PUNA
GEOTHERMAL VENTURE

PROJECT

ENVIRONMENTAL IMPACT STATEMENT

THERMAL POWER COMPANY

November, 1987

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FINAL ENVIRONMENTAL IMPACT STATEMENT

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LIST OF ABBREVIATIONS

AAQS	Ambient Air Quality Standard
ACGIH	American Conference of Governmental Industrial Hygenists
ADA	Anthro-quinone Disulfonic Acid
AMSL	Above Mean Sea Level
ANSI	American National Standards Institute
Ar	Argon
As	Arsenic
BACT	Best Available Control Technology
B	Boron
BLNR	Board of Land and Natural Resources, State of Hawaii
BOP	Blowout Prevention Equipment
BP	Before Present
Br	Bromide
Ca	Calcium
CEC	California Energy Commission
CDP	Census Defined Places
CFR	Code of Federal Regulations
CH_4	Methane
C_2H_6	Ethane
Cl	Chloride
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CO_3	Carbonate
CT	Census Tracts
dB	Decibels
dBA	Decibel, A-weighted
DBED	Department of Business and Economic Development, State of Hawaii
DEIS	Draft Environmental Impact Statement
DLIR	Department of Labor and Industrial Relations, State of Hawaii
DLNR	Department of Land and Natural Resources, State of Hawaii
DOH	Department of Health, State of Hawaii
DOSH	Department of Occupational Safety and Health, State of Hawaii

DPED	Department of Planning and Economic Development
EIS	Environmental Impact Statement
EPC	Estimated Permissible Concentrations
ERZ	East Rift Zone
F	Fluoride
^{o}F	Degrees Fahrenheit
Fe	Iron
g	Acceleration Due to Gravity
gpm	Gallons per minute
GLC	Ground Level Concentration
g/s	Grams per Second
H_2	Hydrogen
HC	Hydrocarbons
HCO_3	Bicarbonate
HECO	Hawaii Electric Company
HELCO	Hawaii Electric Light Company
He	Helium
Hg	Mercury
HGP-A	Hawaii Geothermal Project - Abbott
H_2O_2	Hydrogen Peroxide
HRS	Hawaii Revised Statutes
H_2S	Hydrogen Sulfide
HVAC	Heating, Ventilating and Air Conditioning
Hz	Hertz, Equivalent to Cycles per Second
I	Iodide
KLP	Kapoho Land Partnership
KS	Kapoho State (Wells)
kV	Kilovolt
lb/hr	Pounds per Hour
L_{90}	Sound Pressure Level Exceeded 90% of the Time During a Given Time Period
L_{eq}	Equivalent Sound Level During a Given Time Period
LERZ	Lower East Rift Zone
Li	Lithium
Lp	Sound Pressure Levels
M	Meters

Mg	Magnesium
mg	Milligrams
mg/l	Milligrams per Liter
mg/m^3	Milligram per cubic meter
Mi	Mile
MMD	Mean Mixing Depth
Mn	Manganese
mph	Miles per Hour
Ms	Modified Mercalli Scale
MSL	Mean Sea Level
MW	Megawatt
MWH	Megawatt Hour (Power)
N_2	Nitrogen
NAAQS	National Ambient Air Quality Standards
Na	Sodium
NaOH	Sodium Hydroxide
NH_3	Ammonia
NCG	Noncondensable Gases
NELH	National Energy Laboratory of Hawaii
NO_x	Oxides of Nitrogen
NWS	National Weather Service
O&M	Operation and Maintenance
OSHA	Occupational Safety and Health Administration
OTEC	Ocean Thermal Energy Conversion
pCi/l	Picocuries per liter
PE	Precipitation Evaporation
PEL	Permissible Exposure Limit
PG&E	Pacific Gas and Electric
PGV	Puna Geothermal Venture
PM	Particulate Matter
ppm	Parts per Million
ppmv	Parts per Million-Volume
ppm(w)	Parts per Million-Weight
psi	Pounds per Square Inch
psia	Pounds per Square Inch-Absolute
psig	Pounds per Square Inch-Gauge

S	Elemental Sulfur
SiO_2	Silica
SO_2	Sulfur Dioxide
SO_4	Sulfate
STEL	Short-Term Exposure Limit
TDS	Total Dissolved Solids
TLV	Threshold Limit Value
TPC	Thermal Power Company
TSP	Total Suspended Particulates (Air)
TSS	Total Suspended Solids (Water)
ug	Micrograms
ug/m^3	Micrograms per Cubic Meter
UIC	Underground Injection Control
USDW	Underground Source of Drinking Water
yr	Year

EXECUTIVE SUMMARY

This Environmental Impact Statement (EIS) describes and evaluates the environmental impacts of the Puna Geothermal Venture (PGV) project. The EIS identifies the effects of the proposed action on the environment as well as the economic and social structure of the community and the State. Proposed measures to minimize adverse effects are discussed and alternatives to the proposed actions and their environmental impacts are presented.

A brief overview of the EIS and the conclusions reached is provided in this Executive Summary. To assist the reader in finding detailed information in the EIS, the organization of this summary will follow the same general subject order as the EIS, dealing with the physical (geology, hydrology, air and noise), biological, and human (health and safety, land use, socioeconomics, cultural, and aesthetics) environments. The order of appearance does not indicate an importance or ranking.

INTRODUCTION

The Hawaiian people have enjoyed and utilized the benefits of geothermal resources for centuries. Early Hawaiians used the heat from fumaroles on Kilauea's summit for heating and cooking. Over 100 years ago, King Kalakaua made inquiries about the use of geothermal resources for generating electricity. The use of the power of the volcano for electricity production, now referred to as geothermal energy, has become a reality. The Hawaii Geothermal Project (HGP), located one-half mile south of the PGV power plant location, has demonstrated the technical feasibility and reliability of commercial geothermal operation in Hawaii. HGP Well Abbott (HGP-A) drilled in 1976 and the associated 3 megawatt (MW) power plant have been generating electricity since 1981.

The PGV project consists of a 25 MW (net) geothermal power plant and supporting wellfield facilities. The project is located on the Island of Hawaii in the Puna District, approximately 21 miles southeast of the city of Hilo. The 25 MW of electricity produced will be purchased by the Hawaii

Electric Light Company (HELCO) to provide electricity island-wide. A power transmission line will be needed to transmit power to the HELCO energy grid. Environmental studies for the transmission line are being prepared by HELCO and no information regarding the transmission line is included in this EIS.

The 500-acre project area is in an area designated as a geothermal resource subzone, within the Kapoho Section of the Kilauea Lower East Rift Geothermal Resource Subzone. The PGV project is located in the same geologic zone as the HGP-A facility. The PGV power plant, wellpads and associated structures will occupy only 17 surface acres of the 500-acre site.

DESCRIPTION

Geothermal power production uses geothermal steam to drive a steam turbine, which in turn rotates an electrical generator and produces electricity. Geothermal fluids are produced by wells which tap a geothermal reservoir. The fluids are separated into two components, brine and steam, at the wellpad. The brine is collected and reinjected into the geothermal reservoir. The steam is collected and sent to the power plant steam turbine. Geothermal fluids contain hydrogen sulfide gas (H_2S) which must be contained due to the objectionable odor and possible health impacts associated with exposure to the gas.

The geothermal reservoir is maintained by heat emanating from intruding dikes and possibly from localized secondary magma chambers associated with Kilauea Volcano. The summit of Kilauea is approximately 25 miles west of the project site. Geothermal fluids are found at depths greater than 4,000 feet beneath the ground surface and are above 600°F in temperature.

Up to six wellpads are currently expected to be required over the 35-year life of the project. Currently there are two wellpads located on-site and four additional sites have been selected. As many as four or

five wells may be located at each wellpad. Each wellpad contains a rock muffler, separator, and associated valves and piping for production of the geothermal fluids.

Geothermal wells for the project are identified as either production or injection depending upon the performance of the well. Each production well is anticipated to have an average flow rate of 90,000 pounds per hour (lb/hr) of steam deliverable to the power plant. Injection wells will be those wells with marginal production. The injection wells will be used to reinject fluids generated in the operation of the PGV wellfield and power plant. Two liquid streams will be reinjected into the geothermal reservoir, brine and process fluid. Makeup (replacement) wells will be drilled as required to maintain full plant output when the production or injection capability has declined below acceptable levels.

Geothermal fluids will be separated into brine and steam fractions at the wellpads and then transported from the wellpads to the power plant through gathering systems. These piping systems are designed to withstand the thermal, pressure, dead and seismic loads which may be encountered. The gathering lines will follow the shortest routes from the source to the power plant destination typically following road alignments. The pipelines will be insulated to conserve heat.

The brine gathering system collects the brine from each wellpad before it is reinjected into the geothermal reservoir. The anticipated brine injection rate is 280 gallons per minute (gpm). A surge pond is available for short-term discharge of brine if there is a problem with the injection system.

Geothermal steam is collected and delivered to the power plant. The PGV power plant consists of two steam turbine-electric generator sets and the associated support equipment. Each turbine-generator set is capable of operating independently with each supplying a net of 12.5 MW to the HELCO grid. The total steam requirement for the PGV project is approximately 540,000 lb/hr.

The geothermal steam enters the turbine at approximately 155 pounds per square inch absolute (psia), and after performing work, exits at approximately 2 psia. Upon exiting the turbine, the geothermal steam enters the surface condenser where it is cooled and condensed. The condensed steam is sent to the cooling tower to replace water which is lost to evaporation. Naturally occurring gases in the steam do not condense and are removed by steam ejectors. These noncondensable gases contain H_2S and must be treated before release to the atmosphere.

A turbine bypass system is provided to route the steam around the turbine to the surface condenser during a turbine upset condition. The bypass system allows the noncondensable gases containing the H_2S to be handled in the same manner as when the turbine is operating. Should the condensing system be unavailable the steam is routed to the steam release facility.

H_2S abatement begins in the surface condenser when the steam exits the turbine. Over 99 percent of the H_2S in the surface condenser stays in the noncondensable gases and is removed by the steam ejectors. The noncondensable gases are compressed and sent to an absorber where they are combined with a portion of the cooling water removed as blowdown. The pressure in the absorber (215 psia) dissolves the H_2S in the blowdown. The blowdown containing the dissolved H_2S (called process fluids) is subsequently reinjected into the geothermal reservoir. A maximum of 0.5 lb/hr of H_2S may not dissolve on the blowdown. This H_2S is returned to the cooling tower and vented with the nitrogen and hydrogen which also do not readily dissolve in the blowdown.

The reliability and availability of the reinjection process will be enhanced through appropriate redundancy of mechanical equipment. The operating parameters of the reinjection process such as pressure, temperature and flow rate will be closely monitored, and will provide an early warning in the event of a malfunction or change in the reservoir parameters.

A backup H_2S abatement system, a burner/scrubber system, is included in the PGV design. This system will incinerate the noncondensable gases, burning the H_2S to sulfur dioxide (SO_2). The SO_2 is then scrubbed out of the gases with sodium hydroxide (NaOH), converting the SO_2 into nontoxic sulfites and bisulfites.

The steam condensate from the surface condenser, containing less than 1 percent of the H_2S, is injected into the cooling water return line. Oxygen in the cooling water provides a natural oxidation of the H_2S to sulfites. The gases which did not dissolve in the absorber and other vent gases are also sent to the cooling tower. The total H_2S emissions from all of these sources will not exceed 4.0 lb/hr under all normal operations.

The steam release facility is employed when the condensing system is not available. In such an event, the steam is automatically diverted to one of two rock mufflers located near the power plant. The rock mufflers are constructed of heat resistant reinforced concrete and filled with lava rock. Steam entering the steam release facility is sprayed with water to desuperheat the steam and then treated with NaOH and hydrogen peroxide (H_2O_2) to remove the H_2S. Following chemical treatment, the steam vents to the atmosphere.

ENVIRONMENTAL SETTING

The following paragraphs provide a brief description of the physical, biological, and human environments in the vicinity of the project. Environmental resources that are rare or unique in the region or the project site are emphasized.

PHYSICAL ENVIRONMENT

The PGV project site is located in the Lower East Rift Zone (LERZ) of the Kilauea Volcano. This is one of the most active volcanos in the world, and lava flows occurred in the LERZ as recently as 1961. The geothermal

reservoir heat is believed to be maintained by the very high heat flow within the rift as well as localized secondary magma chambers located below the reservoir.

The geothermal reservoir is largely separated from the overlying aquifer by a relatively impermeable seal which is 1,500 feet thick. This seal is sufficient to maintain the heat and pressure generated within and below the geothermal reservoir. The seal is locally broken by fractures and faults which provide conduits for relatively small quantities of geothermal fluids to migrate upwards.

The site area is characterized by small lava shields, cinder and spatter cones as well as numerous fissures, vents and other minor eruptive features. The project site is underlain by basaltic aa and Pahoehoe lava flows and associated ejecta. Lava flows in the area are highly vesicular, permeable and are often fractured.

The high permeability of the lava flows allows almost all precipitation to rapidly percolate into the subsurface. An average of about 120 inches of precipitation falls on the site annually, and percolates into the ground. This percolation results in a significant infiltration to the groundwater. The only standing body of water known to exist in the Puna area is Green Lake, near Kapoho. The lake exists as a result of an ash layer which seals the permeable soil and prevents the water from percolating downward.

Groundwater in the Hawaiian Islands typically follows the Ghyben-Herzberg principle where a lens of fresh (basal) water floats on, and displaces, denser saltwater. This lens of basal water progressively thickens from the coast to the center of the island. The mechanisms which control groundwater occurrence in the ERZ area are more complex than the Island as a whole.

The chemistry of Hawaiian groundwater varies greatly with location. The main groundwater aquifer beneath the PGV site occurs at a depth of approximately 600 feet and extends to approximately 2,500 feet below the surface. The high recharge rates, coupled with the permeable nature of the rocks containing the aquifer result in high groundwater flow velocities.

As a result of the leakage of geothermal fluids into the overlying groundwater aquifer, groundwater above and downgradient of the geothermal reservoir has been chemically and thermally contaminated. There is no fresh water within or downgradient of the immediate site region. Sampled water in the PGV site region is characterized by temperatures ranging from 100° to 199°F, chloride to magnesium ratios of 18 to 3200, silica content of 24 to 105 part per million (ppm) and total dissolved solids (TDS) concentrations of 762 to 11,700 ppm.

Reinjection of brine and process fluids into the geothermal reservoir should extend the life of the reservoir by replacing some of the liquid supply and assisting in effective heat transfer. The great volume of fluids within the geothermal reservoir and the largely effective overlying seal are sufficient to contain the relatively insignificant volume of fluids reinjected. Reinjection will not impact any fresh drinking water sources because the aquifer over the geothermal reservoir is contaminated already and the geothermal fluids are returned to the reservoir that they originated in.

Groundwater wells in the Pahoa area have been drawing high quality water for many years. Groundwater in this area occurs at an elevation of about 15 feet above mean sea level. This groundwater is recharged from upgradient toward Mauna Loa and represents the only fresh water in the area surrounding the site. The groundwater in the Pahoa area is largely separated from the groundwater beneath the site by structural grain of the LERZ which acts as a partial barrier to lateral groundwater migration.

The regional climate, site meteorology and baseline air quality have been determined. Long term weather data are available from the National Weather Service station at the Hilo Airport. In addition, PGV has conducted meteorology and air quality monitoring studies in the Puna region since 1981.

The Hawaiian Islands lie within the trade winds belt. These winds generally flow from the northeast on the Island of Hawaii. The climate of Hawaii is greatly influenced by the trade winds. Trade winds are prevalent 80 to 85 percent of the time from May to September. From October to April, the trades are prevalent 50 to 80 percent of the time and this is the period of time when most major storms occur. The sky at Hilo is cloudy 203 days per year on average, and rain showers are frequent.

The wind flow at the site is from the north to northwest during the daytime (trade wind influence) and from the west at night. The westerly flow at night stems from downslope flows. The average wind speed for all hours is 7.4 miles per hour. Ambient air quality studies at the site were performed to determine the background levels of H_2S. The results of these studies indicate that the background level of H_2S is below 0.010 parts per million by volume (ppmv) 98 percent of the time.

An environmental noise survey was conducted at the PGV site to determine the current background noise levels during weekday periods. These ambient noise levels were measured for 24-hours at four locations during September 1986. Half of the monitoring locations were located in the residential properties located south and southwest (0.5 and 1.0 miles) from the PGV site. The other two monitors were located on the PGV site.

The background noise levels were determined to range from 34.2 dBA to 53.2 dBA. The high background noise resulted from wind noise and moderate to heavy rainfall. Noise from the HGP-A facility was just barely audible at the PGV on-site monitors and was inaudible at the two residential monitoring sites.

BIOLOGICAL ENVIRONMENT

The wellpad and power plant locations are situated on scrub vegetation and fallow fields. The dominant vegetation is introduced (non-native) weedy species and abandoned papaya orchards. Much of the area within 1 mile of the power plant is covered by either the 1955 lava flow, fallow fields or Metrosideros forests.

A total of 240 plant species were found during a 1984 survey of the area within 1 mile of the power plant. A listing of these species is included in Appendix C. One candidate endangered plant species (Tetraplasandra hawaiiensis) was found within the 1-mile study area. Three rare species of Cyrtandra and a Bobea species (possibly Bobea timonioides, which is a candidate endangered species) were also identified. No rare or endangered plant species occur on the wellpad and power plant sites.

Eleven bird species were observed within a 1-mile radius of Puu Honuaula during a 1984 study. Two of the species are native: the Hawaiian hawk and the lesser golden plover. The Hawaiian hawk is on the Federal List of Endangered Species. Its breeding area encompasses most of the Island of Hawaii.

Four field studies of the Hawaiian hawk have been conducted between 1984 and 1986 in connection with the PGV geothermal project. The studies have shown that the hawks use the project area around Puu Honuaula for hunting. No nests have been found on Puu Honuaula. The nearest nest is located about 1 mile east of the project site.

HUMAN ENVIRONMENT

The 1984 population in the Puna District was 16,530. It was the third most populous of the Island's nine districts. Hilo is the Island's primary city with about 40 percent of the population concentrated around it. In 1980, 43.2 percent of Puna's population was Caucasian, 19.2 percent was of Japanese ancestry, 16.7 percent were Filipino, and 15 percent were native Hawaiians.

Proportionally more Puna workers were engaged in manual occupations (for example agriculture, craft and repair) in 1980 than the Island as a whole. Puna has comparatively higher unemployment rates and lower median family income than other parts of the Island. The Puna district has long been a major sugar-producing area. However, in late 1984 Puna Sugar Company ceased operations. As a result approximately 15,000 acres of sugar production were abandoned and 485 jobs were lost.

In a recent survey, 84 percent of Hawaii residents favor geothermal development. Even in the eastern part of the Big Island, the vast majority (78 percent) of the residents favored geothermal development.

The Puna District was an important religious and cultural center in ancient times. The priest Paao established his line of priesthood in Puna. Puna has played an important role in Pele (the volcano goddess) history, belief and worship. According to folklore, numerous places in the area are important to Pele, and Pele's home is in the fire pit of the Kilauea volcano.

