Baseline Air Quality - Kilauea East Rift

Executive Summary

State of Hawaii

Department of Planning and Economic Development

James E. Houck, Ph.D., Principal Investigator
Gerald O. Lesperance, Program Administrator

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ATTACHMENT 1
APPENDIX **B**
PLAN OF OPERATIONS

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Introduction

The Kilauea East Rift on the Island of Hawaii is the technically most promising area within the State of Hawaii for future geothermal development. However, the East Rift area also contains large tracts of pristine forests, comprises a portion of the Hawaii Volcanoes National Park, and is surrounded by several small communities and a number of residential subdivisions. The Kilauea East Rift is volcanically very active and naturally emits air pollutants normally associated with industrial sources. Extensive baseline air quality monitoring has been conducted along the East Rift to quantify pre-development concentrations of environmentally hazardous pollutants so that any future change in their concentrations which may occur due to geothermal development can be assessed.

The report presented here is a summary of the results obtained from five recent baseline air quality studies. These are:

Environmental Baseline Survey, Kilauea East Rift
December, 1982, through December, 1983, study period
Hawaii Department of Planning and Economic Development (DPED)

Environmental Baseline Survey, Kilauea East Rift (Year Two)
1984 study period
Hawaii Department of Planning and Economic Development

Remote Environmental Baseline Monitoring, Hawaii Volcanoes National Park
1984 study period
National Park Service

Ambient Air Quality Monitoring Survey, Kahauale'a Geothermal Project
February, 1984, through February, 1985, study period
True/Mid-Pacific Geothermal Venture

Ambient Air Quality Monitoring Survey, Puna Forest Reserve
February and March, 1985, study period
True/Mid-Pacific Geothermal Venture

In addition to the data directly generated from these studies, a survey of data obtained from scientific research and other monitoring which have been done on the Island of Hawaii has been conducted. Relevant research performed by scientists associated with the University of Hawaii, the Hawaii Volcano

Observatory, the Mauna Loa Observatory; air quality monitoring conducted by the Hawaii Department of Health; and meteorological monitoring conducted by the National Park Service, Mid-Pacific Geothermal, Inc., the Thermal Power Company, and the National Weather Service have been incorporated into this report.

Six environmental pollutant categories were identified as being most important for study and their baseline levels were documented. These were: (1) atmospheric particles, (2) sulfur dioxide gas, (3) hydrogen sulfide gas, (4) rainwater chemistry, (5) atmospheric mercury, and (6) radon activity. Each of the pollutant categories are impacted by volcanism and/or can be impacted by future geothermal development. In addition to the quantification of specific ambient pollutant levels, wind speed, wind direction, and rainfall data were also studied, as meteorological conditions influence atmospheric pollutant levels.

The baseline study area comprises portions of the Ka'u and Puna Districts on the Island of Hawaii. Monitoring sites were selected along the East Rift from the summit of Kilauea Volcano to Cape Kumukahi; however, major emphasis was placed on the area from the summit to Highway 130. The area along the Pohoiki Road, where geothermal exploration and development have occurred, was purposely avoided to prevent the possible contamination of baseline samples by geothermal emissions. Relatively little sampling or monitoring was conducted at the extreme lower end of the Rift near Cape Kumukahi because that area is considered to have a low potential for future geothermal development.

The combined data base from the five environmental programs and from the meteorological monitoring that provides the basis for this executive summary is extensive. The data has been collected over a two and one-half year period and it includes: (1) approximately 17,000 hours of continuous sulfur dioxide (SO_2) gas measurements made at eleven locations, (2) one hundred and thirty-two integrated multi-day SO_2 gas samples collected at ten locations, (3) approximately 17,000 hours of continuous hydrogen sulfide (H_2S) gas measurements made at eleven locations, (4) one hundred and thirty-two integrated, multi-day H_2S gas samples collected at ten locations, (5) measurements from two hundred and seventy-five passive multi-day H_2S monitors placed at thirty-six locations, (6) atmospheric particulate concentrations determined from more than 750 samples collected at twenty-one

