5	60	700	5	0
20	42	500	2	-9	6	62	500	7	-1
21	46	500	2	-6	7	63	500	4	-6
22	52	500	3	-4	8	60	500	2	-7
23	53	1000	8	1	9	59	500	5	-1
24	55	500	7	0	10	53	500	7	-1
25	55	700	9	2	11	63	1000	3	3
26	56	700	10	0	12	61	1300	7	1
27	59	700	9	4	13	66	700	6	-2
28	58	1000	10	4	14	55	700	15	8
29	62	1000	10	3	15	62	700	10	3
30	65	1000	6	3	16	66	700	6	-2
31	61	500	9	1	17	62	1000	12	4
May					18	65	1000	9	3
Mean	54.4	729	7.15	- .05	19	66	1000	6	-1
SD	6.45	264	3.28	5.11	20	65	1000	11	3
Error of					21	64	500	8	1
Mean	1.56	64	.51	1.24	22	67	500	5	-3
					23	56	700	6	0
					Jun				
					Mean	62.7	704	6.52	- .65
					SD	4.06	234	3.17	3.68
					Error of				
					Mean	.84	.48	.66	.76
TOTAL									
MEAN	59.1	715	6.85						
SD	6.36	244	3.67						
Error of									
Mean	1.0	38	0.58						

COMPOSITE WINDROSE FOR HOUR(S) 1 THROUGH 4

HOT SPRINGS CREEK
SCALING FOR VELOCITY EVENTS

LONG. - 118 DEG, 49.7 MIN W// LAT. - 37 DEG, 00.3 MIN N// YEAR 1975-76

ASTERISK, *, INDICATES THE MONTH AND
ANGULAR REGION THAT CONTAINED THE
MAXIMUM NUMBER OF VELOCITY EVENTS
SCALED TO 3.5 IN.

INNER WINDROSE REPRESENTS
LOWER LEVEL VELOCITY DATA.
OUTER WINDROSE REPRESENTS
UPPER LEVEL VELOCITY DATA.

LOWER LEVEL LEGEND

FOR LARGEST CALM DATA,
NUMBER OF EVENTS = 56

LARGEST NUMBER OF VELOCITY
EVENTS IN ANY MONTH AND/OR
ANGULAR REGION = 63 PER 3.5 IN.

UPPER LEVEL LEGEND

FOR LARGEST CALM DATA,
NUMBER OF EVENTS = 75

LARGEST NUMBER OF VELOCITY
EVENTS IN ANY MONTH AND/OR
ANGULAR REGION = 32 PER 3.5 IN.

Figure B1

COMPOSITE WINDROSE FOR HOUR(S) 5 THROUGH 8

HOT SPRINGS CREEK
SCALING FOR VELOCITY EVENTS

LONG. - 118 DEG, 49.7 MIN W// LAT. - 37 DEG, 00.3 MIN N// YEAR 1975-76

ASTERISK, *, INDICATES THE MONTH AND
ANGULAR REGION THAT CONTAINED THE
MAXIMUM NUMBER OF VELOCITY EVENTS
SCALED TO 3.5 IN.

INNER WINDROSE REPRESENTS
LOWER LEVEL VELOCITY DATA.
OUTER WINDROSE REPRESENTS
UPPER LEVEL VELOCITY DATA.

LOWER LEVEL LEGEND

FOR LARGEST CALM DATA,
NUMBER OF EVENTS = 53
LARGEST NUMBER OF VELOCITY
EVENTS IN ANY MONTH AND/OR
ANGULAR REGION = 51 PER 3.5 IN.

UPPER LEVEL LEGEND

FOR LARGEST CALM DATA,
NUMBER OF EVENTS = 82
LARGEST NUMBER OF VELOCITY
EVENTS IN ANY MONTH AND/OR
ANGULAR REGION = 27 PER 3.5 IN.

Figure B2

COMPOSITE WINDROSE FOR HOUR(S) 9 THROUGH 12

HOT SPRINGS CREEK
SCALING FOR VELOCITY EVENTS

LONG. - 118 DEG. 49.7 MIN W// LAT. - 37 DEG. 00.3 MIN N// YEAR 1975-76

ASTERISK, *, INDICATES THE MONTH AND
ANGULAR REGION THAT CONTAINED THE
MAXIMUM NUMBER OF VELOCITY EVENTS
SCALED TO 3.5 IN.

INNER WINDROSE REPRESENTS
LOWER LEVEL VELOCITY DATA.
OUTER WINDROSE REPRESENTS
UPPER LEVEL VELOCITY DATA.

LOWER LEVEL LEGEND

FOR LARGEST CALM DATA,
NUMBER OF EVENTS = 27

LARGEST NUMBER OF VELOCITY
EVENTS IN ANY MONTH AND/OR
ANGULAR REGION = 52 PER 3.5 IN.

UPPER LEVEL LEGEND

FOR LARGEST CALM DATA,
NUMBER OF EVENTS = 54

LARGEST NUMBER OF VELOCITY
EVENTS IN ANY MONTH AND/OR
ANGULAR REGION = 27 PER 3.5 IN.

Figure B3

COMPOSITE WINDROSE FOR HOUR(S) 13 THROUGH 16

HOT SPRINGS CREEK
SCALING FOR VELOCITY EVENTS

LONG. - 118 DEG. 49.7 MIN W// LAT. - 37 DEG. 00.3 MIN N//

YEAR 1975-76

ASTERISK, *, INDICATES THE MONTH AND
ANGULAR REGION THAT CONTAINED THE
MAXIMUM NUMBER OF VELOCITY EVENTS
SCALED TO 3.5 IN.

INNER WINDROSE REPRESENTS
LOWER LEVEL VELOCITY DATA.
OUTER WINDROSE REPRESENTS
UPPER LEVEL VELOCITY DATA.

Figure B4

COMPOSITE WINDROSE FOR HOUR(S) 17 THROUGH 20

HOT SPRINGS CREEK
SCALING FOR VELOCITY EVENTS

LONG. - 118 DEG, 49.7 MIN W// LAT. - 37 DEG, 00.3 MIN N// YEAR 1975-76

ASTERISK, *, INDICATES THE MONTH AND
ANGULAR REGION THAT CONTAINED THE
MAXIMUM NUMBER OF VELOCITY EVENTS
SCALED TO 3.5 IN.INNER WINDROSE REPRESENTS
LOWER LEVEL VELOCITY DATA.
OUTER WINDROSE REPRESENTS
UPPER LEVEL VELOCITY DATA.