No archaeological resources have been found within 1 mile of the project site. A reconnaissance survey of the area was performed in 1984.

Land use near the site is residential, geothermal, and recreational. Six subdivisions are located within 2 miles of the PGV project site. A field survey in 1986 indicated that only two homes were within 0.5 mile of the power plant and ten additional homes were between 0.5 and 1.0 mile from the plant. Two other geothermal projects are in the vicinity of the PGV project site: HGP-A power plant and the Barnwell geothermal exploration wells. The HGP-A plant is a 3 MW demonstration facility (discussed previously). Two wells were drilled by Barnwell Geothermal, Inc. but both were nonproductive and drilling has been suspended. Lava Tree State Park is 1 mile northwest of the plant site. It is unique in its interesting lava molds of trees which stand among ohia trees and fern growth.

The three major highways in the area are Highway 130 (Keaau-Pahoa Road), Highway 132 (Kapoho Road) and Highway 137 (Puna Coast Road). Highway 130 runs through the center of Pahoa. The State Department of Transportation has proposed construction of a Pahoa Bypass Road, which would carry through-traffic around Pahoa's urban area.

Existing traffic levels at the intersection of Highways 130 and 132 (approximately 1 mile west of the power plant) are between 2,000 and 3,600 vehicles per day. Kapoho Road and Pahoa-Pohoiki Road border the project site. Pahoa-Pohoiki Road is the current access road to the site, but Kapoho Road will be the future site access road since Pahoa-Pohoiki Road has a blind left turn into the site.

BENEFITS OF THE PROPOSED ACTION

The PGV Geothermal project provides both the State and the Island of Hawaii with a number of beneficial aspects and assists in meeting a number of goals. The project is anticipated to:

- Decrease dependence upon imported petroleum products and reduce capital outflow for oil payments.
- Diversify Hawaii's economic base.
- Ensure that the Island of Hawaii will continue to have a sufficient energy supply.
- Provide increased employment opportunities, and personal income.
- Increase public revenues and capital expenditures.
- Provide a dependable, efficient and economical source of energy.
- Increase the energy self-sufficiency of the Island of Hawaii.
- Develop an alternate, renewable energy source which is indigenous to the Island.
- Further the State program to develop further information on the commercialization of geothermal energy.

POTENTIAL ENVIRONMENTAL IMPACTS AND MITIGATION MEASURES

The proposed action will have a variety of impacts on the environment. The following discussion provides a synopsis of the probable and potential impacts and also the measures which will be taken to mitigate the impacts. Unavoidable Adverse Environmental Impacts are discussed in the next section.

PHYSICAL ENVIRONMENT - IMPACTS AND MITIGATIONS

GEOLOGY

There are no significant geological impacts associated with the construction and subsequent operation of the PGV power plant. The impacts of concern deal with the natural hazards associated with the seismicity and volcanism in the site area and the possible damage which such activity might cause to the PGV facilities.

Impact: Earthquake damage to the facility might result in failure of equipment or piping.

Mitigation Measures

- Design critical equipment to the higher Seismic Zone 4 requirements even though the State of Hawaii only requires Seismic Zone 3 designs.
- Add flexibility to the piping design. For example, piping will be designed for expansion due to thermal and pressure conditions, with allowance for average fissure widths.
- Develop emergency procedures that include shutdown and depressurization of pipelines in the event of seismic damage.

Impact: Volcanic activity (i.e. lava flows) might damage facilities and piping.

Mitigation Measures

- Locate major facilities on elevated ground.
- Place wellheads in cellars that can be filled with cinders in the event of a lava flow.
- Employ deflection barriers around threatened wellpads and pipelines.
- Continue to work closely with the U.S. Geological Survey and the Hawaii Institute of Geophysics to ensure early warning of impending volcanic events.
- Develop emergency procedures that include shutdown and depressurization of pipelines in the event of high volcanic risk

HYDROLOGY

There should be no appreciable impacts to the aquifer system as a result of reinjection of brine and process fluids into the geothermal reservoir. Natural leakage of reservoir fluids into the overlying groundwater aquifer will continue to chemically and thermally contaminate this water source. The reinjection of fluids into the reservoir will help to replenish some of the extracted resource and should not affect the natural contamination of groundwater resources which is already occurring. Therefore, no mitigation measures are necessary to control or alleviate potential groundwater contamination with respect to the reinjection process.

Impact: Potential of water contamination from drilling fluids which are discharged to sumps on the wellpads or lost into subsurface cavities during drilling.

Mitigation Measure

- All drilling fluids and additives which are used in any PGV drilling operations are not indicated to be toxic at the level of usage that will occur.
- Toxicity tests of drilling fluids previously placed in the Wellpad A sump show no EPA toxicity levels.

Impact: Potential for geothermal fluids to migrate upwards from the geothermal reservoir along the wellbore.

Mitigation Measure

- Seal the wellbore physically with casing and cement before drilling into the geothermal reservoir.
- Utilize casing design, materials and cementing operations and procedures specifically designed for geothermal well conditions in Puna.

Impact: Potential for silica precipitation in the lines causing problems.

Mitigation Measure

- Maintain a relatively high above-ground temperature in the brine (>300°F)
- Minimize above-ground residence time (less than one hour)
- Use conservative assumptions for silica concentration (1500 ppm)

AIR QUALITY

A number of different air emission impacts exist. Among these, the principal concern stems from the presence of H_2S in the geothermal steam at the PGV facility. In addition, the presence of particulate matter and trace elements in the steam as well as criteria pollutants emitted from construction equipment cause minor air quality impacts. Impacts and mitigations are separated into two broad categories: construction/ decommissioning emissions and plant operating emissions.

Emission calculations and air dispersion modeling of pollutant emissions were conducted to determine maximum ground-level concentrations (GLC) for various operations. Results of these analyses indicated that H_2S GLC's will be less than the proposed State incremental and ambient air quality standards (AAQS) for the proposed regulated operations. Maximum Total Suspended Particulates (TSP) GLC's will not exceed the State 24-hour AAQS for all operations. Trace elements and radon-222 concentrations will not exceed ambient level goals and EPA guidelines.

Impact: Criteria pollutant, H_2S, and fugitive dust emissions during construction, well drilling, short-term venting, testing and workover operations.

Mitigation Measure

- Conduct regular maintenance of construction equipment and drilling rig engines to prevent undue discharges of criteria pollutants (Carbon monoxide, hydrocarbons, nitrogen oxides, sulfur dioxide, and total suspended particulates). Criteria pollutant emissions from these engines do not exceed the significant levels defined in the Hawaii Air Pollution Control Rules (Chapter 60, Title 11).
- Control fugitive dust from construction operations by sprinkling exposed soil in the construction area with water. TSP emissions are below the significant levels and mercury (Hg) concentrations from the dust emissions will be below the ambient level goal of 0.01 ug/m^3.
- Employ mud drilling techniques to reduce H_2S and TSP emissions from wells during drilling operations to a negligible level.
- Inject NaOH and H_2O_2 into the separated steam to control H_2S emissions by 95 percent during well flow testing operations.
- Use water injection and chemical treatment to control H_2S emissions by over 95 percent during well workover operations.
- Perform certain operations (well venting, pipeline cleanout) only during proper meteorological conditions and with proper notifications.

Impact: H_2S, TSP, trace element, and radon-222 emissions during power plant operation

Mitigation Measure

- Use conservative safety factors for design of process facilities and related piping.
- Monitor H_2S levels during all phases of the project.

- Use a noncondensable gas abatement system which reinjects H_2S into the geothermal reservoir as the primary abatement system. This system was selected based upon BACT analysis. H_2S emissions during normal operation are reduced by 99 percent using this system
- Install a backup system (burner/scrubber) for H_2S control when the primary system is unavailable. The backup system controls emissions by 99 percent.
- Ensure that the primary or backup abatement systems will be available more than 97 percent of the time.
- Control cooling tower drift to 0.005 percent of the circulating water flow rate by use of demisters. Concentrations of trace elements (Arsenic, boron, magnesium, manganese, and mercury) and radon-222 in the cooling tower drift are below ambient level goals.
- Design the process plant equipment with automatic instrumentation and controls to minimize the possibility of a rupture disk event resulting from a process upset.
- Use NaOH and H_2O_2 injection at the power plant rock muffler to control H_2S emissions by 98 percent during steam stacking operations (state-of-the-art rock muffler design).

NOISE

A number of different noise impacts exist. The most significant noise levels will be generated during short-term operations such as well venting, flow testing and pipeline cleanout. Less significant noise impacts occur during plant construction, well drilling, well workover, and normal plant operations. Impacts and mitigation measures are divided into two broad categories: construction operations and power plant operations. Decommissioning impacts and mitigations are equivalent to those for plant construction.

Impact: Noise generated during plant construction, well drilling, well workover and short-term venting operations.

Mitigation Measures

- Set equipment backup alarms at minimum legal limits.
- Reduce drill rig noise during well drilling and well workover operations by using residential-grade exhaust mufflers, placing an acoustic enclosure around drill rig engines and other noisy mechanisms, and silencing engine radiator air inlets and outlets.
- Use silencers and/or enclosures on auxiliary equipment used during well drilling and workover operations (diesel generators, pumps, compressors, etc.)
- Employ steam vent muffling system when steam is encountered during well workover operations.
- Use rock mufflers to control noise during flow testing operations.
- Schedule short-term operations, well venting and pipeline cleanout, for daylight hours only and notify the public prior to such operations.

Impact: Noise generated during power plant operation, steam stacking episodes, and rupture disk events.

Mitigation Measures

- Acoustically insulate selected pipes and valves, and steam ejectors.
- Use rock mufflers to control noise during steam stacking.
- Connect pressurized steam outlets to rock mufflers, where possible.
- Design power plant layout to shield residents from cooling tower noise.
- Specify that quiet fans, motors and baffles be used for the cooling towers.
- Insulate and/or enclose the turbine-generator.
- Muffle or baffle ventilation openings to turbine building
- Schedule major maintenance for daylight hours only.

BIOLOGICAL ENVIRONMENT - IMPACTS AND MITIGATIONS

The two principle potential biological impacts are the safety and preservation of the native Hawaiian hawk population, and rare or endangered plant species.

Impact: Potential for agitation/disturbance of the Hawaiian hawk

Mitigation Measure

- Limit disturbances near Puu Honuaula
- Minimize air emission by reinjecting geothermal fluids into a subsurface zone
- Install noise-reducing equipment and insulation materials
- Monitor the activities of the Hawaiian hawk, and its nesting locations
- Schedule drilling and venting around the hawk's breeding season if adverse effects are observed

Impact: Potential for disturbance of rare and endangered plant species.

Mitigation Measure

- Site wellpads and power plant in areas where rare and endangered plant species have not been found
- Minimize grading of project site to approximately 17 acres of the 500-acre site
- Limit disturbance on Puu Honuaula and the adjacent Puu where the majority of the rare and endangered species have been found
- Minimize air emissions by injection of process fluids into a subsurface zone
- Continue to study plants in the vicinity of the project to insure plants will not be adversely effected.

HUMAN ENVIRONMENT - IMPACTS AND MITIGATIONS

The human environment may be impacted by the project in a variety of ways. Possible impacts include areas such as health and safety of the public and workers at the facility, energy self-sufficiency, aesthetics of the area, traffic patterns, land values, employment, and economic well-being.

Impact: Potential for release of radon, arsenic and other trace elements from geothermal fluids

Mitigation Measure

- Establish a baseline level for radon, arsenic and other trace elements of concern.
- Monitor plant operations to determine actual exposures.
- Monitor the plant equipment and surrounding catchment water for any buildup in arsenic and other elements of concern.
- Sample produced geothermal fluids for concentrations of these elements entering the facility

Impact: Potential for accidents during transportation and handling of hazardous materials

Mitigation Measure

- Transport hazardous materials (NaOH and H_2O_2) in accordance with all Federal (DOT) requirements.
- Schedule deliveries to avoid peak traffic periods.
- Minimize the quantity of chemicals used at the PGV geothermal power plant through use of the reinjection process.

Impact: Visual views of the facility

Mitigation Measure

- Minimize ground disturbance to project site
- Revegetate graded areas with native trees and plants shortly after construction to block views of the facility

- Shield site lighting in accordance with regulations
- Paint buildings, structures and pipelines with earth-tone colors to blend with the vegetation
- Remove wellpads, power plant and associated equipment from the site after project decommissioning
- Revegetate the project site after decommissioning

Impact: Potential for a decrease in the housing values of homes closest to the project

Mitigation Measures

- Inject geothermal fluids into a subsurface zone so that the odor associated with hydrogen sulfide (rotten eggs) will not be incurred, and air emissions will be minimized
- Insulate selected pipes and valves, construct acoustic enclosures around drill rig engines, use residential-grade exhaust mufflers, silence engine radiator air inlets and outlets, and schedule loud maintenance activities during daylight hours
- Landscape and revegetate project site to minimize views of the facility

Impact: Potential for a slight increase in area traffic

Mitigation Measure

- Designate Kapoho Road as the main access road.
- Construct a right-hand turn lane into the site to alleviate hazards associated with slowing vehicles entering the site.
- Schedule construction vehicles and any particularly hazardous deliveries to travel and arrive during periods of light traffic.
- Encourage the construction of the Pahoa Bypass Road.

UNAVOIDABLE ADVERSE ENVIRONMENTAL IMPACTS

Most of the potential adverse environmental impacts of the project are mitigated throughout the life of the project. Some impacts cannot be completely mitigated or avoided. Most of the unavoidable impacts occur only throughout the 35-year life of the project. These impacts include:

- Minimal alterations to topography
- Controlled quantities (within regulatory limits) of air emissions during well drilling, well flow testing, steam stacking, well venting, construction, and power plant operation.
- Controlled discharges (within regulatory limits) to subsurface zones during well drilling.
- Temporary commitment of 17 acres of land for the power plant and associated wellfield.
- Temporary visual changes in the immediate area of the project.
- Controlled noise (within regulatory guidelines) during construction, well drilling, well testing, steam stacking, well venting, plant operation, and decommissioning.
- Increased traffic during construction/decommissioning.

ALTERNATIVES INVESTIGATED

Alternatives considered included the "no-action, delayed action, alternative energy sources and alternative sites as well as alternative H_2S control technologies for emissions from the power plant.

The "no-action" alternative was examined and eliminated because this alternative would require that the increased power demand be met by fossil fuel power plants. This goes against the stated objective of reducing the amount of petroleum imported and increasing the use of renewable natural resources.

The delayed action alternative is not preferred because the demand and required time frame for additional electrical power has been forecast by HELCO. The State has an active conservation program, which helps to delay the need for new power sources. However, potential increases in population and tourism may overshadow the savings from conservation. The time for a power plant to be constructed and begin operation is sufficiently long that delays in project schedules may ultimately result in a shortage of power for consumers. Geothermal energy will provide the power needs projected by HELCO in the most economical and environmentally sound manner.

Eleven alternative energy sources were investigated to determine their possible substitution for geothermal energy in the PGV project. The alternatives included: fuel oil, coal, nuclear energy, hydroelectric, wind, biomass, municipal solid waste, solar thermal energy, photovoltaic, ocean thermal energy conversion and ocean wave energy. The small scale of the project (25 MW) eliminated some technologies since they are not practical at this small capacity. Other technologies are not presently available for commercial application. A number of the alternatives are suitable for peak power production but do not have the capability of baseload power production.

A comparison of the emissions produced by fuel oil, coal, biomass (wood) geothermal and municipal solid waste determined that geothermal power presented the lowest criteria pollutant emission rates. Based upon the low emissions, technical feasibility, and relatively low production cost of electricity from geothermal power, the geothermal alternative was determined to be the best alternative energy source.

Alternative sites may exist, but the selected site is within a designated geothermal resource subzone and has known geothermal resources. Within the selected project site, the currently determined power plant and wellpad sites were selected on the basis of topography, minimizing visual and noise impacts to the surrounding neighbors and minimizing impacts to the ecosystems. Additionally, preference was given to sites which were covered with aa lava rather than Pahoehoe lava due to structural concerns. Potential lava flows were also considered in selecting the sites.

Within the process design, an analysis was performed to determine the Best Available Control Technology (BACT) for control of H_2S emissions. Seven alternatives were examined including Burner/scrubber system, Stretford process, LO-CAT process, Claus-SCOT process, Selectox/CI process, Clinsulf process, and the reinjection process. The process which proved to have the lowest overall emissions and also the lowest abatement cost per ton of H_2S handled is Reinjection.

UNRESOLVED ISSUES

The issues which remain unresolved are (1) the actual characteristics of the geothermal resource over the life of the project, (2) the ability to comply with noise guidelines for particular activities, (3) the availability of the electrical transmission line to connect the PGV power plant to the HELCO grid, and (4) the specific regulatory standards and permit conditions for the facility.

CONSISTENCY WITH LAND USE PLANS, POLICIES AND PERMITS

LAND USE LAWS

The PGV geothermal project is consistent with Hawaii Land Use Law (Chapter 205, Hawaii Revised Statutes) since the project is situated within the Kapoho Section of the Kilauea Lower East Rift Geothermal Resource Subzone. Subzones are areas of significant geothermal potential where geothermal exploration and production is encouraged.

HAWAII STATE PLAN

The geothermal project supports and furthers the State's primary economic objective, that of developing and diversifying Hawaii's economic base. A major goal of the State is to increase energy self-sufficiency. A second energy goal is to achieve dependable, efficient, and economical statewide energy systems capable of supporting the needs of the people. The PGV project supports the State's major energy goal of increasing energy

self-sufficiency. Simultaneously, it is consistent with developing a new energy source and meeting the energy demands of Hawaii. Although 25 megawatts is a small percentage of the State's energy needs, it is significant for the Island of Hawaii. Construction of the PGV facility is a step in self-sufficiency for the Island of Hawaii and for the State. HELCO has forecast an increase in energy needs for the near term on the Island of Hawaii. The PGV facility development is scheduled to meet this increase in energy demand.

STATE ENERGY FUNCTIONAL PLAN

The PGV project is consistent with DBED's 1984 Energy Functional Plan. One of five areas of concern addressed in the plan is alternate energy resource development. The objective is to promote alternate energy technologies through commercialization in order to shift demand from petroleum to indigenous renewable resources. The Functional Plan states:

> "Hawaii's near-total dependence on imported petroleum, spiraling oil prices, the net outflow of dollars for oil payments, and the political unrest of major oil-producing nations threaten local economic stability and the ability to serve energy needs over time. Support and assistance for private sector activities to develop local energy resources will reduce dependence on the world oil market, improve the State's balance of payments, and thus promote economic development, and increase the number and diversity of employment opportunities."