locations, (7) analysis for thirty-four elements conducted on approximately 510 particulate samples, (8) additional elemental, anionic, and carbon analyses conducted on subsets of the particulate samples, (9) measurements from fifty-seven continuous quarterly and monthly radon-222 (Rn^{222}) monitors placed at eighteen locations, (10) pH, elemental, and anionic analyses (thirty-six elements and anions) conducted on fifty-one rainwater samples collected at fourteen locations, (11) additional trace elemental analysis conducted on a subset of the rainwater samples, (12) ten elemental mercury vapor samples collected at seven locations, (13) fifty-six total mercury vapor samples collected at nine locations, (14) approximately 510 particulate mercury analyses on samples collected at twenty-one locations, (15) fifty-three integrated multi-day chlorine (CL_2) gas samples collected at six locations, (16) over 60,000 hours of continuous wind speed and direction measurements made at fifteen locations, and (17) approximately 4,000 daily wind observations made at six locations.

The executive summary presented here contains a brief discussion of current pollutant levels and meteorological conditions characteristic of the East Rift area. The reader is referred to the complete summary report document submitted to DPED (July 31, 1985) for detailed data compilations and for a description of the monitoring networks and of the methods used in the environmental studies.

Atmospheric Particles

Monitoring for total suspended particles (TSP), respirable particles and inhalable particles was conducted along the Kilauea East Rift. In addition to atmospheric concentration levels the chemical composition of the particles was studied. Respirable (less than 2.5 microns in aerodynamic diameter) and inhalable (less than 15 microns in aerodynamic diameter) are considered more injurious to human health than larger particles since they reach the gas exchange areas and the air conducting pathways of the lungs, respectively, and are routinely monitored for that reason. Total suspended particles (TSP) are, as the name implies, all particles that are in the atmosphere. Sampling for TSP by utilizing high-volume samplers is a well-established regulatory procedure.

The atmospheric concentration of particulate material along the Kilauea East Rift has been found to be very low. The particulate concentrations

characteristic of the East Rift are much lower than mainland values and U.S. Environmental Protection Agency (EPA) standards. While average TSP, inhalable particulate, and respirable particulate concentration levels are all lower than mainland averages, most dramatic are the exceptionally low respirable particulate concentration values. These are probably due to the absence of major anthropogenic combustion sources (viz, fossil fuel combustion) on the Island of Hawaii. Of interest to the fact that secondary particles formed from volcanic fume are primarily in the respirable size range and considerable volcanic activity did occur during the sampling period. During more typical periods of less active volcanism, respirable particulate levels would ostensibly be extremely low. Dust from geological sources suspended by traffic, agricultural activity, and wind, as well as volcanic tephra, are primarily greater than 2.5 microns in size and is greatest during periods of low rainfall. During the study years of 1983 and 1984, rainfall along the East Rift was lower than normal. At the Hawaii Volcanoes National Park (HVNP) headquarters there was a 40 inch and 13 inch departure from the mean annual rainfall level of 108 inches during 1983 and 1984, respectively. At the community of Pahoa there was a 48 inch and a 18 inch departure from the mean annual rainfall level of 151 inches during 1983 and 1984, respectively. As with the respirable particles; TSP and inhalable particulate levels characteristic of the East Rift area during more typical years are probably even lower than those measured during the baseline studies.

Elemental analyses were conducted on nearly all particulate samples. Several observations could be made by studying the elemental data: (1) the elemental values make up a relatively small percentrage of the overall particulate mass, (2) elements associated with sea salt (sodium, magnesium, sulfur, chlorine, potassium, and calcium), geological dust (aluminium, silicon, potassium, calcium, titanium, and iron), volcanic fume (sulfur and chlorine), smoke (carbon and potassium), and vegetative fragments (phosphorous) have the highest concentration levels, and (3) data for samples collected on the lower rift differ in a predictable way from data for samples collected on the upper rift.

Organic compounds, oxide oxygen, and water of hydration together comprise the largest portion of the particulate mass. Oxide oxygen and water of hydration cannot be easily quantified. Many of the elements measured contain oxygen in the compounds in which they occur, and large amounts of water can be

expected to be associated with secondary volcanic fume particles and sea salt aerosol, especially in the high humidity environment typical of many locations on the rift. Organic carbon, elemental carbon, and carbonate carbon were measured in selected samples. The mass of organic compounds can be estimated from the mass of organic carbon by using a multiplication factor of 1.7 which takes into consideration nitrogen, oxygen, and hydrogen contained in organic compounds along with the carbon. It was found that organic compounds do comprise a significant fraction of the particulate mass. In some cases more than half the aerosal mass can be attributed to the organic compounds.