LOWER LEVEL LEGEND

FOR LARGEST CALM DATA,
NUMBER OF EVENTS = 34
LARGEST NUMBER OF VELOCITY
EVENTS IN ANY MONTH AND/OR
ANGULAR REGION = 64 PER 3.5 IN.

UPPER LEVEL LEGEND

FOR LARGEST CALM DATA,
NUMBER OF EVENTS = 61
LARGEST NUMBER OF VELOCITY
EVENTS IN ANY MONTH AND/OR
ANGULAR REGION = 21 PER 3.5 IN.

Figure B5

COMPOSITE WINDROSE FOR HOUR(S) 21 THROUGH 24

HOT SPRINGS CREEK LONG. - 118 DEG. 49.7 MIN W// LAT. - 37 DEG. 00.3 MIN N// YEAR 1975-76
 SCALING FOR VELOCITY EVENTS

ASTERISK, *, INDICATES THE MONTH AND ANGULAR REGION THAT CONTAINED THE MAXIMUM NUMBER OF VELOCITY EVENTS SCALED TO 3.5 IN.

INNER WINDROSE REPRESENTS LOWER LEVEL VELOCITY DATA. OUTER WINDROSE REPRESENTS UPPER LEVEL VELOCITY DATA.

LOWER LEVEL LEGEND

FOR LARGEST CALM DATA,
 NUMBER OF EVENTS = 45
 LARGEST NUMBER OF VELOCITY
 EVENTS IN ANY MONTH AND/OR
 ANGULAR REGION = 72 PER 3.5 IN.

UPPER LEVEL LEGEND

FOR LARGEST CALM DATA,
 NUMBER OF EVENTS = 76
 LARGEST NUMBER OF VELOCITY
 EVENTS IN ANY MONTH AND/OR
 ANGULAR REGION = 34 PER 3.5 IN.

Figure B6

COMPOSITE WINDROSE FOR HOUR(S) 1 THROUGH 4

LITTLE ANTELOPE VALLEY LONG. -118 DEG, 52.5 MIN W// LAT. - 37 DEG, 01.0 MIN N// YEAR 1975-76
 SCALING FOR VELOCITY EVENTS

ASTERISK, *, INDICATES THE MONTH AND ANGULAR REGION THAT CONTAINED THE MAXIMUM NUMBER OF VELOCITY EVENTS SCALED TO 3.5 IN.

INNER WINDROSE REPRESENTS LOWER LEVEL VELOCITY DATA.
 OUTER WINDROSE REPRESENTS UPPER LEVEL VELOCITY DATA.

LOWER LEVEL LEGEND

FOR LARGEST CALM DATA,
 NUMBER OF EVENTS = 73

LARGEST NUMBER OF VELOCITY
 EVENTS IN ANY MONTH AND/OR
 ANGULAR REGION = 12 PER 3.5 IN.

Figure B7

COMPOSITE WINDROSE FOR HOUR(S) 5 THROUGH 8

LITTLE ANTELOPE VALLEY LONG. -118 DEG, 52.5 MIN W// LAT. - 37 DEG, 01.0 MIN N// YEAR 1975-76
 SCALING FOR VELOCITY EVENTS

ASTERISK, *, INDICATES THE MONTH AND ANGULAR REGION THAT CONTAINED THE MAXIMUM NUMBER OF VELOCITY EVENTS SCALED TO 3.5 IN.

INNER WINDROSE REPRESENTS LOWER LEVEL VELOCITY DATA.
 OUTER WINDROSE REPRESENTS UPPER LEVEL VELOCITY DATA.

LOWER LEVEL LEGEND

FOR LARGEST CALM DATA.
 NUMBER OF EVENTS = 65

LARGEST NUMBER OF VELOCITY
 EVENTS IN ANY MONTH AND/OR
 ANGULAR REGION = 15 PER 3.5 IN.

UPPER LEVEL LEGEND

FOR LARGEST CALM DATA.
 NUMBER OF EVENTS = 79

LARGEST NUMBER OF VELOCITY
 EVENTS IN ANY MONTH AND/OR
 ANGULAR REGION = 14 PER 3.5 IN.

Figure B8

COMPOSITE WINDROSE FOR HOUR(S). 9 THROUGH 12

LITTLE ANTELOPE VALLEY LONG. -118 DEG, 52.5 MIN W// LAT. - 37 DEG, 01.0 MIN N// YEAR 1975-76
 SCALING FOR VELOCITY EVENTS

ASTERISK, *, INDICATES THE MONTH AND ANGULAR REGION THAT CONTAINED THE MAXIMUM NUMBER OF VELOCITY EVENTS SCALED TO 3.5 IN.
 INNER WINDROSE REPRESENTS LOWER LEVEL VELOCITY DATA.
 OUTER WINDROSE REPRESENTS UPPER LEVEL VELOCITY DATA.

LOWER LEVEL LEGEND

FOR LARGEST CALM DATA,
 NUMBER OF EVENTS = 42
 LARGEST NUMBER OF VELOCITY
 EVENTS IN ANY MONTH AND/OR
 ANGULAR REGION = 18 PER 3.5 IN.

UPPER LEVEL LEGEND

FOR LARGEST CALM DATA,
 NUMBER OF EVENTS = 51
 LARGEST NUMBER OF VELOCITY
 EVENTS IN ANY MONTH AND/OR
 ANGULAR REGION = 26 PER 3.5 IN.

Figure B9

COMPOSITE WINDROSE FOR HOUR(S) 13 THROUGH 16

LITTLE ANTELOPE VALLEY LONG. -118DEG, 52.5 MIN W// LAT. - 37 DEG, 01.0 MIN N// YEAR 1975-76
 SCALING FOR VELOCITY EVENTS

ASTERISK, *, INDICATES THE MONTH AND ANGULAR REGION THAT CONTAINED THE MAXIMUM NUMBER OF VELOCITY EVENTS SCALED TO 3.5 IN.

INNER WINDROSE REPRESENTS LOWER LEVEL VELOCITY DATA.
 OUTER WINDROSE REPRESENTS UPPER LEVEL VELOCITY DATA.

LOWER LEVEL LEGEND

FOR LARGEST CALM DATA,
 NUMBER OF EVENTS = 7

LARGEST NUMBER OF VELOCITY
 EVENTS IN ANY MONTH AND/OR
 ANGULAR REGION = 20 PER 3.5 IN.

UPPER LEVEL LEGEND

FOR LARGEST CALM DATA,
 NUMBER OF EVENTS = 31

LARGEST NUMBER OF VELOCITY
 EVENTS IN ANY MONTH AND/OR
 ANGULAR REGION = 36 PER 3.5 IN.