COUNTY GENERAL PLAN

The General Plan articulates several goals and policies that relate directly to the PGV project:

- The County shall strive towards energy self-sufficiency
- The County shall encourage the development of alternative energy resources
- The County shall encourage the expansion of energy research industry

- The County shall ensure a proper balance between the development of alternate energy resources and the preservation of environmental fitness
- The County shall strive to ensure a sufficient supply of energy to support present and future demands

PERMITS

Permits are needed from the Hawaii Department of Health, State Department of Land and Natural Resources, State Department of Labor and Industrial Relations and from the County. The most significant permits are the Authority to Construct air permit, the Geothermal Resource Permit, and the Underground Injection Control permit. The complete list of permits is provided in Table 13-1 of the EIS.

SECTION 1

INTRODUCTION

This Environmental Impact Statement (EIS) is an informational document prepared in accordance with Chapter 343, Hawaii Revised Statutes (HRS), and Title 11, Chapter 200 of the Hawaii Department of Health's Environmental Impact Statement Rules. A Draft EIS was submited to the Hawaii County Department of Planning in August, 1987 for review and public comment. As a result of the comments, some sections have been revised, expanded, and/or clarified. (See Section 18 for comments and responses.) This document is the final EIS.

The project that is covered by this EIS is the Puna Geothermal Venture (PGV) project. The Hawaii County Department of Planning has not determined that the PGV project requires the preparation of an EIS; however, PGV decided to prepare an EIS in order to assure a complete understanding of the environmental aspects of the project.

The EIS identifies the effects of the proposed action on the environment as well as the economic and social structure of the community and State. Proposed measures to minimize adverse effects are discussed. The EIS also presents alternatives to the proposed action and their environmental impacts.

This introduction defines the PGV project, states the purpose and need for the project, describes historical and recent geothermal power development in Hawaii, and discusses the organization of the EIS.

1.1 PROJECT DEFINITION

The proposed project is a geothermal power facility consisting of an electric power plant and supporting wellfield facilities. It is located on the Island of Hawaii in the Puna District, approximately 21 miles southeast of the City of Hilo (See Figure 1-1).

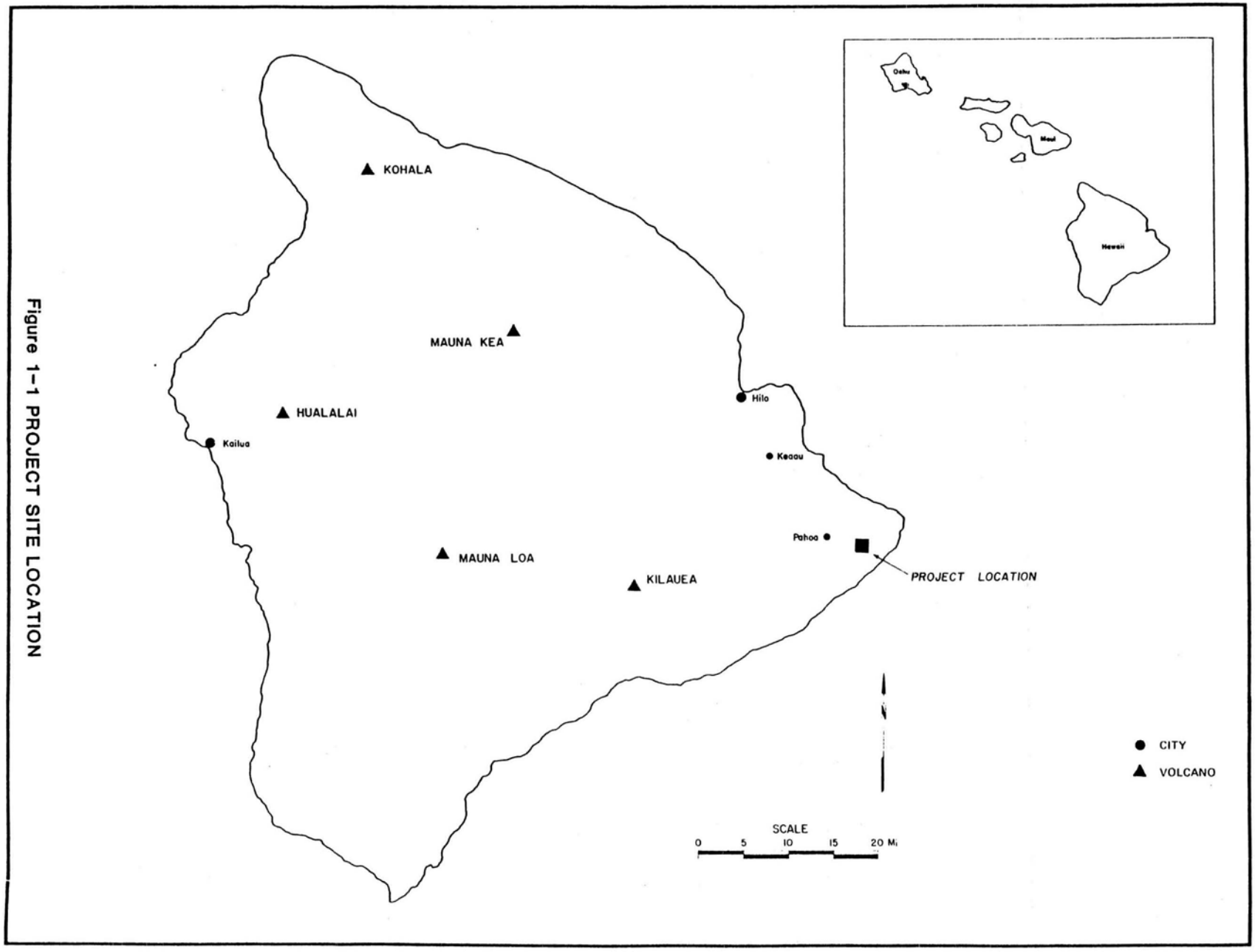


Figure 1-1 PROJECT SITE LOCATION

The power plant uses geothermal steam to drive a steam turbine-generator and produce electrical power. A detailed and a general site plan of the facility is presented on Figures 1-2 and 1-3 respectively. Figure 1-3 delineates the project boundaries. The PGV facility is designed to provide 25 megawatts of electricity to the Hawaii Electric Light Company's (HELCO's) energy grid system for island-wide use. To ensure delivery of 25 megawatts, the power plant is designed to handle a gross capacity of 30 megawatts. The excess capacity will be utilized by the power plant for internal energy requirements and transmission line losses.

The project is located on approximately 500 acres within the Kapoho Section of the Kilauea Lower East Rift Geothermal Resource Subzone. The project site area was designated as a subzone by a 1984 Hawaiian law (Act 151). Geothermal Resource Subzones are areas where geothermal exploration and production are encouraged.

The project lies along the Lower East Rift Zone of Kilauea Volcano. The Rift Zone is one of the conduits for lateral migration of magma from the holding chamber beneath Kilauea's summit caldera. The geothermal resource is maintained by heat emanating from intruding dikes and possibly from localized secondary magma chambers associated with Kilaueea Volcano. Geothermal fluids are found at depths greater than 4,000 feet beneaath the ground surface and are above 600°F in temperature.

A power transmission line will be needed to transmit power to the HELCO grid system. Environmental studies for the transmission line are being prepared by HELCO; no information regarding the transmission line is included in this EIS.

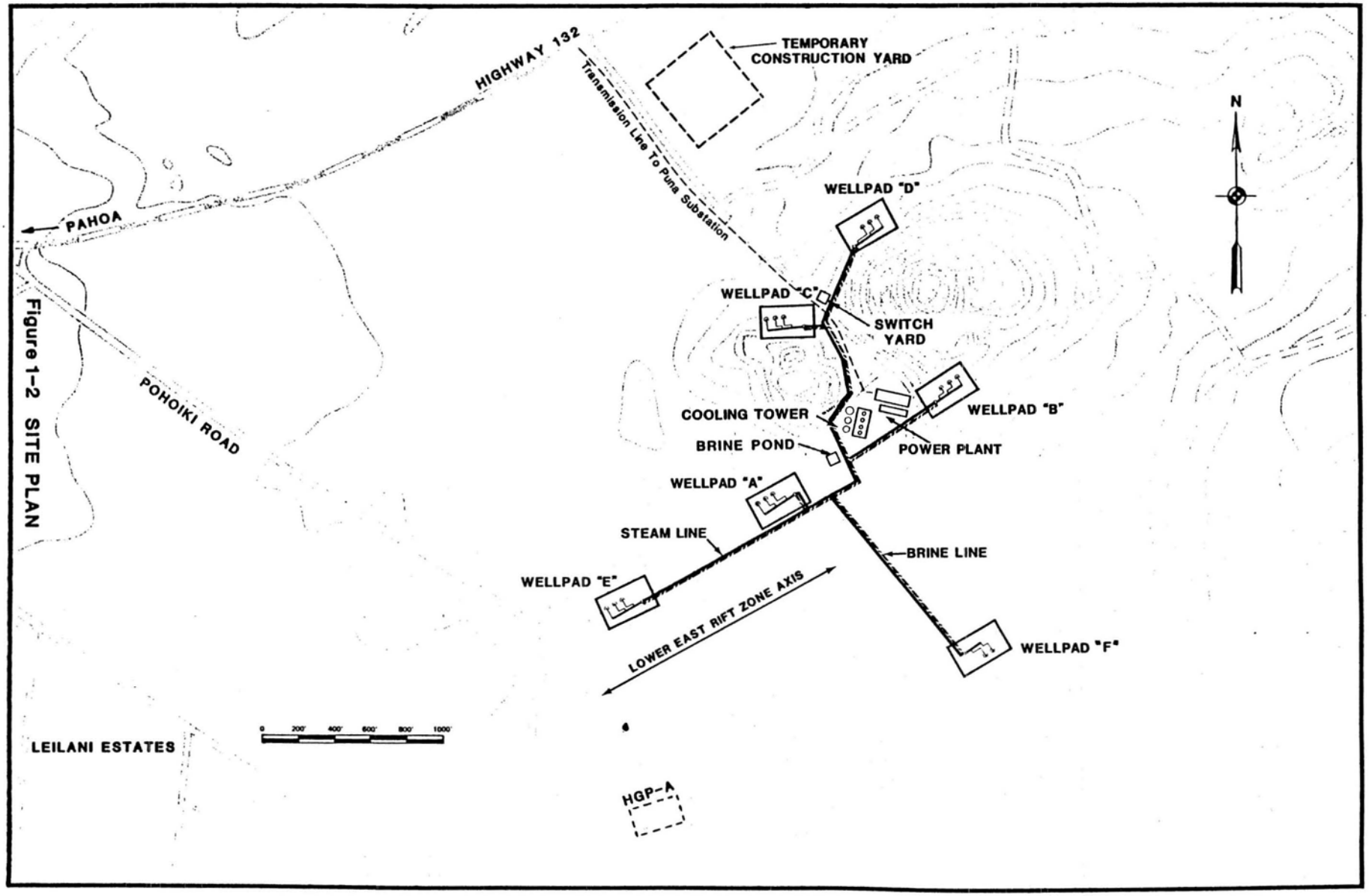
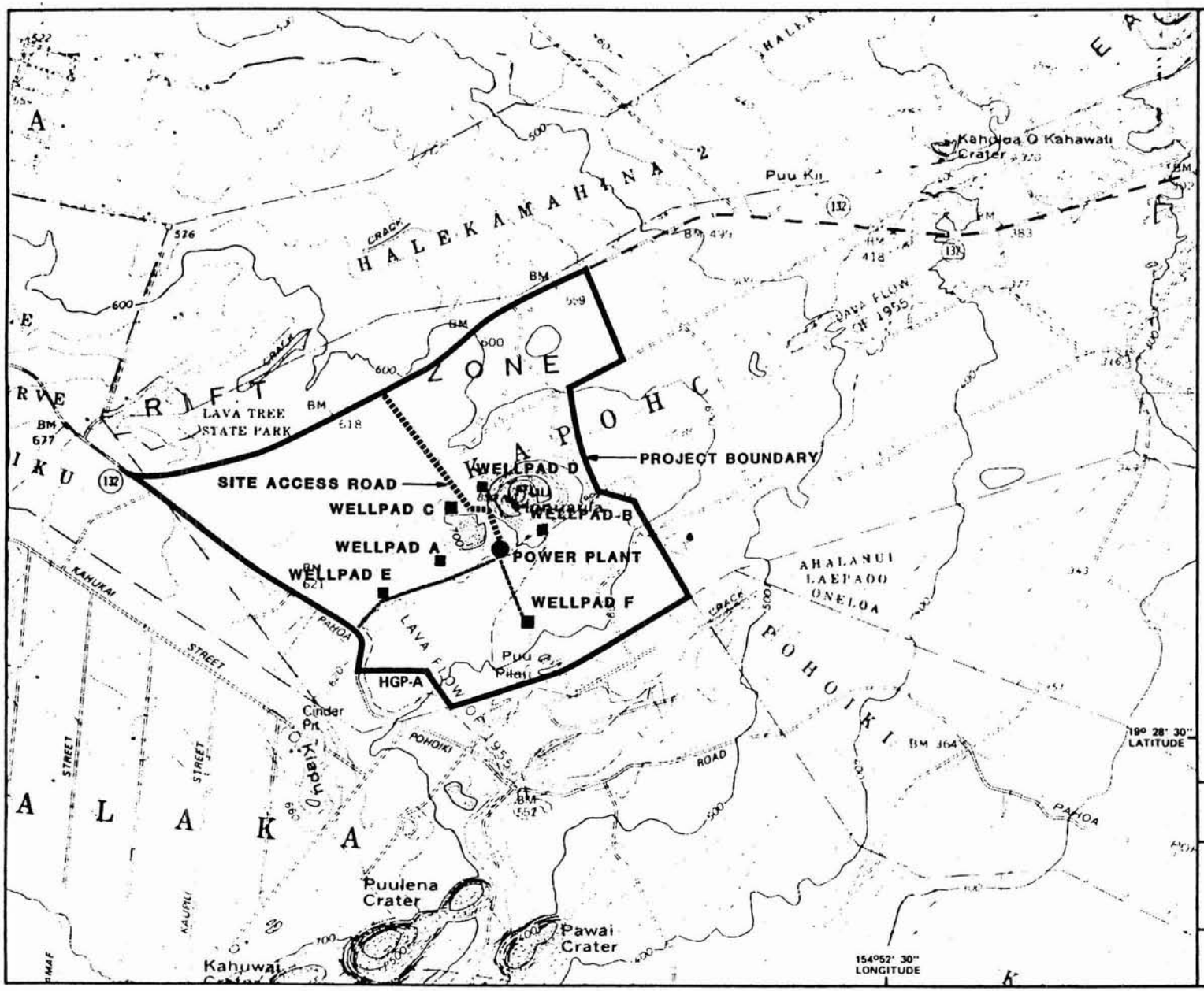
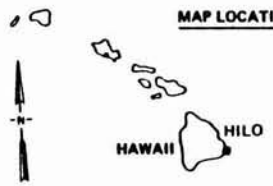


Figure 1-2 SITE PLAN



MAP LOCATION



LEGEND:

- POWER PLANT
- PRODUCTION WELLPAD

SCALE
CONTOUR INTERVAL 20 FEET

0 — ½ MILE
0 — 1000 — 2000 FEET
0 — 1KM

SOURCE: U.S.G.S., 1980, 1981a, 1981b

PUNA
GEOTHERMAL VENTURE PROJECT
HONOLULU, HAWAII

Figure 1-3

PROJECT AREA

FLUOR DANIEL	JOB. NO.	DRAWING NO.	REV.

Thermal Power Company (TPC) will be the operator of the PGV project. The project itself is a joint venture between TPC and AMFAC Energy, Inc. TPC has an extensive background in geothermal power production. Over 25 years of experience has given TPC a wealth of technical and practical expertise which will be utilized in the PGV project. TPC is an industry leader in the production of electrical power from geothermal resources.

1.2 PURPOSE AND NEED

The purpose of the PGV power plant project is to supply electrical power to help meet a need on the Big Island that HELCO forecasts. This forecast projects the need for substantial new capacity by 1989 and an additional increment by 1991. The PGV power plant will be constructed in two phases to be consistent with the utilities phased energy demands. The project is consistent with both State and County goals to increase Hawaii's energy self-sufficiency, reduce its reliance on imported oil, and develop renewable energy resources.

1.3 GEOTHERMAL POWER IN HAWAII

The utilization of the natural heat sources present in Hawaii's volcanos is not a recent idea. The Hawaiian people have used geothermal resources throughout their history for a variety of non-electrical purposes. The earliest use of geothermal resources was by Hawaiians who used the Kilauea summit fumaroles for cooking and heating. Today, Hawaiians continue to utilize and study direct use applications of the resource.

Over 100 years ago, in September of 1881, the last King of Hawaii, King David Kalakaua, made inquiries about the use of geothermal resources for electricity (N.Y. Times, 1881). King Kalakaua and several of his close advisors paid a visit to the celebrated scientist and inventor Thomas A. Edison in his New York quarters. King Kalakaua was introduced by Mr. George Jones, proprietor of the New York Times. Mr. Jones met King Kalakaua in Vienna, during the King's trip around the world, and had offered to set up a meeting with Mr. Edison. The King was interested in Mr. Edison's electric light and the possibility of using it to replace the kerosene lamps being used in Honolulu.

The King was reportedly impressed by Mr. Edison's plans to sell power as well as light, and Mr. Edison was questioned about the possibility of using submarine cables to transmit electricity. Kalakaua's party inquired about the practicality of using the "volcano that burns a thousand million tons of coal a day" to put "boilers on top of the volcano and get power enough to supply this (the United States) country." The King's Attorney-General, when answering a question about the source of coal for the islands, commented that "we build great hopes on that volcano" (N.Y. Times, 1881).

Honolulu eventually received its electricity, but it was not from volcano-produced electricity transmitted by submarine cables. The concept of using the power of the volcano for electricity production, now known as geothermal energy, has only been actively pursued in recent years.

The vision of Hawaii's king can be seen in the practical side of the harnessing of nature's gift of geothermal power. The ideas of Hawaii's last king can now bring increased benefits in energy supply security. Although the PGV geothermal facility is not discussed in the simple terms that King Kalakaua used, the basic concept is the same.

Geothermal heat was first explored for commercial use in Hawaii in 1961, when four test holes were drilled in the Kilauea East Rift Zone by a private company. Twelve years later, a research well was drilled at the Kilauea summit to a depth of 4,141 feet. The temperature of fluids at the bottom of the well was 275°F, and there were indications of much higher temperatures at greater depths. At approximately the same time, the University of Hawaii started an exploration program for a second exploratory well. Based on factors such as numerous shallow warm-water wells in the area, geophysical anomalies, and land availability, a 6,540 foot well was drilled in 1976 in the Lower East Rift Zone. This well is named, Hawaii Geothermal Project - Abbott (HGP-A). The HGP-A well was developed between 1976 and 1981 and has the distinction of being the hottest well in the United States, with a measured bottom hole temperature of approximately 676°F. A 3 megawatt power plant was constructed in 1981 adjacent to HGP-A and has been operating continuously since then. The HGP-A facility established the technical feasibility of commercializing geothermal resources on the Big Island and demonstrated the reliability of

operation. The federal government was the owner of the well and plant until late 1986, when ownership transferred to the State of Hawaii. HELCO has been the operator of the facilities since 1982. In early 1987, TPC announced the signing of an agreement under which it will become the operations and maintenance contractor for the HGP-A power plant. Use of the HGP-A plant will enable long-term flow tests on existing nearby exploration wells. TPC will not become the owner, and has not assumed operating control yet.