Chemical mass balance (CMB) source apportionment was conducted by mathematically comparing the average aerosol elemental data and the elemental data of particles originating from specific sources. The CMB modeling permitted the current sources of atmospheric particles to be estimated. Elemental data for road dust and volcanic tephra sources were directly obtained from samples collected on the Island of Hawaii. Other source data were obtained from reports of previous studies. While the impact of the particulate sources, as calculated by the CMB technique, vary from site to site, the differences between the sites are understandable in light of their geographical locations. Lower Rift sites have a high sea salt impact, a minor volcanic impact, and little or no smoke impact. Upper Rift sites have a low sea salt impact, a high volcanic impact, and a moderate smoke impact. Atmospheric particles in both areas have a moderate dust component, a large vegetative material component (pollen, spores, and vegetative fragments), and a very small vehicular exhaust component. (It should be emphasized that the use of the terms high and large are relative and that the total atmospheric particulate levels are all low.) By examining the CMB results of respirable, coarse (2.5-15 microns), and TSP data, it was obvious that sea salt, dust, and vegetative particles were primarily greater than 2.5 microns and impacted the inhalable and TSP levels much more than the respirable particulate levels. In contrast, volcanic fume, smoke, and vehicular exhaust were more predominant in the respirable size (less than 2.5 microns) category. This finding is consistent with the general understanding that particles entering the atmosphere by physical processes are larger in size than those formed from combustion and other high temperature sources.

In addition to CMB modeling, bivariant plots of elemental concentrations contained in ambient aerosols were helpful in determining the major sources of

particles. Aluminium and silicon are key components in geological material. When dust from geological sources is a measurable component in atmospheric aerosols, there is a high degree of correlation between the two elements. A high degree of correlation was found between those two elements in particles collected at all monitoring sites along the Kilauea East Rift. Similarly, sulfur (as sulfate) and chlorine (as chloride) are key components in sea salt. At lower Rift sites where sea salt impact was greatest, there was a high degree of correlation between these two elements, particularly in the coarse fraction.

Particles originating from some sources are morphologically distinct and can be identified by microscopy. For example, photomicrographs of aerosol samples collected at the Royal Gardens Subdivision monitoring site (less than 50 meters from the coastline) clearly showed the predominant sea salt particles which were mostly 30 to 50 microns in diameter. Photomicrographs of aerosol samples collected at sites in areas of forest or agricultural activity frequently showed large vegetative bodies.

The impact of volcanism is episodic and overall annual means are not particularly illustrative in assessing the volcanic impact on air pollutant levels. During the nearly two and one half years of baseline monitoring, there were thirty phases of the current Kilauea eruption series and a rare eruption of Mauna Loa. By contrasting average values during periods of active volcanism and during periods of no volcanic activity, it was seen that volcanic activity did not significantly contribute to atmospheric particulate levels in the lower Rift area, but it did impact the upper Rift area. Particulate mass, particulate sulfate, and particulate selenium concentrations were most noticeably increased due to volcanic emissions.

Another and unexpected air quality impact of volcanic activity was measured during the first phase (January, 1983) of the current Kilauea eruption series. Apparently, the material emitted during this first phase was fractionated and was enriched in the more volatile chemical compounds; consequently, a dramatic atmospheric increase in transition and heavy metals contained in particles was noted during January, 1983. This phenomenon was seen during the DPED monitoring near the HVNP Visitors Center and by research scientists at the Mauna Loa Observatory. The high levels have not been observed during any subsequent eruption phases.

Sulfur Dioxide Gas

Sulfur dioxide (SO_2) gas was considered as a high priority pollutant for baseline monitoring since it occurs at relatively high concentrations in volcanic fume and would be produced at low levels in the atmosphere by the natural oxidation of hydrogen sulfide emitted from geothermal sources. It would also be produced directly by the geothermal industry at moderate levels if a H_2S incineration abatement system were used. Sulfur dioxide is associated with many industrial activities (viz, fossil fuel combustion and ore smelting) and is one of the principal mainland polluants responsible for acid rain and the formation of fine particles which cause visibility loss.