Figure B10

COMPOSITE WINDROSE FOR HOUR(S) 17 THROUGH 20

LITTLE ANTELOPE VALLEY LONG. -118 DEG, 52.5 MIN W// LAT. - 37 DEG, 01.0 MIN N// YEAR 1975-76
 SCALING FOR VELOCITY EVENTS

ASTERISK, *, INDICATES THE MONTH AND ANGULAR REGION THAT CONTAINED THE MAXIMUM NUMBER OF VELOCITY EVENTS SCALED TO 3.5 IN.

INNER WINDROSE REPRESENTS LOWER LEVEL VELOCITY DATA.
 OUTER WINDROSE REPRESENTS UPPER LEVEL VELOCITY DATA.

LOWER LEVEL LEGEND

FOR LARGEST CALM DATA,
 NUMBER OF EVENTS = 47

LARGEST NUMBER OF VELOCITY
 EVENTS IN ANY MONTH AND/OR
 ANGULAR REGION = 25 PER 3.5 IN.

UPPER LEVEL LEGEND

FOR LARGEST CALM DATA,
 NUMBER OF EVENTS = 47

LARGEST NUMBER OF VELOCITY
 EVENTS IN ANY MONTH AND/OR
 ANGULAR REGION = 17 PER 3.5 IN.

Figure B11

COMPOSITE WINDROSE FOR HOUR(S) 21 THROUGH 24

LITTLE ANTELOPE VALLEY LONG. -118 DEG, 52.5 MIN W// LAT. - 37 DEG, 01.0 MIN N// YEAR 1975-76
 SCALING FOR VELOCITY EVENTS

ASTERISK, *, INDICATES THE MONTH AND ANGULAR REGION THAT CONTAINED THE MAXIMUM NUMBER OF VELOCITY EVENTS SCALED TO 3.5 IN.

INNER WINDROSE REPRESENTS LOWER LEVEL VELOCITY DATA.
 OUTER WINDROSE REPRESENTS UPPER LEVEL VELOCITY DATA.

LOWER LEVEL LEGEND

FOR LARGEST CALM DATA,
 NUMBER OF EVENTS = 70
 LARGEST NUMBER OF VELOCITY
 EVENTS IN ANY MONTH AND/OR
 ANGULAR REGION = 12 PER 3.5 IN.

UPPER LEVEL LEGEND

FOR LARGEST CALM DATA,
 NUMBER OF EVENTS = 80
 LARGEST NUMBER OF VELOCITY
 EVENTS IN ANY MONTH AND/OR
 ANGULAR REGION = 11 PER 3.5 IN.

Figure B12

Figure B13. Comparison of average monthly temperatures at Mammoth Lakes Ranger Station (8 yr record) and Lake Crowley Dam (34 yr record).

APPENDIX C

AIR QUALITY MEASUREMENTS IN AND
NEAR LONG VALLEY

STANDARDS

The California and Federal air quality standards are given in Table C-1. These standards, representing concentrations which should not be exceeded, should be used to compare with the limited measurements taken in and near Long Valley. Note that the state standards are lower than Federal for some pollutants; in these cases, the state standards take precedence.

OXIDANT

Oxidant was measured in Mammoth Lakes Village in June and July 1974 by the California Air Resources Board (ARB).^{*} Hourly averages for the three week period are depicted in Fig. C-1. The highest hourly average for a day was 0.105 ppm.

Ozone measurements were made in Mammoth Lakes Village by the U.S. Forest Service from December 1975 to February 1976. Continuous measurements were made on the roof of the fire station using an instrument with a threshold value of 0.001 ppm and an accuracy of ± 0.005 ppm. During the entire period, no levels greater than 0.08 ppm were observed. The higher readings were usually seen in advance of snow storms.

^{*}This and other data sources are referenced in the main report.

CARBON MONOXIDE

Carbon monoxide (CO) has been measured at Mammoth Lakes Village on two occasions. During December 14-29, 1974, the California Department of Transportation took measurements on the roof of the fire station. Hourly averages for the two week period are shown in Fig. C-2. The highest average occurred between 7:00 to 8:00 a.m. PST, and presumably represents the effect of automobile traffic enroute to the Mammoth Mountain ski slopes. A secondary peak is seen in the evening and is lower and broader. None of the hourly averages shown exceeded state or federal standards for carbon monoxide.

The second set of CO measurements was made by the California Air Resources Board (ARB) in June and July of 1974. Hourly averages for the period of measurement are shown in Fig. C-3. A peak is seen for the hours between 8:00 p.m. and 11:00 p.m. A secondary peak occurred near sunrise. The maximum value is less than 1/10 of state and federal standards.

OXIDES OF NITROGEN

During the same period in June and July 1974, the ARB measured both nitric oxide (NO) and nitrogen dioxide (NO₂) in Mammoth Lakes. A histogram of average hourly values of these pollutants is shown in Fig. C-4. Peak concentrations are present between 6:00 to 8:00 a.m., with a secondary maximum in the early evening. NO_x is approximately the sum of the NO and NO₂ values. The maximum daily values observed during this period were 0.04 ppm for NO_x and 0.013 ppm for NO₂.

HYDROCARBONS

The ARB also measured methane (CH_4) and non-methane hydrocarbons in Mammoth Lakes during June and July 1974. Fig. C-5 shows a plot of hourly averages. Methane is nearly constant during the day, averaging slightly less than 2 ppm. The non-methane hydrocarbons and total hydrocarbons show little variation, with small peaks in early morning and during the evening. Federal standards for hydrocarbons corrected for methane were exceeded on seven days of the three week period.

HYDROGEN SULFIDE

The only documented measurements of hydrogen sulfide taken in Long Valley, near the geothermal area, were made by the U.S. Geological Survey in April and August 1976. Spot readings were made -- there are no continuous samples at a particular location. The map in Fig. C-6, provided by the USGS, shows the locations of sampling stations listed in Table C-2 (also provided by USGS). In addition the table gives spot readings, when available, of sulfur dioxide (SO_2), oxides of nitrogen (NO_x), ammonia (NH_3) and suspended particulates (TSP).

In 1975 single monthly samples of SO_2 were made by Union Carbide Corporation in Rovana, located about 20 km to the southeast of the Long Valley Geothermal Area. The highest reading (in September) was 0.015 ppm. Except for three lesser values, all other monthly samples were 0.010 ppm. Sulfur dioxide measurements were made on seven days between May and December 1975. The highest value (in December) was 0.014 ppm; the mean of all values was 0.008 ppm.