1.4 ORGANIZATION OF EIS

This EIS is comprised of an Executive Summary and 19 sections. Documents and surveys that cannot be obtained through normal channels have been filed with the Hawaii County Planning Department and the Office of Environmental Quality Control. Persons wishing to review the details of such documents should contact one of the two agencies.

Section 2 of the EIS describes the power plant and wellfield, and discusses the project's key power processes, and pollution abatement processes. It is the most informative section with regard to the details of the project. It does not contain extensive discussion on the environmental setting, environmental impacts, or mitigation measures. Those topics are addressed in Sections 3 through 12.

The bulk of the EIS (Sections 3 through 12) describe the environmental settings in the vicinity of the project site and within the site; the probable and potential impacts of the PGV facility on the environment; and the mitigation measures that either have been taken or will be taken to minimize adverse environmental effects. Environment is defined broadly in the EIS to mean humanity's surroundings as it is in the Department of Health's Environmental Impact Statement Rules (Section 11-200-2). It refers not only to the physical environment, such as water quality, air quality, noise, human health and safety, and biological resources, but also to economic and social conditions, including historical and aesthetic resources.

Section 13 discusses the consistency of the project with State and County plans and policies. It also includes a list of the permits and approvals that are required for the construction and operation phases of the project.

Section 14 presents the alternatives to the proposed action. It discusses in length the alternative pollution control abatement systems. It also discusses alternative power sources, alternative geothermal site locations, and describes the no-action/delayed action alternative.

Section 15 identifies what resources are irreversibly or irretrievably committed to the project. It specifies the probable unavoidable adverse environmental impacts. The section also describes the short-term and long-term environmental effects and trade-offs.

Section 16 lists the unresolved issues related to the project. Section 17 is comprised of a list of organizations and persons that have been consulted during preparation of the final EIS.

Section 18 presents the public comment letters received by PGV on the Draft EIS that was published in August, 1987. PGV's responses to the public letters are also reproduced in Section 18.

Section 2

DESCRIPTION OF THE PROPOSED ACTION

This section provides an overview of the Puna Geothermal Venture (PGV) project. It describes the geothermal fluids underlying the site, the geothermal wells (production and injection), wellpad facilities, power plant systems, and power plant structures. The section summarizes the potential environmental impacts, the proposed pollution abatement technology, and other planned mitigation measures. In particular, Section 2 describes the essentially closed-loop production, utilization and reinjection systems for the geothermal fluids. This section also highlights the three basic phases of the geothermal project: construction, operation and maintenance, and decommissioning. The subsequent sections in the Environmental Impact Statement (EIS) more fully discuss the various aspects of the facility, its potential impacts on the environment, and proposed mitigation measures.

2.1 LOCATION AND DESCRIPTION OF GEOTHERMAL RESOURCES

GEOTHERMAL RESOURCES SUBZONE

The project is located on approximately 500 acres of the Kapoho Section of the Kilauea Lower East Rift Geothermal Resource Subzone. In 1983, the State of Hawaii legislature mandated the designation of geothermal resource subzones in which geothermal exploration and development could be considered by appropriate State and County permitting agencies. (Chapter 205, Hawaii Revised Statutes (HRS)). The subzones are defined as areas of significant geothermal potential where the positive economic and social benefits of the development outweigh the potential negative environmental and social impacts. Only those areas designated as geothermal subzones may be used for exploration, development and production of geothermal resources.

The project area, however, was designated as a subzone by Hawaiian legislation. Act 151, signed into law on May 25, 1984 established three areas (one of which is the PGV project area) as geothermal resource subzones since the land owners of these areas had obtained State geothermal mining leases and

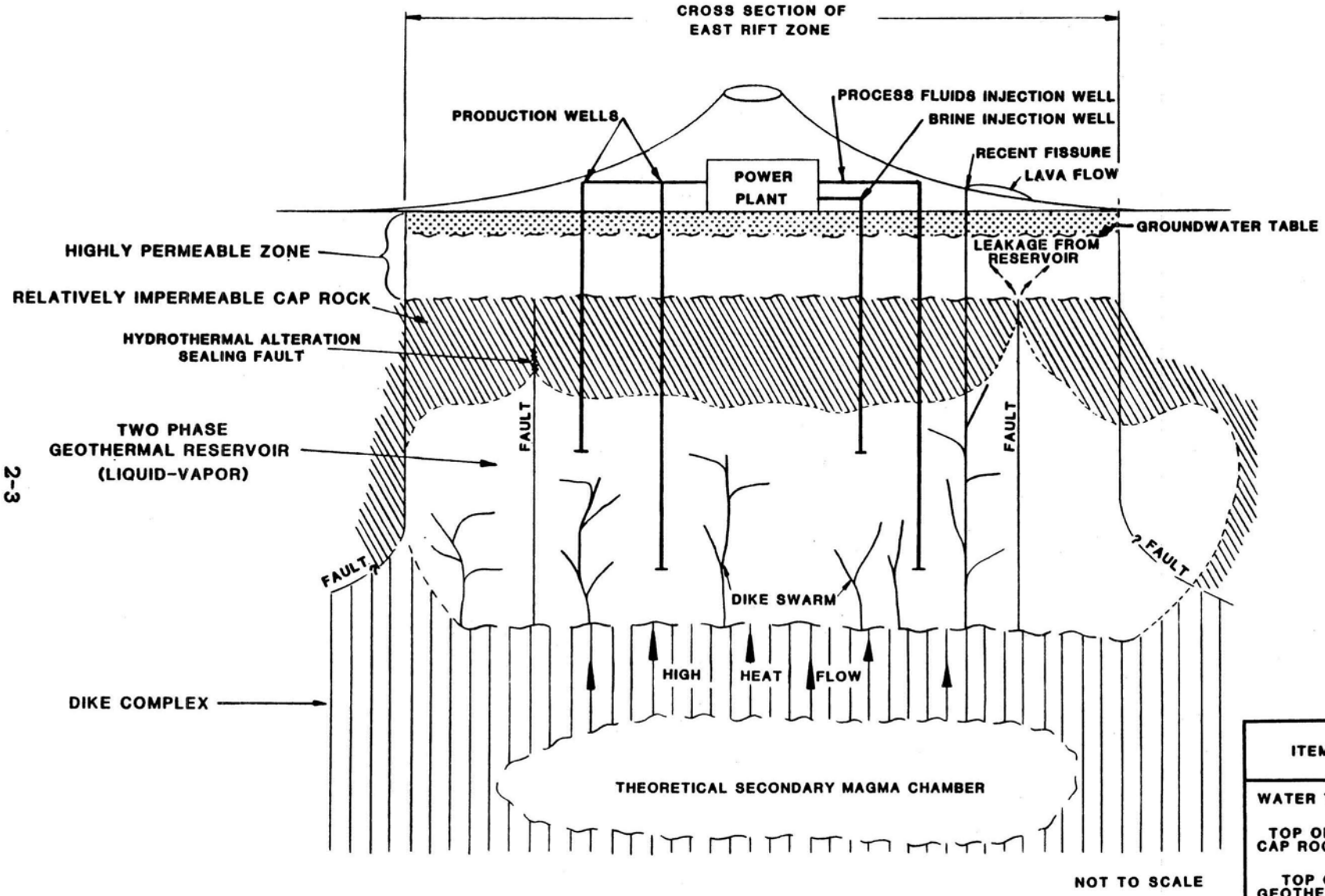
developers of the lands had been issued County special use permits for geothermal development (Department of Planning and Economic Development (DPED), 1986).

The project will be developed on approximately 500 acres (Tax Map Key 3-1-4-01: portions of 2 and 19) of the 816-acre sublease from the Kapoho Land Partnership (KLP). The sublease includes both surface and geothermal rights. KLP holds the surface rights to the parcel and has obtained a State of Hawaii Geothermal Resource Mining Lease (R-2), which includes the rights to the geothermal resource. It was necessary for KLP to obtain a State geothermal lease for the property, because the State of Hawaii claims ownership of the geothermal resources. KLP's State lease was assigned to PGV.

GEOTHERMAL RESOURCE

The Puna geothermal resource is situated in the East Rift Zone of Kilauea Volcano. Kilauea Volcano is one of the world's most active volcanoes. The summit is located in the eastern portion of the Island of Hawaii, approximately 25 miles west of the project site. The East Rift Zone is an underground conduit for lateral migration of molten basalt originating from beneath Kilauea's crater. Well drilling data indicate that the Puna geothermal reservoir is a very high-temperature (over 600°F), two-phase (vapor-liquid) resource, one of the hottest in the world. The reservoir is believed to be maintained by very high heat flow within the rift made move effective by a relatively impermeable seal which inhibits significant venting. A conceptual model of the Puna geothermal resource is shown on Figure 2-1.

The East Rift Zone is characterized by a dike complex some 5 to 15 miles wide at depth. Dikes within the complex increase in number with depth.



ITEM	DEPTH BELOW GRADE
WATER TABLE	~ 600'
TOP OF CAP ROCK	~2500'
TOP OF GEOTHERMAL RESERVOIR	~4000'

Figure 2-1 CONCEPTUAL MODEL OF THE PUNA GEOTHERMAL RESERVOIR

The heat energy of the Puna geothermal resource is maintained by these high-temperature dikes and a suspected secondary magma chamber thought to be located beneath the geothermal reservoir. The top of the reservoir occurs at a depth of about 4,000 feet below ground surface.

The relatively impermeable seal which overlies the reservoir extends upwards from the 4,000-foot depth to approximately 2,500 feet below the surface. A zone of vigorous groundwater flow extends from the top of the seal to the water table which is at a depth of approximately 600 feet below ground surface. This groundwater occurs in highly porous and permeable basalt layers that contain additional secondary fracturing.

The seal is relatively impermeable; nevertheless, leakage of geothermal fluid into the groundwater does occur. This leakage takes place where the seal is locally broken by geologic structure. The geothermal fluid escaping from the reservoir is sufficient to completely alter the fresh water character of the overlying groundwater system. Existing groundwater in the vicinity and down gradient of the site is both chemically and thermally contaminated.

Four productive geothermal wells have been drilled into the geothermal reservoir: HGP-A, Kapoho State 1 (KS-1), KS-2 and KS-1A. HGP-A was drilled by a consortium of government agencies in 1976 and was the discovery well for the Puna Geothermal Resource. The associated power plant was developed between 1976 and 1981 as a research and demonstration project by the federal government and the State of Hawaii. The HGP-A facility is capable of generating approximately 3 megawatts (MW) of electricity. The HGP-A well has demonstrated the use of the geothermal resource as a source for electrical generation. KS-1, KS-2, and KS-1A were drilled by PGV subsequent to HGP-A.

GEOTHERMAL FLUIDS

Geothermal fluids have been chemically characterized through samples obtained from the four wells within the vicinity of the project area. The

geothermal fluid chemistry varies from well to well and sample to sample. Table 2-1 lists the ranges of the chemical composition. When the fluids reach the surface and are flashed, the majority of the dissolved minerals remain in the brine and any gases remain in the steam fraction.

Noncondensable gases (NCG) are associated with the flashed steam fraction. The observed composition of the NCG in the steam fraction is presented in Table 2-2. The design NCG content (3,500 parts per million by weight (ppmw)) is the sum of the maximum measured content in Well KS-1A of carbon dioxide (CO_2), nitrogen (N_2) and hydrogen (H_2) plus the maximum measured content of hydrogen sulfide (H_2S) in the well with the highest H_2S content (KS-1). These gas contents were adjusted to increase the H_2S to 150 percent of the maximum measured content in KS-1A by reducing the amounts of the other constituents to maintain the total of 3,500 ppm(w). This is a conservative design basis for the critical component, H_2S.

Radon gas is a naturally occurring component in geothermal fluids, and measurements of radon gas have been used to study groundwater and geothermal reservoirs. The level of radon-222 identified in the PGV geothermal fluids range from 749 to 3,010 picocuries per liter of condensate (pCi/l). The level of radon content measured for HGP-A is 1,030 pCi/l (Cox, 1980).

2.2 GEOTHERMAL WELLS AND WELLFIELD FACILITIES

WELLPADS

Up to six wellpads are currently expected to be required over the 35-year life of the project. Currently two wellpads are located on-site (A and B). Four additional wellpad sites (labeled C, D, E and F) were selected on the basis of proximity to the power plant, and current knowledge of reservoir extent, optimal drilling targets, directional drilling experiences and reinjection needs. The Steam Gathering and Fluid Handling Systems Process Flow Diagram is shown on Figure 2-2. The wellpad locations may be revised, as additional drilling, production, reinjection, and other information becomes available, to obtain an optimal wellfield with a low surface area requirement.

Table 2-1

GEOTHERMAL FLUID CHEMICAL COMPOSITION
COMPOSITE DATA[a]

Element	Brine[b] (ppm)(w))	Steam Condensate[b] (ppm(w))
Na	600 - 10,000	0.17
K	123 - 2,700	0.1
Ca	40 - 920	0.1
Mg	1 - 2	<0.1
Fe	<1 - 8.4	0.05
Mn	<1 - 8.5	--
B	4 - 11	<0.5
Br	40 - 80	--
I	<20	--
F	0.2 - 0.9	--
Li	1 - 9	<0.01
Cl	925 - 21,000	<2
NH_3	<0.01 - 0.1	0.12
SO_4 (c)	9.2 - 24	13
Hg	<0.001 - <0.05	--
As	0.09 - 0.4	<0.01
S= (d)	5 - 100	--
Total Alkalinity	≤10	<10
HCO_3	0 - 18	0
CO_3	0	0
SiO_2	420 - 1,500	0.7
TSS	70	--
TDS(e)	2,500 - 35,000	15
pH	≤5 - 5.5	3.5
Conductivity (mho/cm)	3,100 - 67,000	120
Density	1.03	--

(a) Composite data from three wells on the PGV site (KS-1, KS-1A, and KS-2) and the HGP-A well.
(b) Wellhead pressure (WHP)-155 psig; Wellhead Temperature (WHT) = 368°F
(c) Concentration high due to oxidation of S= to SO_4.
(d) Concentration low due to oxidation of S= to SO_4.
(e) TDS = Total Dissolved Solids

Table 2-2

NONCONDENSABLE GAS COMPOSITION
COMPOSITE DATA[a]

Element	Observed Content in Steam[b] ppm(w)	Design Composition ppm(w)
CO_2	250 - 1,042	956
H_2S	800 - 1,300	1950
NH_3	(c)	-
Ar	6 - 13	-
N_2	10 - 700	582
CH_4	(d)	-
He	<0.009	-
H_2	11 - 140	12
---	---	---
Total NCG	1,500 - 2,200	3500

(a) Composite data from three wells on the PGV site (KS-1, KS-1A, and KS-2) and the HGP-A well.
(b) WHP = 155 psig; WHT - 368°F
(c) Below Detection Limit (<1.5 ppm NH_3 in KS-1A)
(d) Below Detection Limit (<0.2 ppm CH_4 in KS-1A)

The existing and proposed wellpads measure approximately 400 by 300 feet and may accommodate up to four or five wells each.

Each wellpad will contain a rock muffler, a separator and associated piping. Wellheads will be placed about 30-50 feet apart for optimization of pad space and to allow adequate room to access each wellhead during future workover operations. The wellpad rock muffler will provide noise abatement during well testing. Connections for a portable H_2S chemical abatement unit (consisting of sodium hydroxide (NaOH) and hydrogen peroxide (H_2O_2) tanks, injection pumps and piping) will be provided in the line from the wellhead to each wellpad rock muffler. This chemical abatement unit will be moved to the appropriate wellpad during well testing.

Wellpad Piping Subsystem

Each wellpad contains a wellhead piping subsystem. The subsystem begins downstream of the master shutoff valves at each wellhead and includes production, throttling, and isolation valves; a flow rate metering device with orifice flanges and instrumentation required for local or remote monitoring and control of each well. A rock catcher (rock particle separator) is installed immediately downstream of each wellhead. The subsystem includes a moisture separator that flashes the geothermal fluids into steam and brine fractions.

The system is protected against overpressure damage with passive rupture disk safety devices, in accordance with the American National Standards Institute (ANSI) B31.1 Power Piping Code and applicable state regulations. A rupture disk event is triggered by excessive pressure in the system and results in the venting of steam to the atmosphere.