During the majority of the time during the baseline studies, atmospheric concentrations of SO_2 were below several tenths of a part per billion by volume (ppbv) at locations upwind (under prevailing trade and drainage winds) of the major volcanic vents of Halemaumau and Pu'u O. However, during periods of vigorous volcanic activity or during periods of unusual meteorological conditions, such as winds from the south, episodes of high concentrations, even exceeding the dynamic range of the instruments used, were recorded. Points downwind of the major volcanic vents do, of course, frequently have high atmospheric SO_2 concentrations.

Due to the short-term episodic nature of high SO_2 concentrations, the U.S. EPA annual average standard (30 ppbv) is not likely to be reached. The U.S. EPA twenty-four hour standard (140 ppbv), however, has been exceeded at upper rift sites. Similarly by comparing mainland urban averages, it could also be seen that annual average values typical of industrialized areas are not likely to be reached in the upper rift area (except directly downwind and adjacent to Halemaumau or Pu'u O), but maximum twenty-four hour values typical of urban areas can be exceeded due to active volcanism and/or unusual meteorological conditions.

Sulfur dioxide odor and taste thresholds are often exceeded near the Kilauea summit, as any traveler to the area knows. Plant damage due to SO_2, particularly to introduced species, does occur. During active volcanic periods and/or under poor atmospheric dispersion conditions, short-term health impacts can be expected in residential areas. Documented long-term chronic relationships are less clear, especially in light of the unusual exposure

pattern to which residents of the area are subjected, i.e., short periods of high concentrations followed by long periods of trace ambient levels.

Hydrogen Sulfide Gas

Hydrogen sulfide (H_2S) gas was considered as a high priority pollutant for baseline monitoring since it is the principal pollutant associated with geothermal power plants. It is also a minor component of volcanic fume and is produced naturally by anaerobic respiration. Its atmospheric half-life before it is oxidized to SO_2 is approximately five hours. While H_2S is hazardous to human health and to the environment at high concentrations, at the low levels at which it is likely to be encountered due to geothermal development the major problem is nuisance odor. The human olfactory sensitivity to its "rotten-egg" odor is exceptional.

During the overwhelming majority of the time, the atmospheric concentration of H_2S was below several tenths of a ppbv at the baseline study sites. Very infrequently, concentrations in the 10-30 ppbv range were reached. As with SO_2, these high values were episodic, short-lasting in nature, and due to volcanic fume impact. The episodes measured at the HVNP Visitors Center were possibly due to the site's proximity to the Sulfur Banks, where an early exploratory geothermal well was drilled. Occasionally, H_2S concentrations in the several ppbv range may occur locally at middle and lower rift zone areas due to anaerobic respiration. Water-logged, organic-rich soils, such as occur in much of the Puna District, make ideal conditions for the production of H_2S by anaerobic respiration. Such naturally produced H_2S was measured at a monitoring site referred to as the Waikahekahe site. The Waikahekahe monitoring site was located on the large relatively recent pahoehoe flat that lies to the north of Pahoa. The flat is characterized by shallow soil, thick grass, and scattered, stunted ohia trees. After periods of heavy rain, the shallow soil becomes covered with water due to the poor drainage in the underlying pahoehoe lava.

Rainwater Chemistry

The chemical composition of rainwater is an important parameter to examine on the Kilauea East Rift for three primary reasons: (1) rain "scrubs" the atmosphere of pollutants and by doing so becomes contaminated with them,

(2) acid gases and mists emitted by volcanoes will produce "acid rain," the deleterious impact of which is a topical issue, and (3) many Rift residents use rainwater catchment as their source of drinking water. During the period from December, 1982, through March, 1985, over fifty rainwater samples were collected and analyzed.

Three major factors influence rainwater chemistry along the Rift: (1) all rainfall in Hawaii has a tendency to be slightly acidic due to the long range transport of pollutants from industrialized mainland areas, (2) volcanic emissions locally acidifies rain and impacts its chemical composition, and (3) sea salt aerosol makes rain less acidic due to its bicarbonate content and also impacts the chemical composition of the rain.