SUSPENDED PARTICULATES

Measurements of suspended particulates, taken by the USGS in June and July 1974, are included with the H_2S data in Table C-2. The highest value was $70.7 \mu g/m^3$, below the state standard of $100 \mu g/m^3$.

Other measurements of suspended particulates were conducted by the ARB in June and July 1972, October 1972 to June 1973 and June-July 1974. In Mammoth Lakes three 24-hour readings, observed in June and July 1974, are 154.3, 147.2, and $178.1 \mu g/m^3$. All three values exceed state TSP standards. Five measurements made in Bishop during the period range from 52.7 to $198.2 \mu g/m^3$. Only the upper range value exceeded the twenty-four hour $100 \mu g/m^3$ standard.

The ARB measurements in 1972 and 1973 were made in Bishop, Bridgeport, and Lone Pine. These locations are all outside the Long Valley Area. However, for purposes of comparison, they are shown in Table C-3.

TABLE C1
AMBIENT AIR QUALITY STANDARDS

Pollutant	Averaging Time	California Standards ¹		National Standards ²		
		Concentration ³	Method ⁴	Primary ^{3, 5}	Secondary ^{3, 6}	Method ⁷
Oxidant (Ozone)	1 hour	0.10 ppm (200 ug/m ³)	Ultraviolet Photometry	160 ug/m ³ (0.08 ppm)	Same as Primary Std.	Chemiluminescent Method
Carbon Monoxide	12 hour	10 ppm (11 mg/m ³)	Non-Dispersive Infrared Spectroscopy	—	Same as Primary Standards	Non-Dispersive Infrared Spectroscopy
	8 hour	—		10 mg/m ³ (9 ppm)		
	1 hour	40 ppm (46 mg/m ³)		40 mg/m ³ (35 ppm)		
Nitrogen Dioxide	Annual Average	—	Saltzman Method	100 ug/m ³ (0.05 ppm)	Same as Primary Standards	Proposed: Modified J-H Saltzman (O ₃ corr.) Chemiluminescent
	1 hour	0.25 ppm (470 ug/m ³)		—		
Sulfur Dioxide	Annual Average	—	Conductimetric Method	80 ug/m ³ (0.03 ppm)	—	Pararosaniline Method
	24 hour	0.04 ppm (105 ug/m ³)		365 ug/m ³ (0.14 ppm)	—	
	3 hour	—		—	1300 ug/m ³ (0.5 ppm)	
	1 hour	0.5 ppm (1310 ug/m ³)		—	—	
Suspended Particulate Matter	Annual Geometric Mean	60 ug/m ³	High Volume Sampling	75 ug/m ³	60 ug/m ³	High Volume Sampling
	24 hour	100 ug/m ³		260 ug/m ³	150 ug/m ³	
Sulfates	24 hour	25 ug/m ³	AIHL Method No. 61	—	—	—
Lead	30 Day Average	1.5 ug/m ³	AIHL Method No. 54	—	—	—
Hydrogen Sulfide	1 hour	0.03 ppm (42 ug/m ³)	Cadmium Hydroxide Stractan Method	—	—	—
Hydrocarbons (Corrected for Methane)	3 hour (6-9 a.m.)	—	—	160 ug/m ³ (0.24 ppm)	Same as Primary Standards	Flame Ionization Detection Using Gas Chromatography
Ethylene	8 hour	0.1 ppm	—	—	—	—
	1 hour	0.5 ppm				
Visibility Reducing Particles	1 observation	In sufficient amount to (8) reduce the prevailing visibility to less than 10 miles when the relative humidity is less than 70%		—	—	—

NOTES:

- California standards are values that are not to be equaled or exceeded.
- National standards, other than those based on annual averages or annual geometric means, are not to be exceeded more than once per year.
- Concentration expressed first in units in which it was promulgated. Equivalent units given in parentheses are based upon a reference temperature of 25°C and a reference pressure of 760 mm of mercury. All measurements of air quality are to be corrected to a reference temperature of 25°C and a reference pressure of 760 mm of Hg (1,013.2 millibar); ppm in this table refers to ppm by volume, or micromoles of pollutant per mole of gas.
- Any equivalent procedure which can be shown to the satisfaction of the Air Resources Board to give equivalent results at or near the level of the air quality standard may be used.
- National Primary Standards: The levels of air quality necessary, with an adequate margin of safety, to protect the public health. Each state must attain the primary standards no later than three years after that state's implementation plan is approved by the Environmental Protection Agency (EPA).
- National Secondary Standards: The levels of air quality necessary to protect the public welfare from any known or anticipated adverse effects of a pollutant. Each state must attain the secondary standards within a "reasonable time" after implementation plan is approved by the EPA.
- Reference method as described by the EPA. An "equivalent method" of measurement may be used but must have a "consistent relationship to the reference method" and must be approved by the EPA.
- Prevailing visibility is defined as the greatest visibility which is attained or surpassed around at least half of the horizon circle, but not necessarily in continuous sectors.

Figure C1. OXIDANT AT MAMMOTH LAKES VILLAGE

19 JUNE TO 9 JULY 1974 - HOURLY AVERAGES

Figure C2. HOURLY AVERAGES OF CARBON MONOXIDE AT

HAMMOTH LAKES VILLAGE, DEC. 1974 AND JANUARY 1975

Figure C3. HOURLY AVERAGES OF CARBON MONOXIDE AT

MANMOTH LAKES VILLAGE, 19 JUNE TO 9 JULY 1974

6-9

Figure C4. Hourly averages of oxides of nitrogen, measured at Mammoth Lakes by the California Air Resources Board during June and July 1974.

C-10

Figure C5. Hourly averages of hydrocarbons, measured at Mammoth Lakes by the California Air Resources Board during June and July 1974.

Figure C6
Locations of Ambient
Air Monitoring Stations

TABLE C2 - Inyo National Forest/Mono-Long Valley KGRA

AMBIENT AIR SAMPLING STATION LOCATIONS AND ANALYSES DATA

Station #	Location	Sample #	Type of Sample	Date	Time	Total Time (min.)	Parts per million				ug/m ³ Particulates	ppm H ₂ S Tabs	Remarks
							H ₂ S	SO ₂	NO _x	NH ₃			
23AB1	T3s, R29E, Sec.29, SW,NE	1	Bubbler	4/26	1930	1440	<0.01	<0.01	<0.01	<0.024			
	SE	2	H ₂ S Tab	4/27	1330	2880						N.D.*	
23AB2	Sec.28 SE,NE SE	1	Bubbler	4/27	1900	1440	<0.01	<0.01	<0.01	0.024			
23AB2		2	High Vol.	4/28	1000	300					70.7		
		a	H ₂ S Tab	4/28	1045	3060						N.D.	
		b	H ₂ S Tab	4/28	1045	3060						N.D.	
23A1	T3S,29E Sec 19 SW,NW,SE		H ₂ S Tab	4/27	1000	3000						N.D.	
23A2	Sec.30,SW,NW,NW		H ₂ S Tab	4/27	1015	3000						N.D.	
23A3	Sec.30 NW,NE,SW		H ₂ S Tab	4/27	1030	3120						N.D.	
23A5	Sec 29, NE,NW,SW		H ₂ S Tab	4/27	1400	2820						N.D.	
23A8	T3S, 29E, Sec 28, SE,NE,SE	1	H ₂ S Tab	4/28	1100	3060						N.D.	
23A9	NE,NE,SE	1	H ₂ S Tab	4/28	1130	3060						N.D.	