GEOTHERMAL WELLS

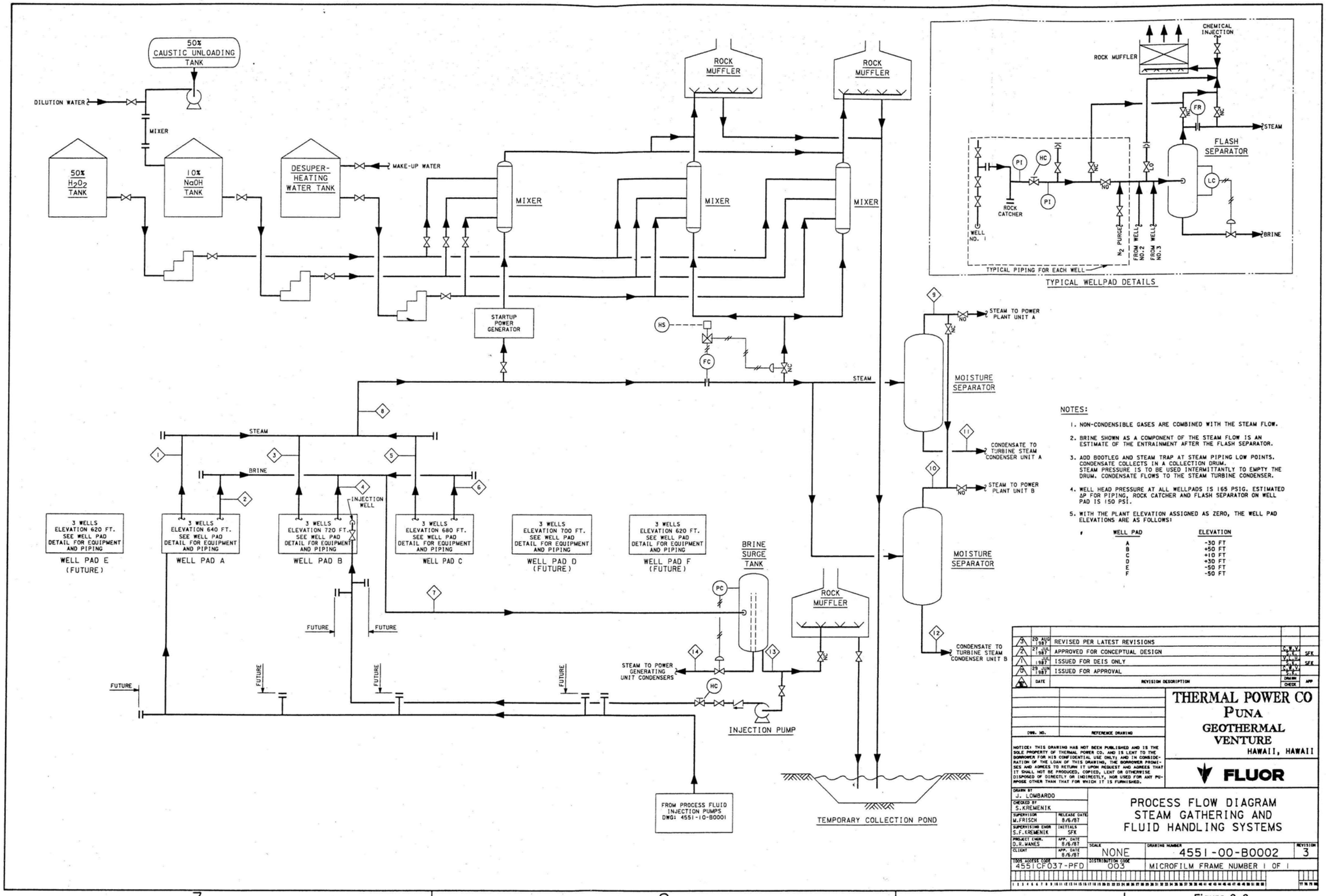
The current plan anticipates about 20 geothermal wells over the 35-year life of the project. The current wellfield development plan anticipates the following types and quantities of wells:

Figure 2-2

Steam Gathering and Fluid Handling Systems

Process Flow Diagram

(11 x 17)


50% CAUSTIC UNLOADING TANK
DILUTION WATER
MIXER
50% H_2O_2 TANK
10% NaOH TANK
DESUPER-HEATING WATER TANK
MAKE-UP WATER
MIXER
MIXER
MIXER
ROCK MUFFLER
ROCK MUFFLER
STARTUP POWER GENERATOR
HS
FC
STEAM
STEAM
BRINE
INJECTION WELL
3 WELLS ELEVATION 620 FT. SEE WELL PAD DETAIL FOR EQUIPMENT AND PIPING
WELL PAD E (FUTURE)
3 WELLS ELEVATION 640 FT. SEE WELL PAD DETAIL FOR EQUIPMENT AND PIPING
WELL PAD A
3 WELLS ELEVATION 720 FT. SEE WELL PAD DETAIL FOR EQUIPMENT AND PIPING
WELL PAD B
3 WELLS ELEVATION 680 FT. SEE WELL PAD DETAIL FOR EQUIPMENT AND PIPING
WELL PAD C
3 WELLS ELEVATION 700 FT. SEE WELL PAD DETAIL FOR EQUIPMENT AND PIPING
WELL PAD D (FUTURE)
3 WELLS ELEVATION 620 FT. SEE WELL PAD DETAIL FOR EQUIPMENT AND PIPING
WELL PAD F (FUTURE)
FUTURE
FUTURE
FUTURE
FUTURE
FUTURE
FUTURE
BRINE SURGE TANK
PC
ROCK MUFFLER
STEAM TO POWER GENERATING UNIT CONDENSERS
HC
INJECTION PUMP
FROM PROCESS FLUID INJECTION PUMPS DWG: 4551-10-B0001
TEMPORARY COLLECTION POND
MOISTURE SEPARATOR
MOISTURE SEPARATOR
STEAM TO POWER PLANT UNIT A
CONDENSATE TO TURBINE STEAM CONDENSER UNIT A
STEAM TO POWER PLANT UNIT B
CONDENSATE TO TURBINE STEAM CONDENSER UNIT B
ROCK MUFFLER
CHEMICAL INJECTION
FR
STEAM
FLASH SEPARATOR
LC
BRINE
PI
HC
PI
ROCK CATCHER
WELL NO. 1
N_2 PURGE
FROM WELL NO.2
FROM WELL NO.3
TYPICAL PIPING FOR EACH WELL
TYPICAL WELLPAD DETAILS
NOTES:
1. NON-CONDENSIBLE GASES ARE COMBINED WITH THE STEAM FLOW.
2. BRINE SHOWN AS A COMPONENT OF THE STEAM FLOW IS AN ESTIMATE OF THE ENTRAINMENT AFTER THE FLASH SEPARATOR.
3. ADD BOOTLEG AND STEAM TRAP AT STEAM PIPING LOW POINTS. CONDENSATE COLLECTS IN A COLLECTION DRUM. STEAM PRESSURE IS TO BE USED INTERMITTANTLY TO EMPTY THE DRUM. CONDENSATE FLOWS TO THE STEAM TURBINE CONDENSER.
4. WELL HEAD PRESSURE AT ALL WELLPADS IS 165 PSIG. ESTIMATED ΔP FOR PIPING, ROCK CATCHER AND FLASH SEPARATOR ON WELL PAD IS 150 PSI.
5. WITH THE PLANT ELEVATION ASSIGNED AS ZERO, THE WELL PAD ELEVATIONS ARE AS FOLLOWS:
WELL PAD ELEVATION
A -30 FT
B +50 FT
C +10 FT
D +30 FT
E -50 FT
F -50 FT
3 20 AUG 1987 REVISED PER LATEST REVISIONS
2 27 JUL 1987 APPROVED FOR CONCEPTUAL DESIGN SFK
1 JUL 1987 ISSUED FOR DEIS ONLY SFK
0 29 JUN 1987 ISSUED FOR APPROVAL
DATE REVISION DESCRIPTION DRAWN CHECK APP
DWG. NO. REFERENCE DRAWING
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PUNA GEOTHERMAL VENTURE
HAWAII, HAWAII
FLUOR
DRAWN BY J. LOMBARDO
CHECKED BY S.KREMENIK
SUPERVISOR M.FRISCH
RELEASE DATE 8/6/87
SUPERVISING ENGR S.F.KREMENIK
INITIALS SFK
PROJECT ENGR. D.R.WANES
APP. DATE 8/6/87
CLIENT
APP. DATE 8/6/87
IDOS ACCESS CODE 4551CF037-PFD
DISTRIBUTION CODE 003
PROCESS FLOW DIAGRAM
STEAM GATHERING AND
FLUID HANDLING SYSTEMS
SCALE NONE
DRAWING NUMBER 4551-00-B0002
REVISION 3
MICROFILM FRAME NUMBER 1 OF 1

Figure 2-2

Type	Quantity
Production Wells	6
Injection Wells	3
Makeup Wells	11
Total	20

Three of the four wells drilled into the geothermal reservoir to date are on the project site: KS-1, KS-1A (on Wellpad A), and KS-2 (on Wellpad B). Currently, KS-1 and KS-2 are suspended with cement plugs in their bores. KS-1A is shut in and awaiting pipeline connection to commence a flow test to the HGP-A plant. Some or all of these wells may be used for the PGV project.

Additional wells will be drilled from one of the six wellpads on an as-needed basis only. The bottom hole locations will all be within the 500-acre project area. The specific drilling target and wellpad location for each well cannot be precisely determined with the limited reservoir information available but will be specified in the drilling permit application which is required by the Department of Land and Natural Resources (DLNR). Directional drilling will be used to increase the potential bottom hole target area without a corresponding increase in wellpad area. The bottom hole location may be up to 1,500 feet from the wellhead. Drilling mud techniques will be used during the installation of the wells.

All wells will be drilled to the depth of the geothermal resource approximately 4,000 feet below the surface. Wellls will consist of 20-inch, 13-3/8-inch, and 9-5/8-inch diameter casings. The 20-inch diameter casing provides hole stability and reduces the loss of drilling mud into fractures near the surface. The 13-3/8-inch diameter casing extends from the surface down to the cap rock at approximately 2,500 feet. A 9-5/8-inch casing will extend from the surface to about 4,100 feet. A 7-inch perforated liner will be installed from the bottom of the 9-5/8-inch casing to the bottom of the well.

All casings are steel and the 13-3/8-inch and 9-5/8-inch casings are joined with premium threaded couplings and cemented to ensure their structural integrity. (See Figure 2-3 for a diagram of a typical well.)

Wells will be equipped with blowout prevention equipment (BOP). The safety equipment will be capable of shutting in a well during drilling operations to prevent uncontrolled release of geothermal fluids at the wellhead. Detailed well drilling and well completion procedures are contained in PGV's well drilling permit applications. Applications for the existing wells were previously approved by DLNR as required by Chapter 183 of the HRS. Applications will be submitted for all new wells. A special well casing procedure, used earlier on the KS-1A well, has been designed and approved to safely contain and produce the geothermal resources and to protect human health, the groundwater, and other parts of the environment.

Production Wells

Each production well is anticipated to have an average flow rate of 90,000 pounds per hour (lb/hr) of steam deliverable to pipeline. Wellhead pressures of flowing wells are expected to range from 160 to 180 pounds per square inch, gauge (psig) with wellhead temperatures expected to range from 370° to 380°F.

Injection Wells

Fluids generated in the operation of the PGV wellfield and power plant will be reinjected into the geothermal reservoir (below 4,000 feet). The two fluid streams to be reinjected are brine and process fluid, both of which are liquids. The two separate injection systems have different handling requirements as follows:

Process Fluids Reinjection: Steam condensate and other collected liquids will contact the noncondensable gases in an absorber and dissolve the H_2S

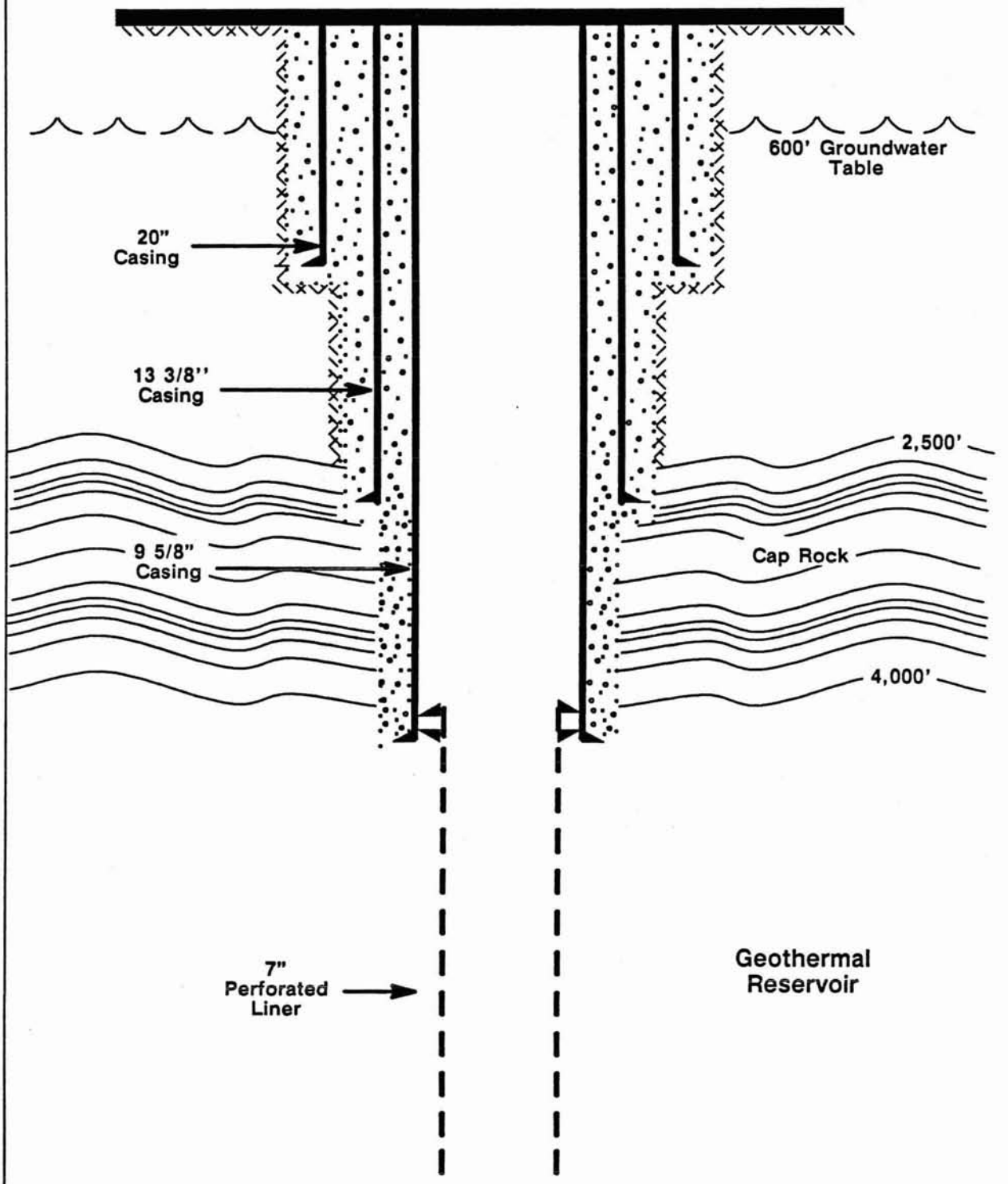


Figure 2-3
TYPICAL PGV GEOTHERMAL WELL

and CO_2 at elevated pressures. This liquid stream is transported through pipelines to the process fluids injection well for return to the reservoir.

Brine Reinjection: Silica-laden brine recovered at each wellpad separator must be quickly transported at high temperature through insulated pipelines to a brine injection well for reinjection into the reservoir. Cooling of the brine stream should be avoided as it may result in the silica precipitating out of solution.

The use of marginal geothermal production wells is preferred over drilling new wells for both process fluid and brine reinjection. Marginal production wells contain less than desired steam flow or steam fraction, and, therefore, are not efficient to use in producing electrical energy. It is likely that the brines and process fluids reinjection location will change over time in order to maximize well utilization. "Hang-down strings" of special or coated solid steel liners will be used to protect the premium 9-5/8-inch casing of the well during its use as a process fluid injection well. These removable strings of pipe are placed inside the larger diameter casing. Three injection wells are required: one for process fluids; one for brine; and a standby which will be used as a common spare.

The required drilling and well conversion permits will be obtained from the DLNR and will comply with applicable regulations and permit conditions.

Makeup Wells

Individual geothermal wells may require replacement because the production or injection capability of the well has declined to a point where its contribution to the project is marginal. Makeup (replacement) wells will be drilled to maintain full plant output throughout the life of the project. Abandoned wells will be plugged with cement in accordance with procedures contained in the well drilling permits.

WELLFIELD GATHERING SYSTEMS

Gathering systems are the piping networks which collect the fluids from the individual sources and then transport the fluids to appropriate downstream processing units. Three gathering systems are used in the PGV design: steam, condensate and brine. Each gathering system is independent of the other systems, interconnecting only at the points where two streams are present; for example, wellpad separators (steam and brine), low point drains (steam and condensate), etc.

All pressure piping is designed in accordance with ANSI B31.1 Power Piping Code. The piping systems are engineered for the stresses induced by thermal, pressure, dead, and seismic loads, taking into account all planned system operating conditions. Sufficient horizontal and vertical flexibility is incorporated in the design to withstand ground movements along the rift axis, in accordance with Seismic Zone 4 standards.

The external surfaces of the pipelines are covered with insulation and painted dark green or gray in order to blend with the background vegetation and reduce visual impacts. Vegetation will be encouraged around the pipelines to further reduce the visual impacts.

Gathering lines generally follow the shortest route from the source to the power plant destination. This practice minimizes the heat and frictional losses during transit. However, the pipeline layout is dictated in part by the terrain, visual impacts, and existing road alignments. Pipelines will follow road alignments, wherever possible, to minimize the ground disturbance during installation and maintenance.

Steam Gathering System

Each wellpad separator discharges steam into the steam gathering system. The steam gathering system then transports the steam to the turbine in the power plant. The steam gathering system starts out as a single line from each wellpad and then increases in diameter as wellpads are connected together.

Pipeline diameters will depend upon both the amount of steam and the distance over which the steam must be transported. The expected diameters are approximately 16 inches at the wellpad end and 24 inches at the power plant end.

In addition to the pipes and valves involved in the system, the steam gathering system includes the moisture separators at the power plant. These separators remove any entrained water from the steam going to the steam turbine. (Any water droplets carried into the turbine can cause increased wear.)

The steam gathering system pipelines are constructed of carbon steel. Allowances will be made for corrosion and other forms of long-term degradation of the carbon steel pipes. The pipelines are insulated to conserve as much heat as possible. Heat loss leads to condensation of part of the steam and therefore less power production.

Steam gathering system pipelines will typically be supported from 2 to 4 feet above the ground. Actual heights will be determined by the terrain and other pipeline design considerations. Steel pillars with cement foundations will support the pipelines at appropriate distances to prevent sagging. Thermal expansion of the pipe requires that expansion loops be used to prevent damage to the pipes. These loops will be kept horizontal as much as possible, but some vertical loops may be unavoidable such as at road crossings.

Steam Condensate Gathering System

The steam condensate gathering system should not be confused with the power plant condensate system. The condensate gathering system collects the steam which condenses in the steam gathering pipelines. The steam condenses continuously as heat is lost to the surroundings.

The principal condensate collection points from the steam gatherings system are the two moisture separators. In addition, the steam gathering lines will have low points due to the terrain. Low point drains are required at these positions to remove the condensate from the steam pipelines. These drains will prevent the condensate from accumulating in the steam gathering system.

The condensate gathering system pipelines are also constructed of carbon steel but will be smaller in diameter than the steam gathering system pipelines. Allowances will be made for corrosion and other forms of long-term degradation of the pipes. The pipelines are insulated to conserve as much heat as possible.

The condensate gathering system transfers the collected condensate under pressure to the steam turbine condenser. In general, the condensate gathering system will parallel the steam gathering system in order to reach all low point drains and minimize distances.

Brine Gathering System

The brine gathering system is responsible for the transportation of the brine separated in the wellpad separators. The brine gathering system discharges the brine to the brine surge tank, from which it is pumped to the brine injection well and reinjected. The pipelines used in the brine gathering system will be smaller in diameter than the corresponding steam gathering pipelines.

The brine gathering system will follow the same routing as the steam gathering system. Again, the carbon steel pipelines will be insulated to maintain heat, and painted to blend with the vegetation.

2.3 POWER PRODUCTION

The PGV power plant will be designed to provide 25 MW of electricity to the Hawaii Electric Light Company (HELCO) energy grid system. The power plant will be built with a gross capacity of 30 MW to deliver 25 MW of electricity to the HELCO System. The excess capacity will primarily be utilized by the power plant for internal energy requirements and transmission line losses. Actual operating conditions will vary the amount of electricity generated by the turbines. The power plant will consist of two units, each capable of functioning independently and supplying 12.5 MW to HELCO. A flow diagram of one of the power plant units is contained on Figure 2-4.