By contrasting the average chemical composition of rain collected at several sites, the impact of volcanic emissions and sea salt could be illustrated. A monitoring site near the Royal Gardens Subdivision was located less than fifty meters from the coastline and hence rain collected there was heavily impacted by sea salt. The major sea salt species (calcium, magnesium, potassium, sodium, strontium, chloride, and sulfate) were relatively higher in the rain collected there than in rain collected at any other site. A monitoring site on the Chain of Craters road was downwind of Pu'u O. The major chemical species associated with volcanic fume (fluoride, chloride, and sulfate) and volcanic tephra (aluminium, calcium, iron, manganese, potassium, and silicon) were apparent in the chemical composition of the rain collected there. In rain collected at sites which were at greater distance from the coastline and which were not heavily impacted by volcanic emissions, the concentrations of the aforementioned chemical species were lower.

The impact of sea salt is elevation-dependent on the Island of Hawaii. Using the average sodium concentration in rainwater samples collected for the baseline studies and in samples collected and analyzed in a previous scientific study, the decrease in the impact of sea salt with elevation could be graphically illustrated.

The impact due to volcanism is also elevation-dependent mainly because the major volcanic vents and fumaroles are above 2,000 feet. Using pH as an indicator of volcanic impact, the increase in volcanic impact at about that elevation could be seen.

The pH of the Kilauea East Rift rainwater falls between literature values for polluted and unpolluted rain and the rainwater is more acidic than typical river water and the drinking water criteria acceptable range. The concentrations of the major chemical species in the Kilauea East Rift rainwater, however, are all much lower than literature values for unpolluted coastal rain and are also well below average river water values. River water is, of course, the source of drinking water for much of the world's population. The concentrations of sulfate, of nitrate, and of race elements except cadmium, lead and selenium were demonstrated as being below drinking water criteria levels. Rainwater cadmium and lead values may be below the drinking water criteria levels, but the analytical technique used for their analysis in rainwater was not sensitive enough to document that fact. Selenium concentration, while measured in only five samples, was above the drinking water criteria value (0.01 ppm) in three of the samples (0.04-0.06 ppm). A possible secondary impact of the mild acidity characteristic of the Kilauea rainwater should be noted. Elevated concentrations of copper, lead, and zinc may appear in catchment drinking water if copper pipes, lead solder, or galvanized (zinc) pipes or roofing are used in the catchment system. This exposure risk would be greater in the upper portions of the Rift where the acidity of the rainwater is higher.

Mercury Vapor

The toxicity of mercury and the devastating health impact of acute and chronic industrial exposures have historically been very well documented. Numerous mercury vapor measurements have been made on the Kilauea East Rift. Reported total mercury vapor (elemental, organometallic, and halide) values typically range from several ng/m^3 to several hundred ng/m^3. Temporal, spatial, and analytical differences are probably responsible for the range in values. Two opposing factors control mercury vapor on the Rift. The unpolluted atmosphere above the open ocean (i.e., the tradewinds) have a very low mercury content (less than 1 ng/m^3). Volcanic fume, on the other hand, can contain hundreds to tens of thousands of ng/m^3 of mercury. The degree of volcanic activity, the location of a given sampling site with respect to vents and/or geological features, and the meteorological conditions during sample collection can all alter the observed atmospheric mercury concentration. It should also be emphasized that the measurement of any pollutant to the nanogram per cubic meter range should be viewed cautiously,

and the values reported should be considered order of magnitude values at best. (One nanogram is 0.000000001 gram and there are 454 grams in a pound. Stated another way, 1 ng/m^3 is approximately one part in a trillion by weight.)

In addition to total mercury vapor, elemental vapor and total particulate mercury measurements have been made. The average elemental mercury vapor values ranged from 4 to 30 ng/m^3. The average particulate mercury vapor values were less than or equal to the average uncertainties associated with the measurement technique (several ng/m^3). During the Phase I eruption of Kilauea (January, 1983), measurable particulate mercury concentrations were, however, observed (4 ng/m^3 was the highest value).

By comparing the ambient mercury values with values characteristic of other locations, it could be seen that values measured on the East Rift, except for the summit of Kilauea, are more or less typical of continental sites and dramatically lower than occupational health standards. The values reported for the Kilauea summit are reasonable in comparison with the other volcanic values and are also lower than occupational health standards.