*N.D. NOT DETECTED

TABLE C2 - Inyo National Forest/Mono-Long Valley KGRA (Cont'd.)

AMBIENT AIR SAMPLING STATION LOCATIONS AND ANALYSES DATA

Station #	Location	Sample #	Type of Sample	Date	Time	Total Time (min)	Parts per million				ug/m ³ Particulates	ppm H ₂ S Tabs	Remarks
							H ₂ S	SO ₂	NO _x	NH ₃			
23A10	Sec. 33, SE crn.	1	H ₂ S Tab	4/28	1145	1620						N.D.	
23A11	Sec.32, SE crn.	1	H ₂ S Tab	4/28	1210	1500						N.D.	
INA1	T3S, R28E, Sec.22 Cen. NW,NW	1	Bubbler	4/28	2000	1440	<0.01						Meteorological Station No. 1
			"	4/28	"	"		<0.01					
			"	4/28	"	"			<0.01				
			"	4/28	"	"				<0.02			
		a	H ₂ S Tab	4/28	1045	300						N.D.	
		b	H ₂ S Tab	4/28	1045	300						N.D.	
		2	High Vol	8/19	1500	1480					43.9		
INA2	T3S, R28E, Sec.23 SW,SE,SE	3	" "	8/20	1715	820					26.2		
		1	Bubbler	8/18	1345	630	<0.01						Meteorological Station No. 2
			"	8/18	"	1445	<0.01						
			"	8/18	"	"		<0.01					
			"	8/18	"	"			0.104				
		2	High Vol.	8/18	"	"					15.4		
		3	" "	8/21	1500	1440					26.5		
		a	H ₂ S Tab	8/21	"	"						N.D.	Tabs installed in
		b	H ₂ S Tab	8/21	"	"						N.D.	Hi. vol. shelter in Air Stream.

TABLE C2 - Inyo National Forest/Mono-Long Valley KGRA (Cont'd.)

AMBIENT AIR SAMPLING STATIONS LOCATIONS AND ANALYSES DATA

Station #	Location	Sample #	Type of Sample	Date	Time	Total Time (min)	Parts per million				ug/m ³	ppm	Remarks
							H ₂ S	SO ₂	NO _x	NH ₃	Particulates	H ₂ S Tabs	
INA3	T3S, R28E, Sec.35 NW,SE,SE	1	Bubbler	8/20	0950	370	<0.01						
				8/20	1715	1440		<0.01					
				8/20	1715	"			0.068				
		2	High Vol.	8/18	1615	1430					40.3		
		3		8/19	1615	1440					38.0		
		4		8/20	1635	1380					56.7		
		5		8/21	1535	1445					51.7		
INA4	T3S R28E Sec.32 NE,NE,NW	1	Bubbler	8/17	1015	420	<0.01						
		1		8/17	"	1245	<0.01						
		1		8/17	"	"		<0.01					
		1		8/17	"	1440			0.075				
		2		8/18	"	315				0.034			
		3	High Vol.	8/17	1037	300					30.1		
		4	"	8/17	1815	750					16.5		
INA4	Steam Vent	a	H ₂ S Tabs	8/17	1030	1						8.0	
	3-12" from vent	b	"	8/17	1045	2						9.5	
	30' above vent	c	"	8/17	1000	150						0.15	
	15' west of vent	d	"	8/17	"	30						N.D.	
	60' east of vent	e	"	8/17	"	135						N.D.	
	120' east of vent	f	"	8/17	"	1590						N.D.	
	200' east of vent	g	"	8/17	"	"						N.D.	

CASA DIABLO HOT SPRINGS
10 Meters East AND 2
METERS DOWN SLOPE OF
HOT GAS VENT.
SEE FIG 5.

TABLE C2 -Inyo National Forest/Mono-Long Valley KGRA (Cont'd.)

AMBIENT AIR SAMPLING STATIONS

Station #	Location	Sample #	Type of Sample	Date	Time	Total Time (min)	Parts per million				ug/m ³ Particulates	ppm H ₂ S Tabs	Remarks
							H ₂ S	SO ₂	NO _x	NH ₃			
INAS	T3S, 28E, Sec 25, Hot Creek NE, SE, NE	1	Bubbler	8/21	1210	122	0.103						HOT CREEK See figure 2
		1	"	8/21	"	"	0.100						
		1	"	8/21	"	"		<0.01					
		1	"	8/21	"	"				0.0050			
INAS	Large hot spring with observation deck, . above water level. 80 meters upstream from Hot Springs @ new activity. 100 meters upstream from Hot Spring.	a	H ₂ S TABS	8/21	1015	150						0.150	FIG 2
		b	H ₂ S TABS	8/21	1035	30						N.D.	FIG 4
		c		8/21	1045	135						0.150	
INA6	T3S, R27E, Sec. 36, SE, NE, SW	1	Bubbler	8/20	1715	990	<0.01						MAMMOTH LAKES WATER TREATMENT PLANT.
		1		8/20	"	"		<0.01					
		1		8/20	"	315			0.071				
		1		8/20	"	"				0.143			
INA6		2	High Vol.	8/18	1700	1440						13.5	
		3		8/19	"	"						18.7	
		4		8/20	"	1415						13.7	
		5		8/21	1645	1430						33.9	
		6		8/22	1700	960						20.1	

TABLE C2 - Inyo National Forest/Mono-Long Valley KGRA (Cont'd.)