TURBINE-GENERATOR SYSTEM

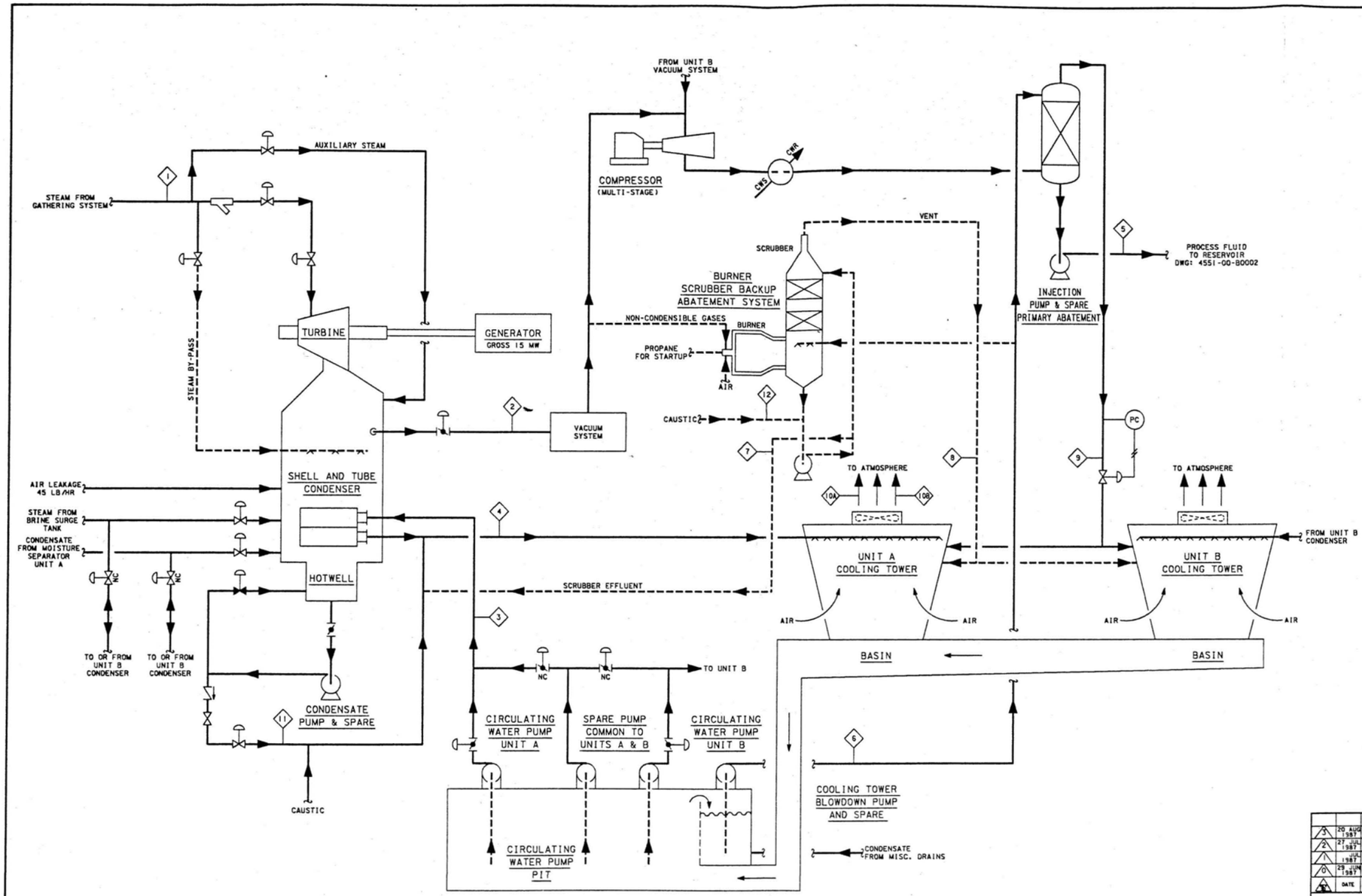
Electricity is generated in the power plant through the use of a steam turbine coupled to an electric generator. The steam turbine is powered by the energy in the high-pressure 155 psia geothermal steam. The steam turbine converts the energy of the steam into mechanical work which is then used to rotate the generator creating electricity. The details of the turbine-generator during normal operation and upset conditions are provided below.

Steam Turbine

A steam turbine operates by removing the heat energy from the steam and converting it into mechanical work. Steam is expanded to increase its velocity. The high-velocity steam is then directed against a series of blades in the turbine. The steam pushes against and rotates the blades. The blades are connected to a central shaft which, when rotated, turns the generator.

Steam enters the turbine at approximately 155 pounds per square inch absolute (psia) during normal operation and, after driving the turbine, exits at approximately 4 inches of mercury absolute (2 psia). The steam leaving the turbine flows into a heat exchanger where the steam is condensed. (The condenser is described in a following subsection.)

The turbine bypass system is used to route the steam around the turbine during a turbine upset condition. (The turbine bypass system is described in more detail in a subsequent subsection.) The instrumentation and control equipment associated with the turbine and all of the auxiliary subsystems are tied into the turbine shutdown controls. This gives the plant operators a warning of problems which could damage the turbine or associated equipment. Turbine controls will automatically open the bypass valves, close the turbine inlet valves and shut down the turbine in case of a turbine trip. The phrase "turbine trip" refers to an event where a turbine shutdown is triggered by one of the many safety monitors on the turbine or its auxiliary systems. Examples of items which could cause a turbine trip are low lubricating oil pressure, high bearing temperatures, high vibration, etc.



NOTES:

1. UNIT A SHOWN ABOVE.
2. UNIT B IS IDENTICAL TO UNIT A. UNIT B COOLING TOWER AND CW PUMP SHOWN ON THIS DWG.
3. NET POWER OUTPUT:
   UNIT A - 12.5MW
   UNIT B - 12.5MW
4. FLOWS SHOWN FOR STREAMS 7 AND 8 ARE THE RATES WHEN THE BACKUP H_2S ABATEMENT SYSTEM IS USED.
5. NON-CONDENSIBLE GAS SYSTEM SHOWS FLOW RATES FOR 3500 PPMW NCG IN STEAM AND 1950 PPM H_2S.
6. STREAM 10A IS THE FLOW FROM FIRST UNIT ONLY. STREAM 10B IS THE FLOW FROM BOTH UNITS. RATES SHOWN ARE THOSE THAT RESULT WHEN THE PRIMARY ABATMENT SYSTEM IS USED.
7. RATE SHOWN IS FOR 30 MW GROSS STATION RATING.
8. DASHED LINES SHOW SYSTEMS THAT NORMALLY HAVE NO FLOW.

	DATE	REVISION DESCRIPTION	DRAWN / CHECK	APP
3	20 AUG 1987	REVISED PER LATEST REVISION	J.C.M. / A.S.	
2	27 JUL 1987	APPROVED FOR CONCEPTIONAL DESIGN	J.C.M. / S.K.	STK
1	JUN 1987	ISSUED FOR DEIS ONLY	J.C.M. / S.K.	STK
0	29 JUN 1987	ISSUED FOR APPROVAL	J.C.M. / S.K.	

DWG. NO. | REFERENCE DRAWING

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GEOTHERMAL VENTURE
HAWAII, HAWAII

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PROCESS FLOW DIAGRAM
POWER GENERATION

SCALE: NONE | DRAWING NUMBER: 4551-10-B0001 | REVISION: 3
TOOL ACCESS CODE: 4551CF038-PFD | DISTRIBUTION CODE: 003 | MICROFILM FRAME NUMBER 1 OF 1

Figure 2-4

Standard industrial steam turbines will be modified as needed to accommodate the special characteristics of the Puna geothermal steam. Turbine control and isolation are provided by control and stop valves in the main steam line, positioned just upstream of the turbine.

The turbine manufacturer is responsible for providing the necessary auxiliary systems (such as lubrication, shaft sealing, cooling, etc.) for turbine operation.

Turbine Bypass

The turbine bypass subsystem can bypass up to 100 percent of the plant inlet steam around the steam turbine if the turbine is not operating. The bypassed steam is directed to the condenser. The noncondensable gases contained in the bypassed steam are handled in the same manner as when the steam turbine is in operation. The turbine bypass system operates during plant start-up, part-load operation, turbine-generator trip, and shutdown. Water consumed during bypass operation will be supplied from the cooling tower basin, rainwater, or excess steam condensate.

The turbine bypass allows a full-load turbine trip without diverting flow to the steam release facility. Upon initiation by a turbine-generator trip device, the turbine bypass valve(s) open and the steam flow bypasses the turbine and proceeds directly to the condenser.

Each unit of the power plant can continue to handle full bypass flow for at least 24 hours while the cause of the trip is analyzed to determine the length of time needed for repair. If corrective actions can be completed within a reasonable period of time, the turbine bypass continues to operate until the plant can be restarted. If a longer outage is required or the turbine bypass is not functional, the steam will be diverted to the steam release facility for chemical abatement. (The release facility is discussed later in this section.)

Electrical Generator

The generator converts mechanical energy to electrical power. The generators are coupled to the main turbines which supply the mechanical energy. The power plant will contain two generator units. The generators are inner-cooled by air, which is in turn cooled by water through internal heat exchangers. Protective devices will guard against overcurrent, overvoltage, loss of field, and fluctuation in frequency. Power circuit breakers will serve the generators.

Start-Up Turbine-Generator

A start-up steam turbine generator unit that produces power for essential electrical services during plant start-up will be used. The start-up unit is capable of powering one cooling tower fan, one cooling water circulating pump, the brine and process fluids injection systems, heating, ventilating and air conditioning (HVAC), and emergency lighting. The start-up generator will also be available for emergency situations. Steam discharging from the start-up turbine will be chemically treated in one of the power plant rock mufflers.

ELECTRICAL SYSTEMS

The power plant will contain numerous electrical systems. Major electrical equipment includes: the main power, auxiliary, station service, and current and potential transformers; generator circuit breakers; high-voltage switchgear; load centers; motor control centers; and station batteries.

The generators will have a main power transformer to boost the generator voltage level to the required 69 kV transmission level. The main power transformer will also function to reduce off-site power to auxiliary loads when the generators are not operating. An auxiliary transformer in each generator will reduce the generator output voltage to supply power to the circulating water pumps and station auxiliary transformers. The station service transformers further reduce the voltage for in-plant use.

Switchgear at the load centers and motor control centers is designed to funnel some of the generated power to meet in-plant electrical requirements.

A small emergency diesel-generator unit will be installed that can produce power for essential electrical services at the PGV site, if needed. The power that would be generated from the diesel-generator would be sufficient to support one firewater pump, one air compressor, the battery chargers, the HVAC system, control room systems, steam release facility H_2S abatement system and emergency lighting.

CONDENSING SYSTEM

The power plant condensing system handles the condensation of the steam exiting the turbine or turbine bypass. Several systems are included in the condensing system, such as the steam condenser, the condensate handling subsystem, the cooling towers, and the steam release facility. The last item is only employed when the condensing system is not available.

Condenser

The steam from each turbine exhausts into a heat exchanger which condenses the steam. The heat exchanger is referred to as either a shell and tube exchanger or a surface condenser. Both of these terms are descriptive of the type of exchanger used. The shell and tube name refers to the passage of the cooling water through tubes (or small pipes) while the steam passes through a larger-diameter "shell" which surrounds the tubes. The cooling water reduces the temperature of the steam, causing it to condense on the surface of the tubes, hence "surface condenser."

The pressure in the condenser is about 4 inches of mercury absolute (approximately 2 psia) at full turbine load and with cooling water at the design temperature of 85°F.

The steam condensate drains from the top of the condenser into the hotwell in the bottom. The hotwell is essentially a holding tank at the bottom of the

condenser in which condensate is collected and maintained. The condensate is pumped from the hotwell to the cooling tower recirculation lines by the condensate subsystem.

Condensate Subsystem

Steam condensate is removed from each condenser hotwell by one of two condensate pumps. Each condenser requires one pump for normal operation; the other pump is on standby. The pumps will most likely be vertical can-type pumps. High and low-level instrumentation in the hotwell starts and stops the pumps. The pumps discharge the condensate into the cooling water recirculation lines.

The instrumentation and control equipment associated with the condensate subsystem is tied into the shutdown controls of the steam turbine. This arrangement provides a safety function so that a warning is given to the plant operators if a problem develops which could damage the turbine or downstream equipment. If the problem is serious or cannot be readily corrected, a turbine trip is automatically initiated, stopping steam to the turbine and shutting it down. The steam is automatically diverted to the power plant rock mufflers in this event.

Cooling System

Cooling water leaving the surface condenser is hotter than the water entering the condenser and, therefore, must be cooled before it may be reused. The cooling water is cooled by dissipating the heat to the atmosphere through evaporation. The device which actually cools the water is the cooling tower. A cooling tower functions by forcing ambient air to flow through a cascading sheet of water. As the air contacts the water, heat is transferred to the air, thereby cooling the water.

Two cooling tower units, each consisting of two cells, are required. Each cooling tower unit can cool approximately 15,300 gallons per minute (gpm) (or 30,600 gpm total for both units) of circulating water from 105°F to 85°F. The cooling tower design is based on ambient temperatures of 94°F dry bulb and 73°F

wet bulb. Meteorological data indicate that these conditions will not be exceeded more than 2.5 percent of the time at the project site. Tower outlet temperatures, therefore, will be below 85°F for 97.5 percent of the time.

Evaporation loss to the atmosphere at design conditions will be approximately 420 gpm per cooling tower. Design drift loss through the tower stacks is 0.005 percent of the circulating water flow, or less than 380 lb/hr. Makeup water for the cooling tower comes from the condensate subsystem.

Cooled water collects in the basin under the cooling tower and then flows to the circulating water pump structure. This structure is located at one corner of the cooling tower and houses the pumps for both units. The cooling water pumps send the water to the turbine building, through the condensers, and back to the cooling tower.

The mineral content of the condensed steam is very low as previously discussed. The evaporation of water from the cooling towers increases the concentration of the minerals in the remaining water and, if additional water were not added, the cooling water would eventually cause scaling problems. The continual addition of condensate will offset the water lost to evaporation and help maintain the total dissolved solids within acceptable levels. To prevent the solids from increasing to more than about five times the condensate concentration, a purge stream (called "blowdown") will be removed from the basin. Additional condensate must be added to the cooling water system to balance the amount of blowdown removed. Cooling tower blowdown will be piped to an absorber and subsequently delivered to the process fluids injection well.

STEAM RELEASE FACILITY

The steam release facility is employed when the surface condenser is not available. In such an event, referred to as steam stacking, automatic control valves divert the steam to one of the rock mufflers located near the power plant. The rock mufflers are constructed of heat-resistant reinforced concrete

and filled with lava rock. The mufflers are designed to dissipate the steam's acoustic energy, thereby reducing the noise associated with a steam release. Each muffler is designed to handle 100 percent of the total plant steam flow.

Steam entering the steam release facility will be treated with NaOH and H_2O_2 to remove a majority of the H_2S. Based upon state-of-the-art rock muffler design (Dames and Moore, 1984) and current experience, 98 percent removal of the H_2S is anticipated for the NaOH and H_2O_2 treatment system. Storage tanks will be provided for the treatment chemicals. Injection pumps will meter the chemicals into the steam line. Water will be injected to desuperheat the steam prior to the chemical injection so that the necessary chemical reactions can take place.

It is estimated that the steam release facility will be used roughly 3 percent of the time, or approximately 263 hours per year during unscheduled outages. These outages could be caused by malfunctions in either the cooling system, condensers, condensate subsystem or the noncondensable gas removal system.

NONCONDENSABLE GAS REMOVAL SYSTEM

The steam entering the surface condenser from the turbine will contain the noncondensable gases which do not condense with the steam. These gases contain the majority of the H_2S, CO_2, N_2 and H_2 and must be removed from the condenser. The pressure in the condenser is too low to allow the gases to flow under their own pressure; therefore, a vacuum system must be used.

The noncondensable gas removal system that will be used at the PGV facility is expected to be a steam ejector vacuum system. These systems are highly reliable, have no moving parts, and are capable of handling the volume of gas expected. Any vacuum system which is capable of maintaining the surface condenser pressure at, or below, 4 inches of mercury (approximately 2 psia) and moving the volume of noncondensable gases present is suitable. Maintenance of the condenser pressure is a prerequisite for 99 percent removal of H_2S.

The principle behind steam ejectors is that high-pressure steam is admitted to a nozzle which increases its velocity. The high velocity creates a vacuum as the nozzle discharges the steam into a cone pulling the vapor from the condenser. The velocity of the steam mixes the vapor and steam and carries the mixture into a a water-cooled condenser which removes the steam from the mixture.

Two stages of steam ejectors are used in the noncondensable gases removal system. The second stage ejector discharges to a compressor which pressurizes the gas to approximately 200 psig and sends it to the gas absorber, as described later in this section.

AUXILIARY SYSTEMS

Auxiliary power plant systems refer to systems that are not primarily concerned with power generation. The main auxiliary systems are the compressed air system, service water system, makeup water system, fire protection system, and the HVAC system.

Compressed Air System

Compressed air is required for instrumentation, control, and plant maintenance (service air) requirements. Compressed air is distributed throughout the plant at 100 psig from a central compression system that includes air compressors, desiccant-type dryers, and dry-air storage tanks.

Service Water System

Service water is required for drinking water, sanitation, occupational safety, and chemical mixing. Normal usage during operation is estimated at 200 gallons per day. A water line will supply potable water from the County water main. Part of this water is utilized in emergency showers and eyewash stations which are provided in areas where exposure to chemicals is likely (e.g., chemical mixing area, power plant rock mufflers).

Makeup Water System

Makeup water is the replacement water which is needed to offset the evaporation and other losses from the cooling system. The primary source of makeup water will be the steam condensate. If needed, rain catchment water, piped-in County water, and trucked-in water can be used.

Fire Protection System

The fire protection system will be designed in accordance with National Fire Protection Association standards and may include the following:

- Fire protection water supplies, pumps and controllers, yard mains, hydrants, and valves
- An automatic wet pipe and fusible link sprinkler system over the operating bay, storage areas, the turbine lube-oil reservoirs, diesel generator fuel tank, and oil-containing areas of the switchyard
- A wetdown system at the cooling tower
- Automatic fire protection system for electrical systems
- Portable extinguishers with backup water hoses in the control room

The cooling tower basin is the primary source of water for fire suppression. Each of the two basin sections stores approximately 125,000 gallons of water. Firewater pumps for the entire plant will be available. The pumps will be electrically driven, with emergency power for one pump available from either the start-up turbine generator or the emergency diesel-generator. Water loops around the plant will provide the main coverage for all buildings and enclosures. Hose stations will be strategically positioned around the turbine building.

The control room, motor control center, and electrical equipment rooms will be protected with an automatic fire protection system. Carbon dioxide (CO_2) or

halon fire extinguishing equipment may be used in these areas to prevent water damage. If CO_2 is selected, water hoses would also be installed in the event that the CO_2 fails to extinguish the fire. Portable extinguishers will also be provided in the control room.