The concern over atmospheric mercury appears at times to be excessive and should be placed in its proper perspective by doing a simple calculation. Assuming a 200 ng/m^3 atmospheric concentration, a normal human lifetime of seventy years, a normal human inhalation rate of 20 m^3/day and assuming that all mercury in the air which is inhaled is absorbed, the amount of mercury "collected" by an individual over a lifetime can be easily calculated as being 0.1 grams. It should also be emphasized that mercury is ubiquitous and that there are many other current pathways of exposure other than air. For example, virtually all individuals within the United States have dental fillings which are essentially a mercury-silver analgam, many medications contain mercury (e.g., mercurochrome), and unfortunately so do many foods.

Radon Activity

Radon-222 is a radioactive gas naturally formed from the decay of radium contained in geological materials. Radon-222 has a 3.8 day half-life and decays via an energetic alpha particle. Two of its daughter products (Polonium-218 and Polonium-214) also have very short half-lives (3.0 minutes

and 1.6×10^{-4} seconds, respectively) and also deay by energetic alpha particles. Due to the radioactivity of Radon-222 and its daughter products, and the fact that Radon-222 is a gas which can be inhaled, high Radon-222 concentrations are injurious to human health. As with atmospheric mercury, two opposing factors control the atmospheric radon content on the Kilauea East Rift. High radon emission rates are associated with volcanic areas. Conversely, air above the open oceans, such as constitutes the trade winds, has a very low radon activity (approximately 0.01 pCi/l).

A total of fifty-seven passive radon monitors were located at eighteen different sites along the Rift during the two and one-half years of baseline monitoring. Two sites had significantly higher average radon activities than the others: the Napau Crater Site and the Kahauale'a Proposed Drill Site. During the DPED baseline study, the Napau Crater Site routinely had the highest quarterly radon activity among the six sites. Conversely, the high average calculated for the Kahauale'a Proposed Drill Site is due to a single very high value (3.43 pCi/l) obtained when a monitor was placed over a fresh, still-hot lava flow to replace a monitor that was destroyed several weeks earlier by the flow. The values obtained with monitors before the flow and the value obtained with a monitor installed after the high-level monitoring period, show that radon activities during those periods at the site were more or less typical of the Rift area as a whole. The high value obtained with the monitor above the fresh lava flow apparently was either due to the fresh lava emanating radon at a high rate or due to the emanation rate of the soil beneath the flow increasing as a result of being heated by the flow. The routine higher values obtained at the Napau Crater Site are understandable in light of the fact that the site is directly on the Rift and that the monitoring period for the DPED baseline study was December, 1982, through December, 1983. The January 3, 1983, eruption was only several hundred meters uprift of the sampling site. During the sampling period, the eruption moved down the Rift past and in line with the Napau Crater Site with some spattering occurring as close as 100 meters to it. Consequently, the Napau monitors were exposed to vigorous volcanic degassing.

The lowest radon activity was measured at the Waikahekahe Site. This is consistent with the water saturated soil observed at the site. The emanation rate of radon from water saturated soil has been shown to be lower than that of drier soil since soil voids are filled with liquid rather than air under

saturated conditions. Radon, a gas, diffuses faster through another gas than through a liquid.

The average radon activity levels ranged from 0.16 pCi/l to 1.14 pCi/l at the various monitoring locations on the Rift. If the Napau Site and the Drill Site are excluded, the range of values is from 0.16 pCi/l to 0.52 pCi/l. The latter range is more representative than the former of the range of values to which the residents of the Rift area are exposed, since few people live for long periods directly over eruption sites or lava flows. The range in Radon-222 values along the Rift is more or less typical of mainland outdoor exposure values and is below standard levels. The Kilauea outdoor levels are also lower than values typical of many North American and European homes. The build-up of indoor radon will not occur in typical Hawaiian homes, as it does in continental homes, due to the single-wall construction and high air exchange rates characteristic of most homes in Hawaii. The high build-up of radon in continental homes is principally due to low air exchange rates caused by intentional weatherization to conserve energy for heating and/or air conditioning, and due to simply keeping windows and doors closed during cold (or hot) weather. Most Hawaiian homes in the Puna and Ka'u Districts also have crawl spaces because of moisture and insect problems. Separation of homes from the soil by a crawl space was shown to markedly decrease the indoor radon activity in homes built in Florida above phosphate mining regions.