AMBIENT AIR SAMPLING STATIONS

Station #	Location	Sample #	Type of Sample	Date	Time	Total Time (min)	Parts per million				ug/m ³ Particulates	ppm H ₂ S Tabs	Remarks
							H ₂ S	SO ₂	NO _x	NH ₃			
INA7	T3S, R27E, Sec.36 SW,NE,NW	1	Bubbler	8/21	1522	1437	<0.01	<0.01	0.168				MAMMOTH LAKES FIRE HOUSE ROOF
		1		8/21	"	"							
		1		8/21	"	1457							
		2	High Vol.	8/18	1800	1430					30.7		
		3		8/19	1730	1440					60.7		
		4		8/20	"	1380					68.1		
		5		8/21	1700	1445					57.7		
		6		8/22	1515	1085					57.5		

MINIMUM DETECTION LIMITS

<0.01 PPM FOR H₂S<0.01 PPM FOR SO₂<0.01 PPM FOR NO_x<0.24 PPM FOR NH₃

TABLE C3. Summary of total suspended particulates -- 1972, 1973, ARB

		Particulate Matter					$\mu\text{g}/\text{m}^3$ (Hi Vol Sampler)			
		<u>OCT</u>	<u>NOV</u>	<u>DEC</u>	<u>JAN</u>	<u>FEB</u>	<u>MARCH</u>	<u>APRIL</u>	<u>MAY</u>	<u>JUNE</u>
Bishop		7*(83)*	5(79)		16(88)	3(78)	24(75)	4(74)	4(117)	5(109)
		27(101)	10(128)			13(94)	31(94)	10(112)	30(155)	21(152)
			23(57)			19(149)		17(123)		27(82)
						27(127)		22(48)		
Lone Pine		6(34)	17(39)	6(82)	4(38)	16(12)	7(17)	12(50)	1(36)	5(68)
		26(35)		13(47)	10(51)	22(54)	16(67)	17(67)	8(51)	
				17(65)		27(50)		24(50)	15(42)	
Bridgeport		3(41)	5(17)	5(10)	4(6)	3(7)	5(16)	5(31)	30(45)	3(24)
		7(25)	11(15)	11(15)	10(5)	9(33)	11(13)	10(36)	4(99)	9(49)
		14(38)	29(29)	17(2)	22(9)	24(23)	17(16)	16(27)	10(52)	15(52)
		18(14)		23(5)	28(7)	27(11)	23(18)	22(29)	16(30)	21(62)
		24(42)		29(16)				28(449)	22(33)	27(53)
		30(54)							28(35)	

* = Day of Month

* = $/\text{m}^3$

APPENDIX D
CALCULATIONS OF DIFFUSION AND
RESULTANT AIR QUALITY IN AND
NEAR LONG VALLEY

The year of meteorological data obtained at the 5 m and 15 m levels of the tower near Hot Creek has been used to estimate the effect on the surrounding environment of normal and accidental releases of geothermal-related gases and particulates at release heights of 10 m and 50 m. Specifically, we have considered the following types of releases:

- Normal releases from typical venting and from large cooling towers.
- Releases during production testing of geothermal wells.
- Accidental releases from a pipe leak or a possible blowout.

The Continuous Point Source (CPS) Gaussian diffusion code^[D1] has been used for this assessment. The CPS code is capable of evaluating the average and "5% probability of being exceeded" air concentrations and deposition of particulates and gases using hourly averages of wind velocity and stability over an entire year. The code accounts for plume depletion when deposition occurs. It also adjusts for topographical variations, an important feature in the Long Valley area. Atmospheric stability is determined by using the standard relationship between stability and hourly extremes in the wind direction trace obtained from strip charts. The CPS code distinguishes between normal and accidental releases by recognizing that an accidental release can occur at any time when the wind may be from any direction.

Consequently, the cumulative concentrations are divided by the total number of hourly average observations for a normal release, but division is made by the total number of observations within each of sixteen 22.5° sectors for accidental releases. All calculations have been made for a source strength of 1 unit/sec where the units are selected by the user (e.g., $\mu\text{g}/\text{sec}$).

The surface air concentration contour maps for normal releases are presented in Figs. D1a to D4b. Corresponding maps for an accidental release are shown in Figs. D5a to D8. The "Exceeded 5% of the Time" figures are obtained by assuming that the hourly concentrations are lognormally distributed; the contour charts are based on the calculated 95% concentrations at the upper wing of the distribution. Statistically, the "5%" concentration values will be exceeded only one time in twenty. Deposition rates of particulates and gases can be obtained from the product of the concentration at a specific point and the deposition velocity, assumed to be 0.01 m/sec for all charts. The deposition rate is then expressed in $\text{units}/\text{m}^2\text{-sec}$. Multiplication by the exposure time in seconds yields total deposition in units/m^2 (e.g., $\mu\text{g}/\text{m}^2$).

Until the proposed deep geothermal wells are operating, it is difficult to determine with precision the source terms of the various constituents that might be released to the atmosphere. Therefore, we have used the CPS calculations to determine the maximum source terms that would be permissible without violating state or federal air quality standards. For this purpose, calculated concentrations at three distances have been selected for the purpose of determining maximum release rates. These distances are the location of the maximum concentration at or beyond 1 km, the U.S. Forest Service's Mammoth Ranger Station (on the east side of Mammoth Lakes), and

Lake Crowley. Hydrogen sulfide and total suspended particulates (TSP) were selected as the two pollutants that might have the most deleterious effects in Long Valley. No gravitational settling velocity is assumed for the TSP. Table D1 presents an analysis of these maximum release rates that, according to the CPS code output from a year of wind data at the Hot Creek meteorological tower, are estimated not to exceed state or federal standards. The values for the 10 m release height would apply to a near-surface pipe leak or to dust and other particulates that become airborne from dirt roads or other areas where the landscape has been altered. The 50 m release height applies to effluents released during normal venting, production testing, blowouts, and cooling tower operations. The accidental release columns in the table should be used for blowouts or near-surface pipe breaks.

Maximum release rates for other pollutants with deposition velocities of 0.01 m/sec may be estimated by calculating the following:

(Standard for selected pollutant - $\mu\text{g}/\text{m}^3$) X

$$\left(\frac{\text{Table D1 value for H}_2\text{S}}{42 \mu\text{g}/\text{m}^3} \right)$$

In Table D1, the estimated maximum release rates at 1 km are most restrictive. The average values would be exceeded about 50% of the time, while the 5% values would be exceeded one time in twenty. A rough estimate of the maximum release rates for a 0.5% probability (values would be exceeded one time in 200) may be obtained by dividing Table D1 values by five.

At Mammoth Lakes and at Lake Crowley the maximum release rates are significantly larger. The odor threshold for H_2S varies considerably among individuals. Miner^[D2] states observed variations range between 1 and $45 \mu\text{g}/\text{m}^3$. Therefore if the release rates given in Table D1 are realized,

some residents of Mammoth Lakes will smell H_2S at times. However, since the wind blows toward Mammoth Lakes less than 5% of the time, there should be discomfort (from the odor) less than one day per month.