HVAC System

Air conditioning will be provided for the electrical equipment and control rooms. The system will be designed to prevent heat buildup and maintain a positive pressure in the rooms. The air conditioning unit includes a sealed refrigeration system and coil, outside air supply duct, and an air distribution fan. The turbine-generator building will be ventilated.

2.4 POLLUTION ABATEMENT AND HAZARD CONTROL

The principal pollution abatement systems are described in this subsection. The primary abatement for H_2S is reinjection into the geothermal reservoir. Reinjection is essentially a closed loop disposal system since the fluids are returned to the same geologic zone from where they originated. This subsection also describes some of the steps used to mitigate noise impacts and potential geologic hazards at the site.

POLLUTION ABATEMENT SYSTEMS

All geothermal fluids produced from the reservoir (steam, noncondensable gases and brine) will be processed to reduce hazardous emissions. The following subsections describe the primary and backup H_2S abatement systems, as well as cooling tower emissions, brine disposal and solid wastes.

Noncondensable Gas Abatement System

The primary noncondensable gas (H_2S) abatement system is reinjection, and a schematic diagram of the system is shown on Figure 2-5. The primary abatement system treats the H_2S that remains in the vapor phase in the surface condenser. More than 99 percent of the H_2S is expected to remain in the vapor due to the operating conditions in the condenser based on computer modeling. The division

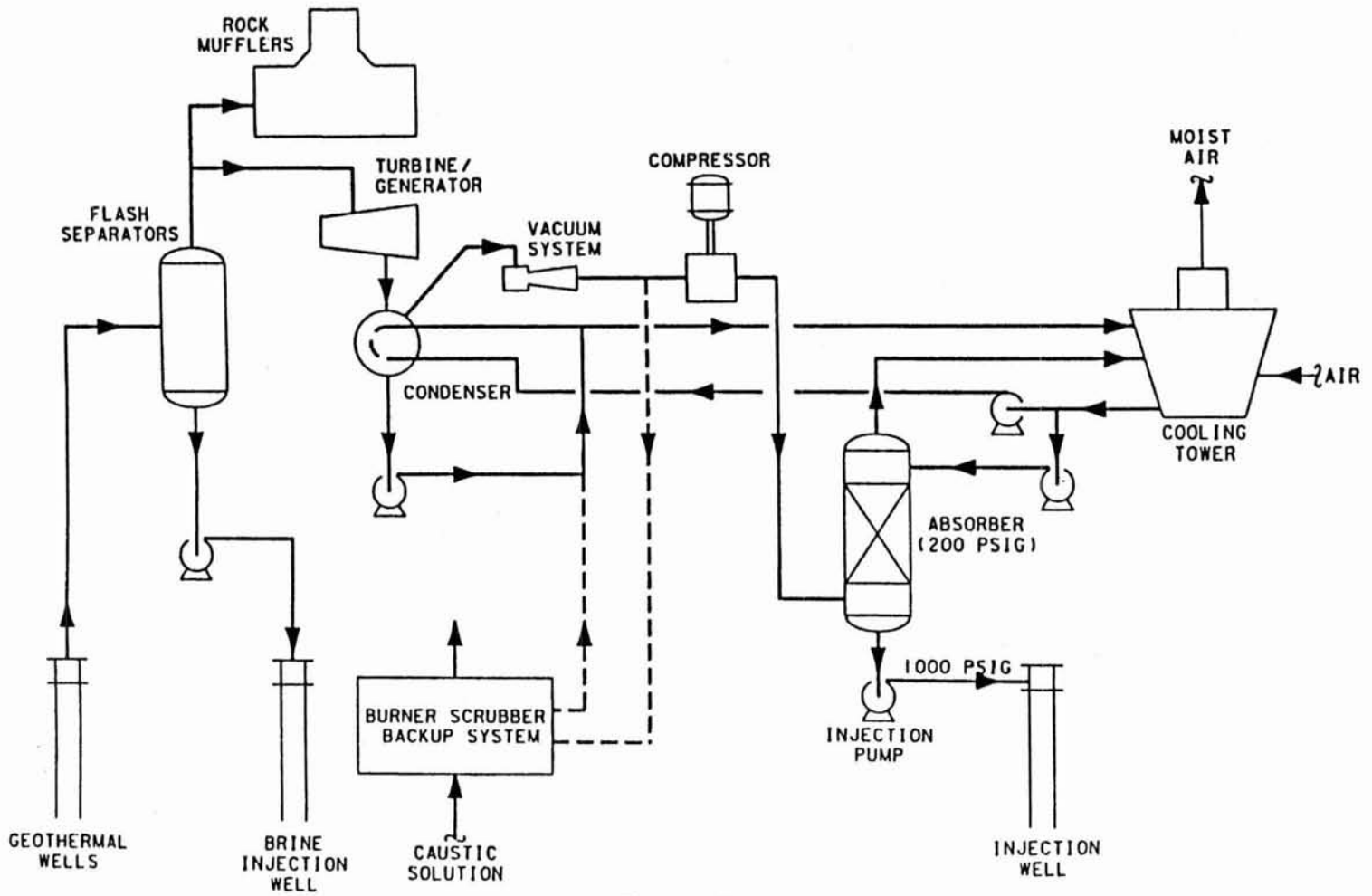


Figure 2-5

PRIMARY ABATEMENT-REINJECTION

of H_2S between the vapor phase (>99%) and the liquid phase (<1%) is called partitioning. The HGP-A power plant, which utilizes a well that produces steam of chemical composition similar to wells on the project site, has obtained similar partitioning. (The remaining 1 percent dissolves in the condensate and is discussed under cooling tower emissions).

The primary abatement system removes the noncondensable gas stream from the condenser, compresses it to approximately 200 psig and sends it to an absorber. The absorber mixes the noncondensable gases with the blowdown water from the cooling tower. The H_2S and CO_2 in the noncondensable gas stream dissolve in the water while the other components (nitrogen and hydrogen) do not dissolve in the water. Based upon the calculations of absorber performance, the maximum amount of H_2S which does not dissolve in the water is 0.5 lb/hr. The gaseous components which do not dissolve in the water pass through the absorber and are sent to the cooling tower where they are vented to the atmosphere with the cooling tower air.

Process fluids consist principally of the cooling tower blowdown with the dissolved gases and lesser amounts of liquids from the condensate gathering system and moisture separator. The liquids are collected and pumped into the process fluids injection well, eliminating the need to discharge any process fluids to the surface. A similar system is employed for noncondensable gas abatement at Coso Hot Springs geothermal facility in California. Liquid reinjection is performed routinely at geothermal facilities around the world. The average process fluid reinjection flow rate during normal plant operation is about 280 gpm.

A pilot demonstration of the absorber has been selected to receive funding from the DBED to test the efficiency of the system. The tests will also provide useful information to the final design of the system. Reliability and availability will be enhanced through appropriate redundancy of mechanical equipment. The injection well will be protected with a hangdown string inside the 9-5/8-inch casing. The operating parameters of the reinjection process, such as injectate chemistry, pressure, temperature, and flow rate, will be closely monitored. This procedure will provide information on the efficiency of the process as well as an early warning in the event of a malfunction.

Backup H_2S Abatement

In the unlikely event that the primary abatement system has an upset or shutdown, a backup H_2S abatement system will be utilized. The backup system is a Burner/Scrubber system that incinerates the H_2S into sulfur dioxide (SO_2) and then scrubs the noncondensable gases with sodium hydroxide converting the SO_2 to nontoxic sulfites and bisulfite compounds.

If the backup system is not functioning, the power plant will shut down and steam will be diverted to the steam release facility (rock muffler) and chemically abated with sodium hydroxide and hydrogen peroxide.

Cooling Tower Emissions

The steam condensate stream from the main condenser, containing less than 1 percent H_2S, is directed to the cooling tower. (The remaining 99 percent was discussed under "Noncondensable Gas Abatement.") It is estimated that the total amount of H_2S from all sources (noncondensable gas absorber vent, condensate, brine surge drum, etc.) which are vented to the cooling tower and emitted will not exceed 4 pounds of H_2S per hour under worst-case design criteria. Oxygen, dissolved in the cooling water, will oxidize most or all of the H_2S to sulfites under normal operating conditions, thereby resulting in nondetectable air emissions of H_2S. In all normal operating cases, H_2S emissions would be less than 4 lb/hr. H_2S emissions from the cooling tower are discussed in detail in Section 5.

The water droplets making up the cooling tower drift contain dissolved solids and noncondensable gases in the same low concentrations as the circulating water. The design of the cooling tower limits the drift loss to less than 0.005 percent of the circulating water flow, which is less than 380 lb/hr for each generating unit. This drift has a maximum of about 400 ppm TDS. The water droplets evaporate in the air or fall to the ground within a few hundred yards of the cooling tower, where they either evaporate or percolate into the ground.

Brine

Brine from each wellpad separator is collected and brought to the brine reinjection well through pipelines adjacent to the steam lines. The pipelines are sized according to the expected volume of flow. The total volume of fluids is anticipated to be 280 gpm; however, future wellfield development will determine the exact quantity. The lines are insulated to retain heat, and the above-ground residence time of the brine is kept to a minimum in order to minimize silica precipitation.

The brines will be combined in a level-controlled, pressurized brine tank where an injection pump will drive the fluids into the reservoir. If the injection wells or pumps fail, a surge pond will be available for short-term discharge.

Solid Waste

The only solid waste that will be produced at the PGV facility is sludge accumulating in the cooling tower basins. The sludge consists of sulfite, iron, and bacterial growth. The sludge will be tested for hazardous characteristics and disposed of accordingly. It is expected to be a nonhazardous waste and will be removed periodically from the cooling tower basins and placed in a wellpad sump for evaporation. The solids that remain will be periodically covered with soil on-site. If the sludge proves to be a hazardous waste, it will be transported and disposed of according to applicable hazardous waste regulations.

Noise

Anticipated noise levels have been calculated for the construction, operation and maintenance, and decommissioning phases of the project. Decommissioning noise levels will be similar to construction noise levels, except that no drilling will occur. The noise levels produced by the project will not endanger the public health of nearby residents or the wildlife in the vicinity. Adherence to Hawaii guidelines on geothermal noise will generally be assured.

Noise affects hearing only when noise levels exceed 70 dBA for extended periods. Noise from the facility will be substantially below this level. The only potential sources of noise that could exceed 70 dBA are either short in duration or highly improbable, such as well venting, pipeline cleanout, or a rupture disk event. Noise levels associated with these sources could range between 50 to 80 dBA at 1 mile and between 75 to 125 dBA at 50 feet.

Well venting will consist of two events of up to 4 hours each per well. Pipeline cleanout is a one-time event lasting about one hour prior to pipeline usage. The public will be notified in advance of both events. The other sources of high noise levels are all very unlikely events. A rupture disk event would require less than 2 hours to correct.

The following mitigation measures are planned during construction:

- Employ mud drilling rather than air drilling techniques
- Build an acoustic enclosure around the drilling rig engines and associated mechanisms
- Install highly effective exhaust mufflers on portable generators, air compressors, and other construction equipment.

Several steps will be taken to reduce normal operation noise levels. These steps include:

- Insulating pipes, valves, and equipment
- Enclose equipment in structures
- Install silencers on pressurized steam outlets
- Purchase quiet fans and motors

More information about project noise levels may be found in Section 6.

GEOLOGIC HAZARDS

The East Rift Zone has two types of potential geologic hazards: volcanic and seismic. The risks posed to engineered structures and installations can be significantly mitigated by appropriate procedures in facility siting, design, and operation. A detailed description of potential geologic hazards and planned mitigation measures is presented in Section 3.

Potential volcanic hazards consist of lava eruptions, lava flows, ash falls, splatter falls, and their associated surface disruptions. The risk associated with these hazards has been greatly reduced by locating the plant site and new wellpads on high ground to avoid lava flows in the low areas. Quickly constructed berms or blankets of volcanic cinders will be utilized to protect the lower wellpads and key elements of pipelines from lava flow. Each wellhead in low ground will be protected from lava flow by timely full closure of the master valves and by burying the cellar and wellhead with insulating cinder piles.

Potential seismic hazards are generated by earthquakes and include ground motion, ground ruptures, and subsidence. The strength and duration of motion from the strongest projected earthquake that might impact the Puna project area can be largely mitigated by appropriate design. Critical components of the site (e.g., cooling tower, abatement equipment, above-grade pipe supports) will be constructed to comply with the most stringent (Seismic Zone 4) seismic building requirements, even though the project area is officially in a Seismic Zone 3.

Fluid pipelines are the structures most vulnerable to disruption from geologic hazards. This risk can be minimized by appropriate design of the piping system to allow flexibility and movement. Automatic shutoff of the power plant can take place under extreme conditions, and pipeline damage will be repaired in the shortest practical period of time. Close coordination is planned with the Hawaii Volcano Observatory, the Hawaii Institute of Geophysics, and State and County officials to further reduce risk and ensure timely warnings of impending geologic hazards.

2.5 POWER PLANT STRUCTURES

The power plant will be designed and built using modular construction methods. The exact location and dimensions of the structures required for the power plant will be determined with detailed and engineering design completion. The preliminary design includes two main structures: the main turbine generator building and the two adjacent cooling towers. (Shown on Figure 2-6). Several smaller structures and buildings, including an administration building, control building, machine shop, warehouse facilities, transformers, and chemical tanks, are also included in the design.

BUILDINGS

The turbine-generator building is the largest structure on-site, approximately 50 feet wide by 180 feet long. The height is not set yet, but the highest point is in the main turbine bay, where the need for an overhead crane requires at least a 30-foot ceiling. The structural steel side walls and roof framing are covered with aluminum siding and roofing. The structure will be painted to blend with the surrounding area.

The support buildings are adjacent to the turbine-generator building. They contain the control room, electrical equipment room, maintenance room, battery room, administration offices, and lavatories.

STRUCTURAL DESIGN

All structures are of steel frame construction. The structures and major equipment rest on footings. Minor equipment is placed on slab floors or mounted on walls. Anchors will secure all equipment to foundations, mounting pads, or surfaces. All structures, foundations, and footings will be designed to support all applicable loads.

FOUNDATION DESIGN

A slab foundation will be provided for the turbine-generator building, with footings for each column. The turbine-generators will be supported on a

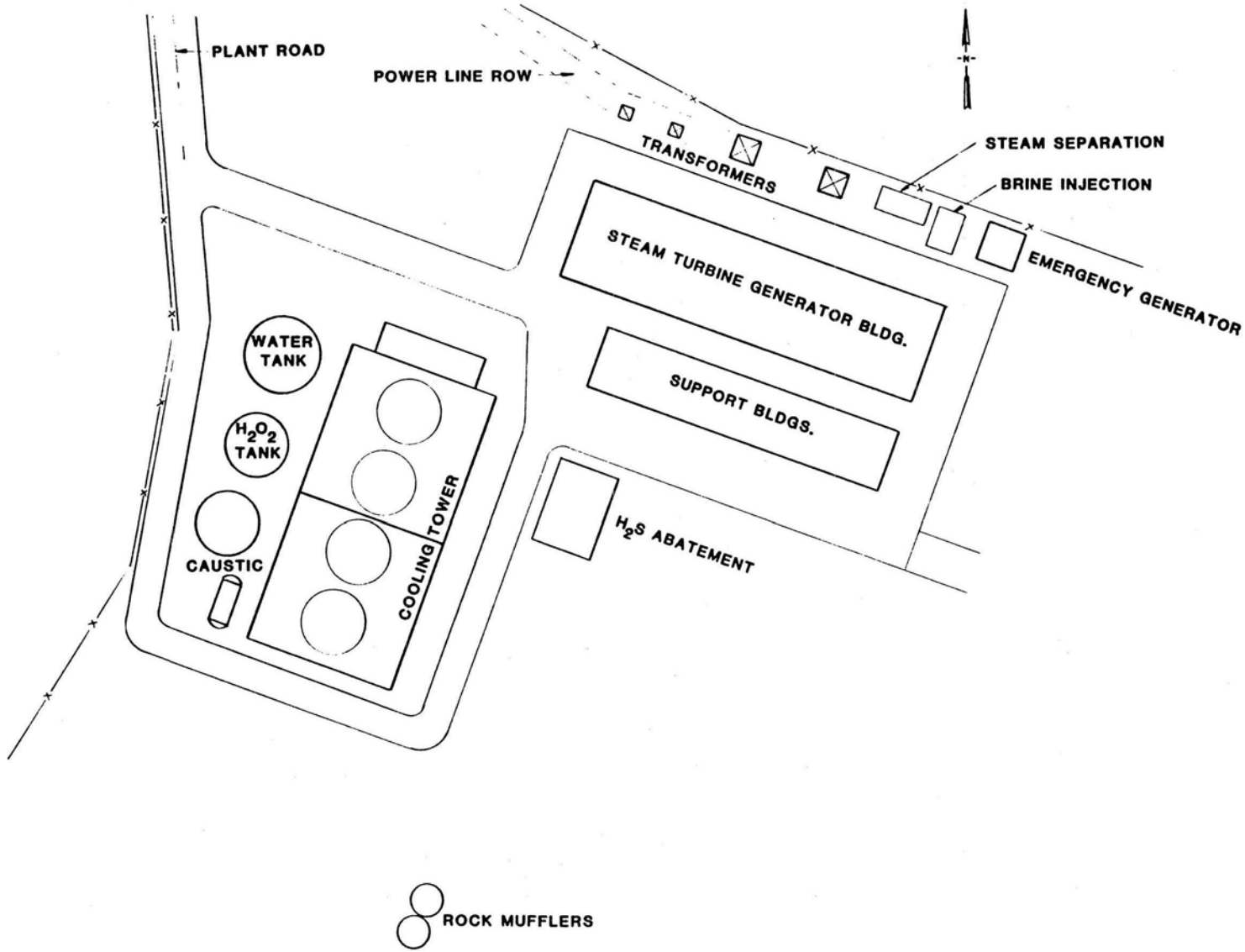


Figure 2-6 POWER PLANT ARRANGEMENT

reinforced-concrete foundation that sits within this slab. The main condensers will each sit on their own separate foundations. The outdoor electrical transformers will be mounted on concrete foundations.

COOLING TOWERS

The cooling towers are positioned to maximize access to wind flow. The current design calls for two adjacent cooling towers to be built each approximately 75 feet long by 75 feet wide by 40 feet high. Each tower is a two-cell mechanical induced-draft unit. A reinforced-concrete basin, lined with a protective coating, lies below each structure. The plumes from the cooling towers are not normally expected to be visible since the temperature in the area is warm and humidity is average. On cool days with high humidity, which is rare in the project area, the water vapor emitted from the towers will tend to condense and will be visible as white plumes (see Section 12).

CIRCULATING WATER PUMP INTAKE STRUCTURE

The circulating water pump intake structure is located on one side of the cooling tower basin. Each unit will have a full-capacity pump, and there will be a common standby. Two firewater pumps can draw water from the basin.

SITE DRAINAGE

The high porosity of the volcanic soils and rock in the site area results in rapid percolation of rainwater. Concrete pads and berms are provided to contain possible spills in areas where chemicals are handled. Catch basins, culverts, ditches, and berms are provided for drainage control where necessary.