Other Air Pollutants

Three other air pollutants which merit discussion are: carbon monoxide (CO), nitrogen oxides (NO_x), and chlorine gas (Cl_2). Even though CO and NO_x are often major air contaminants in many airsheds, they were not considered as high priority pollutants for study on the Kilauea East Rift. They are primarily associated with industrial combustion sources, not geothermal activities. Their current atmospheric concentrations above the East Rift are unquestionably very low, although some CO is present in volcanic fume, some is produced by automobiles, and some is produced by industrial activity in the Hilo area. Three CO grab samples were collected on the Rift in 1983. The sampling technique used was not very sensitive, and the data simply illustrates that the atmospheric CO concentrations were below U.S. EPA Standards. No nitrous oxide gas measurements were made during the baseline studies; however, nitrate (NO_3) and nitrite (NO_2) concentrations were

measured in selected particulate samples and in all rainwater samples. Nitrite was below the analytical detection limits in all particulate and rainwater samples. Nitrate, on the other hand, occurred at low, but measurable, concentrations in the particulate and rainwater samples.

Multi-day sampling was conducted for chlorine gas during the DPED and National Park Service baseline studies. Chlorine gas is not a pollutant normally studied in air quality programs; however, since Cl_2 gas can be used for hydrogen sulfide abatement in the geothermal industry and it is a very hazardous and environmentally damaging gas, baseline data for it was collected at six locations during 1983 and 1984. The concentrations measured on the Rift were very low and well below industrial exposure standards and biological impact levels.

Meteorology

Wind speed, wind direction, and rainfall patterns on the Kilauea East Rift were studied during the baseline programs. The obvious relationship between these parameters and atmospheric pollutant levels necessitates their inclusion into any discussion of air quality. Continous wind measurements have been made at fifteen locations in the Kilauea East Rift area for various time periods, and regular wind observations hve been made at another six relevant sites. Rain gages have long been maintained at a great number of locations on the Island of Hawaii by various organizations and individuals.

Wind direction and speed summaries were prepared illustrating average daily wind speed and directions made from continuous monitoring records and from single daily observations. The summaries based on single daily observations provide a somewhat biased picture of the average wind conditions as regular diurnal shifts have been found to occur.

The diurnal shifts in wind speed and direction are the result of the interactions of katabatic-anabatic flows (downslope-upslope mountain flows) and the land-sea breeze phenomenon with the prevailing trades (as they are deflected by the local topography). Due to these interactions, average nighttime wind speeds are lower than average daytime speeds, and wind directions tend to shift toward the west at night from the typical north to northeast daytime trade conditions. When average wind directions were

examined for two hour increments, the diurnal shift was very apparent. The occurrence of winds from the north and northeast is at a maximum in the late afternoon and the occurrence of winds from the west and northwest is at a maximum in the early morning.

The environmental significance of the diurnal change in wind conditions is that there is not a single prevailing downwind point from any emission source, and moreover, the point of maximum impact for any given emission source (volcanic or anthropogenic) can be expected to shift 45^{o} to 90^{o} daily ostensibly everywhere in the Kilauea East Rift area. The lower nighttime wind speed coupled with the typical ground level nighttime temperature inversion caused by radiational cooling (a few degrees over several hundred feet), suggest that atmospheric dispersion will be poorer during the night.

It is clear from the summary data that prevailing winds on the Kilauea East Rift range from the west to the east over the "northern half" of the compass points depending on the exact location on the Rift. It, however, should not be forgotten that winds from the southerly direction do also occur a measurable fraction of the time. Unusual weather conditions, such as kona storms and tropical cyclones, can cause these southerly winds.

Rainfall levels impact air quality. The magnitude of the "scrub-out" effect, the suspension of dust, and the production of spores and pollen by plants are all directly or indirectly dependent on rainfall. Significant temporal and spatial rainfall variability both occur in the Rift area. As previously discussed, a drought occurred during portions of 1983, and rainfall levels during 1984 were below normal as well. Consequently, most pollutant levels measured during 1983 and 1984 were probably higher than levels that would be typical during wetter years if all else were equal. A high spatial variability in precipitation over short distances also occurs in the region due to orographic rainfall patterns. Average annual rainfall ranges from less than 19.7 inches to more than 196.9 inches in less than 35 kilometers.