All the maximum release rate estimates in Table DI are based on wind observations at the Hot Creek meteorological tower, located near the center of the geothermal field. Full development of the Long Valley Geothermal Area will place some wells several kilometres from the site of the meteorological tower. Although variations in topography would result in differences up to a factor of a few, it is reasonable to apply the 1 km maximum release rates to the entire area of geothermal development. The values for Mammoth Lakes and Lake Crowley are not applicable for a well location more than one or two kilometres from the Hot Creek tower site.

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TABLE D1. Maximum source rates that are estimated not to exceed state or federal standards at:

	a. Distance to max. conc. (≥ 1 km)				b. Mammoth Lakes Ranger Stn				c. Lake Crowley			
	Normal Release		Accidental Release		Normal Release		Accidental Release		Normal Release		Accidental Release	
	AVG	5% ⁽²⁾	AVG	5%	AVG	5% ⁽¹⁾	AVG	5%	AVG	5% ⁽¹⁾	AVG	5%
<u>10m Release Hgt</u>												
Distance (km)	1	1	1	1	11.5	11.5	11.5	11.5	10	10	10	10
Direction Toward	N	N	N	N	WSW	WSW	WSW	WSW	SE	SE	SE	SE
Max H ₂ S (kg/day) ⁽³⁾	600	80	100	10	5x10 ⁵	<u>2x10⁴</u>	2x10 ⁴	1x10 ⁴	1x10 ⁶	<u>1x10⁴</u>	1x10 ⁴	1x10 ⁴
Max TSP (kg/day) ⁽⁴⁾	1000	200	300	30	1x10 ⁶	<u>4x10⁴</u>	4x10 ⁴	2x10 ⁴	2x10 ⁶	<u>3x10⁴</u>	3x10 ⁴	3x10 ⁴
<u>50m Release Hgt</u>												
Distance (km)	1	1	1	1	11.5	11.5	11.5	11.5	10	10	10	10
Direction Toward	E	N	E	E	WSW	WSW	WSW	WSW	SE	SE	SE	SE
Max H ₂ S (kg/day)	2000	600	50	5	1x10 ⁶	<u>5x10⁵</u>	1x10 ⁴	6x10 ³	4x10 ⁵	<u>1x10⁴</u>	1x10 ⁴	8x10 ³
Max TSP (kg/day)	5000	2000	100	10	3x10 ⁶	<u>1x10⁶</u>	3x10 ⁴	1x10 ⁴	9x10 ⁵	<u>2x10⁴</u>	2x10 ⁴	2x10 ⁴

1. Underlined values are for 1% probability of being exceeded. Wind blows toward these locations less than 5% of time.
2. Standard exceeded 5% of the time.
3. California standard for hydrogen sulfide is 42 $\mu\text{g}/\text{m}^3$, averaged over one hour.
4. California standard for total suspended particulates is 100 $\mu\text{g}/\text{m}^3$, averaged over one day.

Figure D1a. Normalized annual surface concentrations for a normal release at 10 m. Long range average contours.

GROUND LEVEL SECTOR AVERAGED ARITHMETIC AVG CONCENTRATION - UNITS / M³

HOT CREEK CONC., ANNUAL, 100 METRES, NORMAL RELEASE

Figure D1b. Normalized annual surface concentrations for a normal release at 10 m. Short range average contours.

Figure D2a. Normalized annual surface concentrations for a normal release at 10 m. Long range contours that will be exceeded 5% of the time.

WILL BE EXCEEDED 5.0 PERCENT OF THE TIME

Figure D2b. Normalized annual surface concentrations for a normal release at 10 m. Short range contours that will be exceeded 5% of the time.

Figure D3a. Normalized annual surface concentrations for a normal release at 50 m. Long range average contours.

Figure D3b. Normalized annual surface concentrations for a normal release at 50 m. Short range average contours.

GROUND LEVEL SECTOR AVERAGED CONCENTRATION UNITS/M³

WILL BE EXCEEDED 5.0 PERCENT OF THE TIME

Figure D4b. Normalized annual surface concentrations for a normal release at 50 m. Short range contours that will be exceeded 5% of the time.

Figure D5a. Normalized annual surface concentrations for an accidental release at 10 m. Long range average contours.

Figure D5b. Normalized annual surface concentrations for an accidental release at 10 m. Short range average contours.

Figure D6. Normalized annual surface concentrations for an accidental release at 10 m. Long range contours that will be exceeded 5% of the time.

Figure D7a. Normalized annual surface concentrations for an accidental release at 50 m. Long range average contours.

GROUND LEVEL SECTOR AVERAGED ARITHMETIC AVG CONCENTRATION - UNITS / M³

HOT CREEK AIR CONCENTRATIONS. ANNUAL. ACCIDENT

Figure D7b. Normalized annual surface concentrations for an accidental release at 50 m. Short range average contours.

Figure D8. Normalized annual surface concentrations for an accidental release at 50 m. Long range contours that will be exceeded 5% of the time.

APPENDIX E
AIRBORNE PARTICULATES IN THE
LONG VALLEY GEOTHERMAL AREA

The presence of suspended particulates in Long Valley depends upon (a) a source for the particulates, (b) the prevalence of climatic conditions conducive to wind erosion, including sufficiently strong winds and low humidities, (c) sparse or no vegetative cover, (d) the length of wind fetch and (e) the degree of local roughness and its orientation to the wind direction. As shown in Fig. E1, the minimum wind speeds necessary to initiate particulate movement depends upon the particle size, the friction (or adhesion) between adjacent particles and the local roughness of the ground. The recorded threshold wind speeds that have initiated sand and dust storms vary from 5 to 13 metres per second.

After soil particles begin to move, they are carried by the wind in three ways - suspension, saltation, and surface creep. Sand and soil particles less than 100 micrometres in diameter have fall rates less than 10^{-2} metres per second [E1]. They can be lifted and carried in suspension to altitudes as great as 5 kilometres and for distances on the order of hundreds of kilometres. Coarser particles (100 to 500 micrometres) move in a bounding, jumping action called saltation. They rarely rise more than one metre above the ground and travel horizontally 10 to 15 times their height of rise. Particles in the 500 to 1000 micrometre size range move by surface creep, rolling and bouncing very near the surface.

WIND RAISED DUST

The initial suspension of dust particles is similar to that of sand, in that it is raised by saltation of larger particles.^[E2] The subsequent dispersion in the atmosphere to great heights and distances is possible because of the low fall-speeds as compared to the vertical eddy velocities (0 to 1 m/sec).^[E3] Near the surface, the variance of the vertical velocity is a function of the surface stress (i.e., the friction velocity, u^*) and the stability as defined by the Richardson number. The Richardson number is the ratio of the buoyancy forces due to density differences and the mechanical overturning forces due to the wind movement. It is clear that small dust particles are picked up by eddies and swirls in the wind generated by the local roughness elements. The particles subsequently enter the air immediately adjacent to the surface where they are diffused in a random motion which can be approximately treated by standard diffusion theory. Barenblatt and Golitsyn,^[E2] have shown that sufficiently high concentrations of dust and sand can reduce the level of air turbulence and may cause an acceleration of the mean wind. Other examples of this phenomena are snow avalanche winds^[E5] and winds associated with volcanic eruptions. These winds have reached speeds of more than 50 m/sec.^[E6]

Most of the ground in the Long Valley Area consists of sands rather than finer soils, except in the recently exposed bottoms of lake beds. Apparently most of the finer material has been exported in the past because of the high incidence of strong winds from a preferred direction in areas subject to wind erosion. As a result, a quasi-equilibrium has been established. Removal or alteration of vegetative cover disturbs the

equilibrium and makes new material available to wind erosion. This can result in severe sand and soil movement as shown in Fig. E2. This area east of Mono Lake was lightly forested with Pinyon pine, Juniper and sagebrush that was cut, piled and burned in 1964. Subsequent wind erosion has removed as much as one metre of sand leaving behind only the larger gravel, except in the lee of the sagebrush.

Clearing of vegetated areas also exposes the underlying soil to removal by whirlwinds. When the soil surface is bare, a strongly superheated, shallow layer of air is formed during the day. This air is in a potentially unstable equilibrium. When a small vertical air motion occurs, the resultant convection can induce strong vertical motions and dust whirls.^[E7] These effects have been observed over the exposed bottom of Owens Lake (Fig. E3) and Mono Lake (Fig. E4, St. Armand, private communication). These dust whirls can raise particulates to great altitudes. Whirlwinds tangential velocities have been measured up to about 11 m/sec, although stronger whirls probably exist. As an upper limit, firewhirl speeds have been measured in excess of 75 m/sec. Winds less than 11 m/sec^[E8] are sufficient to loft particles less than 100 micrometres in diameter. For instance, the dust whirl in Fig. E3 over the dry bed of Owens Lake raised a cloud of fine calcium carbonate particles from the lake bed;^[E9] but these dust whirls are not visible when they move out of the dry lake bed and over the surrounding sandy areas.

The dust that reduces visibility in Bishop occurs primarily during southerly winds as shown in Fig. E5. Dust raised over the cultivated areas and dry lakes in the southern Owens Valley by the Sierra wave (Fig. E7), but this dust does not usually reach Bishop. The dust raised by strong southerly

winds as shown in the satellite photo in Fig. E6 is carried north through the Chalfant, Hamil, and Queens Valley and does not significantly affect Long Valley.

Dust from the exposed, former bottom of Mono Lake is carried south by northerly winds into Long Valley. This dust frequently reaches June Lake when the winds are northerly, but the frequency of occurrence decreases southward.^[E10] The ground in Long Valley that may be subject to wind erosion is primarily sand, which behaves in a manner significantly different from wind-blown dust.

WIND-BLOWN SAND

Sand is moved by the wind in a ballistic, chain-reaction process. This is called saltation after a similar process that has been observed in water. The initial description of this phenomena was developed by Bagnold.^[E1] If the wind is sufficiently strong, the first particles of sand (diameter 10 to 100 micrometres) are moved and carried aloft a short distance. Since the wind speed usually increases with height, the particles are strongly accelerated to an increased velocity. When they fall back to the ground the ballistic impact upon the underlying sand ejects additional particles which in turn accelerate, fall back and form additional ejecta continuing the process. The effectiveness of wind in raising sand depends greatly upon the character of the underlying surface. In dune areas, winds of 4 to 7 m/sec are sufficient to initiate movement. In sandy flat areas, a wind of 9 m/sec is required, while on alluvial fans speeds of 13 to 16 m/sec are necessary. If the surface is disturbed the threshold speed may be lowered by 2 to 3 m/sec.

Sand particles have a relatively high terminal velocity (0.2 to 2 m/sec) because of their large size (100 to 500 micrometres). Consequently they do not rise to very great heights above the ground. True sandstorms (as opposed to duststorms) are rarely more than one to two metres deep. Consequently, the density and height of vegetation, such as sagebrush, and other obstacles to the low level air flow are important in determining the occurrence of blown sand. A stand of vegetation with a dense canopy will obviously prevent blown sand because the wind below the canopy is greatly reduced by the drag of the vegetation on the wind. Widely spaced clumps of vegetation will only have a local effect. There is an intermediate spacing which will accelerate the wind between clumps and increase saltation and creep. This increase in erosion on newly exposed areas can be as much as 0.1 metres per year (Fig. E2).

Many of the potential dust and sand sources in Long Valley are snow covered during the winter months, when the winds are the strongest. The major storms of this type occur in the fall and early winter, just before the first winter rain and snow storms and in the late spring after the snow cover has melted. Natural wind-borne dusts and sand in Long Valley cause the levels of Total Suspended Particulates (TSP) to frequently exceed the 75 micrograms per cubic metre primary standard and the 60 micrograms per cubic metre secondary standard. Use of drift fences and dust control by wetting can probably keep project related airborne particulates at or near present levels. There are economic advantages to suppression of blown sand because of its extremely abrasive nature.

Fig. E-1. Threshold friction speed versus particle diameter for particles with and without cohesion. (After Iverson, Greeley, and Pollack, [E4])

Figure E2. Wind erosion in area east of Mono Lake. Pinyon Pine and Juniper were removed in 1964. 1947 photo shows resultant erosion to gravel which removed as much as one metre of sand.

Figure E3. Dustdevil over Owen Lake raises a fine mineral dust.

Figure E4. Dustdevils over Pelican Island in Mono Lake carries the fine mineral particles of the former lake bed to great heights.

Figure E6. Dust sources in the Owens Valley during strong southerly winds is carried northward.

FIGURE E5. The envelopes of direction (S = south, N = north), wind speed and visibility show that most dust storms in Bishop, CA are associated with southerly winds.

Figure E7. Dust raised in the Owens Valley by the Sierra wave. Note the tendency for sources to be associated with disturbed soils. Courtesy of Dr. P. St. Armand, China Lake, NWC.

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