ROADS AND FENCING

Primary access to the site will be afforded by the existing farm road off Highway 132 (Kapoho Road). The access will be upgraded to handle heavy construction equipment. A right-hand turn lane will be constructed on the highway to mitigate possible traffic congestion. A secondary entrance will be afforded by the current entrance on Pahoa-Pohoiki Road, although this entrance

will not normally be used and will not be upgraded. Final engineering plans will be provided to the County, DLNR, and the Department of Transportation before the roads and associated improvements are constructed.

A six-foot-high chain-link fence, topped with barbed wire, will be installed around the power plant boundary and each of the wellpads. A gate at each entrance to the site will restrict unauthorized access.

2.6 CONSTRUCTION

The development schedule for the wells, wellfield facilities, and power plant shows that the first unit is scheduled to be in commercial operation by the end of 1989 and the second unit by the end of 1991, (Figure 2-7).

Wellfield drilling and development is scheduled in two increments to support the two generating units. Drilling time for the wells to supply each unit will be approximately 8 to 12 months. Wells will be drilled 24 hours per day and will take approximately 60 days to complete.

A well flow test will be conducted on each production well after drilling to determine its individual steam producing capacity. The testing procedure will include a minimum period (2 tests of 4 hours each) of vertical venting (unmuffled) to clean the wellbore of rock particles. This will be followed by a flow test to measure mass flow rate, brine to steam ratio, temperature, and fluid composition. The duration of the flow test will vary, ranging from 2 to 20 days. Initially, well testing may require up to 20 days; however, testing durations are anticipated to decrease as wells are added and reservoir experience increases. Wells may be flowed continuously or intermittently during the test period.

Noise abatement and chemical abatement will be employed throughout the well test. Noise will be controlled through the use of the wellpad rock muffler. A portable H_2S chemical abatement unit will be connected to the rock muffler inlet piping prior to testing. The abatement unit will inject NaOH and H_2O_2 to control H_2S emissions. This system was used successfully during exploration.

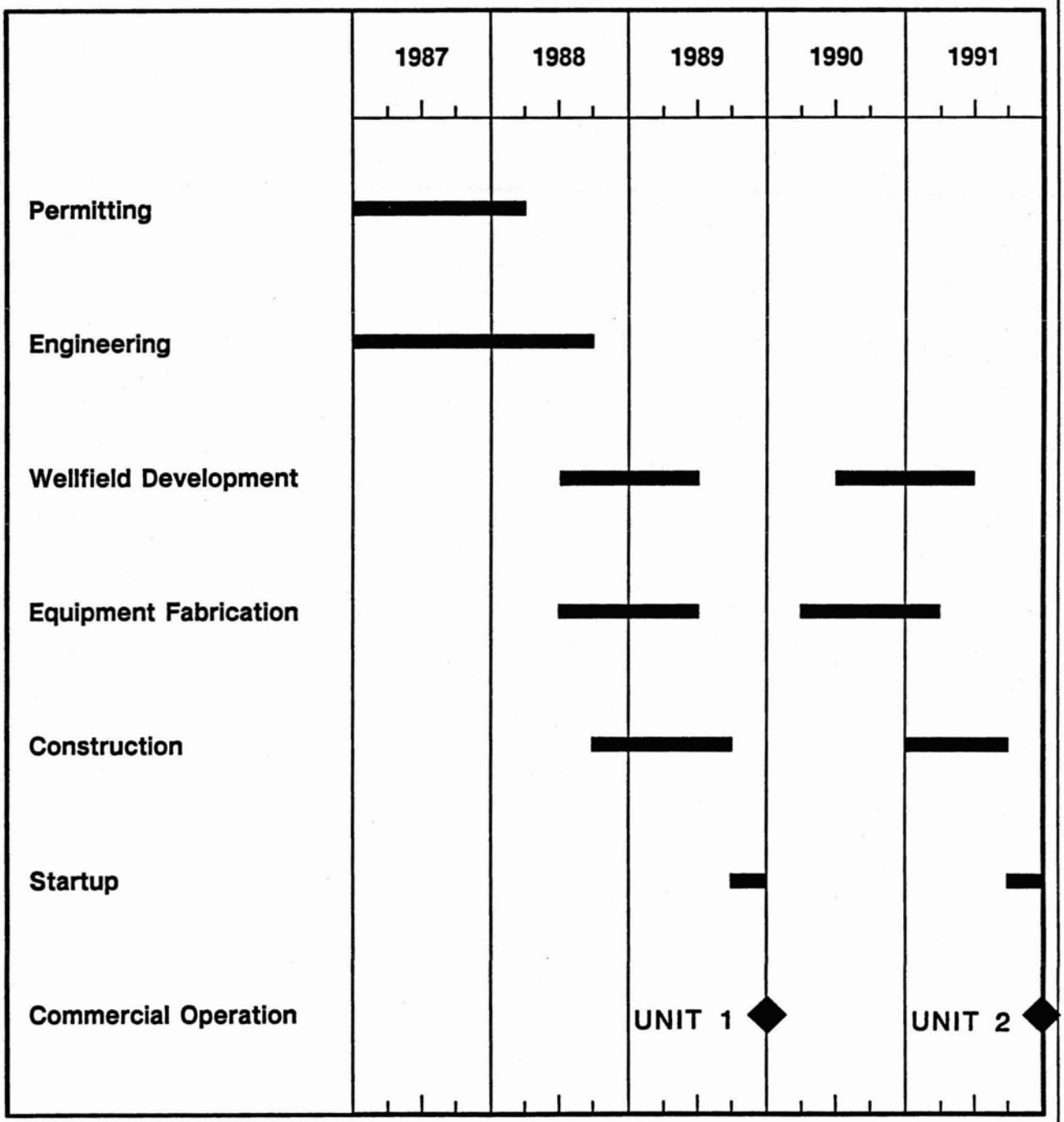


Figure 2-7
DEVELOPMENT SCHEDULE

The total project construction time for start-up of the first unit is estimated to be 18 months after the start of site preparation activities. Construction of the second unit is anticipated to begin six months after completion of the first unit and is also estimated to take 18 months. Site construction activities will be restricted to daylight hours.

Site construction presents employment opportunities for skilled and unskilled labor. Approximately 23 people will be needed during construction. Estimated peak employment at the site during construction may be up to 100 persons. Most of the construction work is anticipated to be accomplished by local contractors and the local labor force.

A temporary construction yard of about 5 acres will be located next to the main entrance road to the plant, off Highway 132 (shown on Figure 2-1). The construction yard will be fenced. The fence will be removed at the end of construction and the growth of natural vegetation encouraged.

Visual impacts will be mitigated throughout the construction phase by use of low-impact paint schemes and landscaping with native plants. Cut-and-fill slopes, as well as any uncovered level areas, will be seeded or planted with native vegetation when construction is complete. Landscaping will be performed around the wellpad and power plant, and paint schemes will be used to blend in structures with the surrounding environment.

Removal of all structures from the construction yard site, the fence surrounding the site and surplus materials will take place after construction is completed and growth of natural plants will be encouraged.

2.7 OPERATION AND MAINTENANCE

The operational life of the PGV facility is estimated to be 35 years. The power plant and wellfield will be operated in a manner that protects human health and the environment. The facility staff will operate equipment, oversee

production, and respond to emergencies. An important part of the operational phase of the project is regular monitoring and maintenance of both the power plant and the wellfield.

STAFFING

Approximately 19 employees will be required for operation and maintenance of the facility. Most, if not all, of the employees will be from the local area.

The power plant and wellfield will operate continuously seven days per week. Qualified operators will be on-site at all times when the plant is operating. Routine maintenance is conducted by workers during the normal daytime work shift. If either of the plant's two units is out of service or operating at a reduced output due to malfunction, the maintenance work will continue 24 hours per day, seven days per week, until full power output can be resumed. If both units are operating at approximately full power, the maintenance work will be done by one shift per day, five days per week.

MONITORING AND MAINTENANCE

Operation of the facility necessitates the monitoring of wellfield and power plant equipment and periodic maintenance.

Wellfield Monitoring

All wellheads will be equipped with temperature and pressure gauges on the well casing below the master valves. Flow from each well is measured by an orifice flow meter in the line downstream of each control valve. Flow indication will be local, and operation of the flow control valves will be manual. The control valves at the steam release facility will have air-piston operators that respond automatically to signals from the plant control room or upon sensing overpressure in the steam pipeline. The H_2S abatement system at the steam release bypass will operate automatically when steam is vented.

Wellfield Maintenance

Wellfield maintenance will generally be performed without shutting off the flow of steam from any well. When this action cannot be taken or is unsafe, maintenance work for the wellfield will be phased so that the fewest possible number of wells will be shut in and that wells will be shut in for a minimum time. Remedial drilling of wells, called well workover, is usually needed for proper wellfield maintenance. Well workovers are anticipated every two to five years for each well.

Power Plant Monitoring

The power plant is designed with a computerized automatic control system that will require a minimum number of personnel to operate the plant. The plant operator will perform prestart checks and manual valving, monitor the plant during operation, and periodically inspect the equipment. The two power plant units will be operated from a single control room. Control systems will operate automatically to prevent injuries to plant personnel or equipment. Standby equipment will start automatically to avoid tripping a turbine-generator unit during normal operations. An independent, self-contained control system will be provided for each generating unit.

Power Plant Maintenance

Scheduled maintenance will be conducted for each generating unit at intervals of one to two years, as needed. Thorough maintenance procedures, such as turbine disassembly/inspection and condenser inspection/repair, will be conducted during these planned outages. These scheduled maintenance periods will require approximately three to four weeks for each unit and will be coordinated with HELCO to ensure the maintenance of a reliable power system. Appropriately sized maintenance crews will be engaged around the clock, seven days per week during this time. Work crews will work 8- to 12-hour shifts.

PLANT START-UP AND SHUTDOWN

The start-up turbine-generator will receive steam from the wells when the plant is first started. This generator provides a sufficient amount of power to start the equipment needed to bring the main turbine onstream. Steam from the start-up turbine is sent to a rock muffler.

One or both of the main turbines may be started once the cooling tower, cooling water pump and any other necessary equipment are started and operating normally. Steam flow will initially be sent to the condenser through the turbine bypass, allowing all downstream equipment (such as the noncondensable gas removal and process fluid injection systems) to be started and operating before flow will be introduced to the turbine. The steam flow will be gradually increased to the working level of one turbine, and the flow will be gradually shifted from the bypass to the turbine. The second turbine will then be started in a similar fashion.

Plant shutdowns will be handled in a similar, but reverse, fashion depending upon the cause of the shutdown. The diesel generator instead of the start-up turbine may be used during shutdown if the start-up turbine will not be available. The wellfield will be shut in only in the case of emergencies and long-term outages. Shutting down wells and returning them to service is generally minimized in geothermal operations around the world because it can cause damage to the wells and/or reduces their expected life.

EMERGENCY RESPONSE PLAN

An emergency response plan for the project's well drilling and testing activities has been prepared and was approved by the County. It contains the details of procedures and chain-of-command that apply in the case of an emergency. Similar emergency response plans for construction and plant operations will be prepared prior to plant start-up and training will be provided, when required. Section 9, Public Health and Safety, contains an outline of the construction and plant operations plans.

2.8 DECOMMISSIONING

Decommissioning refers to the shutdown of the wellfield and removal of structures and equipment at the end of the useful life of the project. Economic and resource conditions will dictate when the facility should be decommissioned. The facility is currently expected to have a 35-year life, after which the plant and wellfield will be decommissioned. The site will then be returned to its natural state. The following steps will be taken during the decommissioning:

- Structures and piping will be removed.
- Dry or abandoned wells will be plugged with concrete, wellhead equipment and casing removed to below grade, well casing capped, and the surface restored.
- Roadways will be abandoned to the extent agreed upon with the landowner.
- The site will be regraded to approximate original contours, and the project area will be seeded or planted with natural vegetation.

Section 3

GEOLOGY

This section describes the geology, soils, and seismic and volcanic risks of the project area. This presentation is based on a review of available published and unpublished reports and maps, geologic field visits and discussions with experts on the project area. The geothermal reservoir for the Puna Geothermal Venture (PGV) project site is located in a geologic region known as the Lower East Rift Zone (LERZ) of the Kilauea Volcano. The existence of magma in subsurface conduits within the LERZ provides the heat source for the geothermal reservoir. The presence of this magma warrants careful evaluation of volcanic and seismic risks based on historical records pertaining to eruptions, land movements, and faulting.

3.1 ENVIRONMENTAL SETTING

REGIONAL GEOLOGY

The PGV project site is located near the eastern tip of the Island of Hawaii in the LERZ (Figure 3-1). This region is on the eastern flank of Kilauea Volcano, the southernmost of five volcanoes that make up the Big Island. Kilauea is one of the world's most active volcanoes. Recent and current activity is manifested by lava flows originating near the caldera area on the East Rift Zone (ERZ) that flow south-southeastward toward the ocean. The ERZ is one of the conduits for subsurface lateral migration of basaltic magma from the holding chamber beneath Kilauea's summit caldera. Magma moves within the ERZ from the summit holding chamber to either erupt offshore or to storage in secondary chambers within the LERZ (Moore, 1983). Volcanic eruptions (lava flows) in the LERZ have occurred as recently as 1961. Other flows have occurred in 1960, 1955, 1840 and 1740.

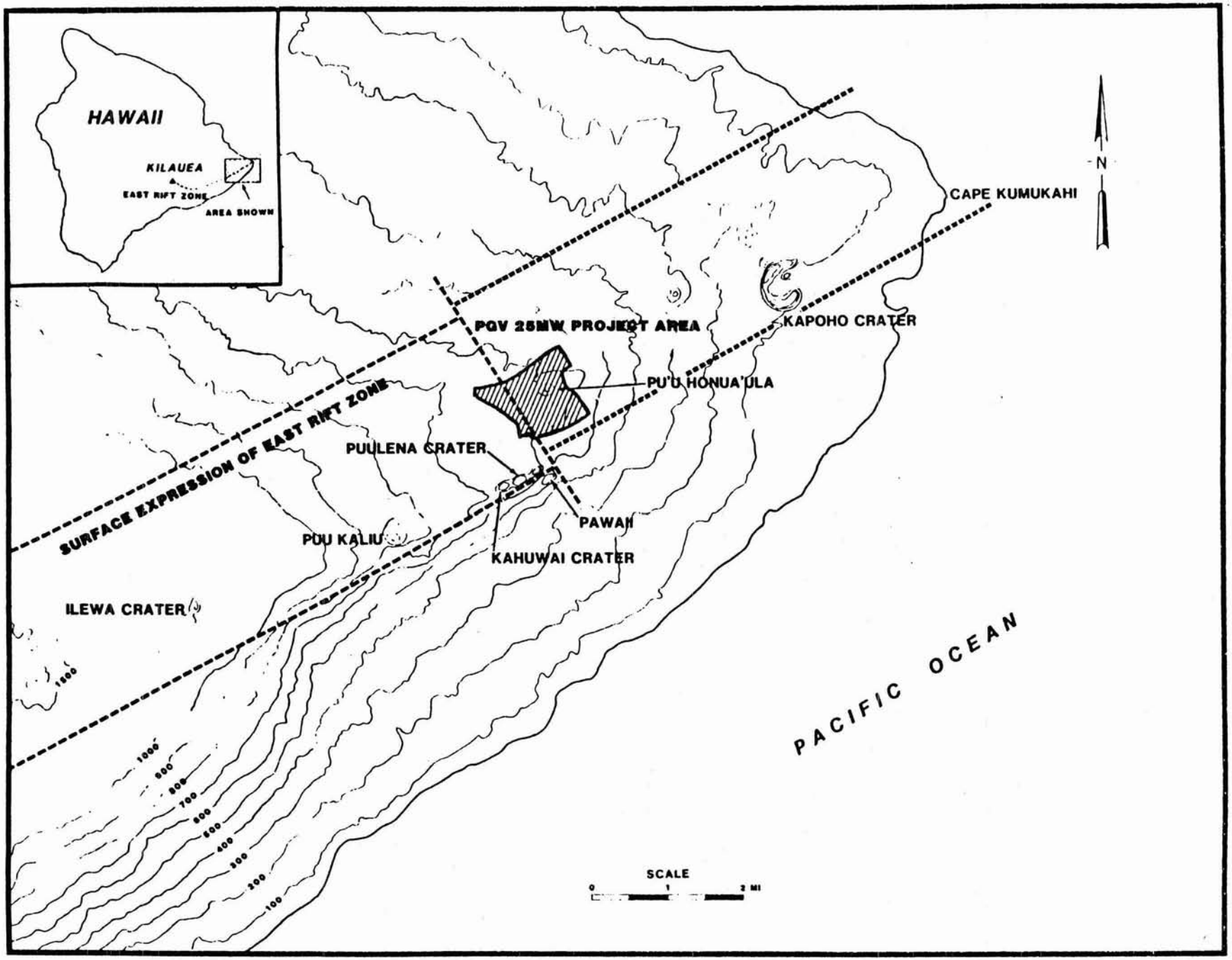


Figure 3-1 PROJECT LOCATION MAP

The rift zone is expressed at the surface as a linear belt, 1 to 2 miles wide, consisting of linear and open fissures, faults, small grabens, pit craters, cones, and vents related to numerous volcano-tectonic events. These events have produced variations in lava flow type, topographic expression, and basalt morphology. Variations of this type often occur during the course of a single eruptive event. This range of eruptive expression suggests that changes in magma supply occur between and during eruption episodes. A single eruption phase will often exhibit variable crystal composition, lava flow type (e.g., aa and pahoehoe), and constructional effects.

Throughout its length, the rift is topographically a constructional ridge some 150 to 1,500 feet above the adjoining terrain, except in its lowermost and farthest east portion. Here the ridge disappears into a low-lying area consisting of a series of grabens and spatter deposits (Moore, 1983). This marked topographic change corresponds to the structural intersection of the east-northeast trending rift zone with a north-northwest trending transverse fault. This transverse fault is further expressed by transverse trending spatter cones (e.g., Kiapu) and by topographic suggestion of a left-hand displacement in the LERZ as shown on Figure 3-1. Initial geothermal development activities were focussed on the area around this structural intersection.

Underlying the surface expression of the LERZ is a subsurface, 5- to 15-mile wide dike complex. This complex is thought to consist of an aggregate of closely spaced, parallel to subparallel, vertical to steeply dipping dikes. The top of this complex is thought to vary at approximately 8,000 feet below the surface. These dikes intrude a sequence of layered Mauna Loa and Kilauea lava flows. Temperatures in close proximity of this complex are reported to be above 1,000°F and, in some locations, may even approach 1,900°F, the melting point of basalt (Furumoto, 1978). The dike complex is the primary heat source for the Puna geothermal system. Mineral differentiation within lavas suggests the existence of local magma chambers beneath portions of the LERZ where storage and partial cooling of the magma take place. These magma chambers may provide a supplemental heat source for the geothermal reservoir.

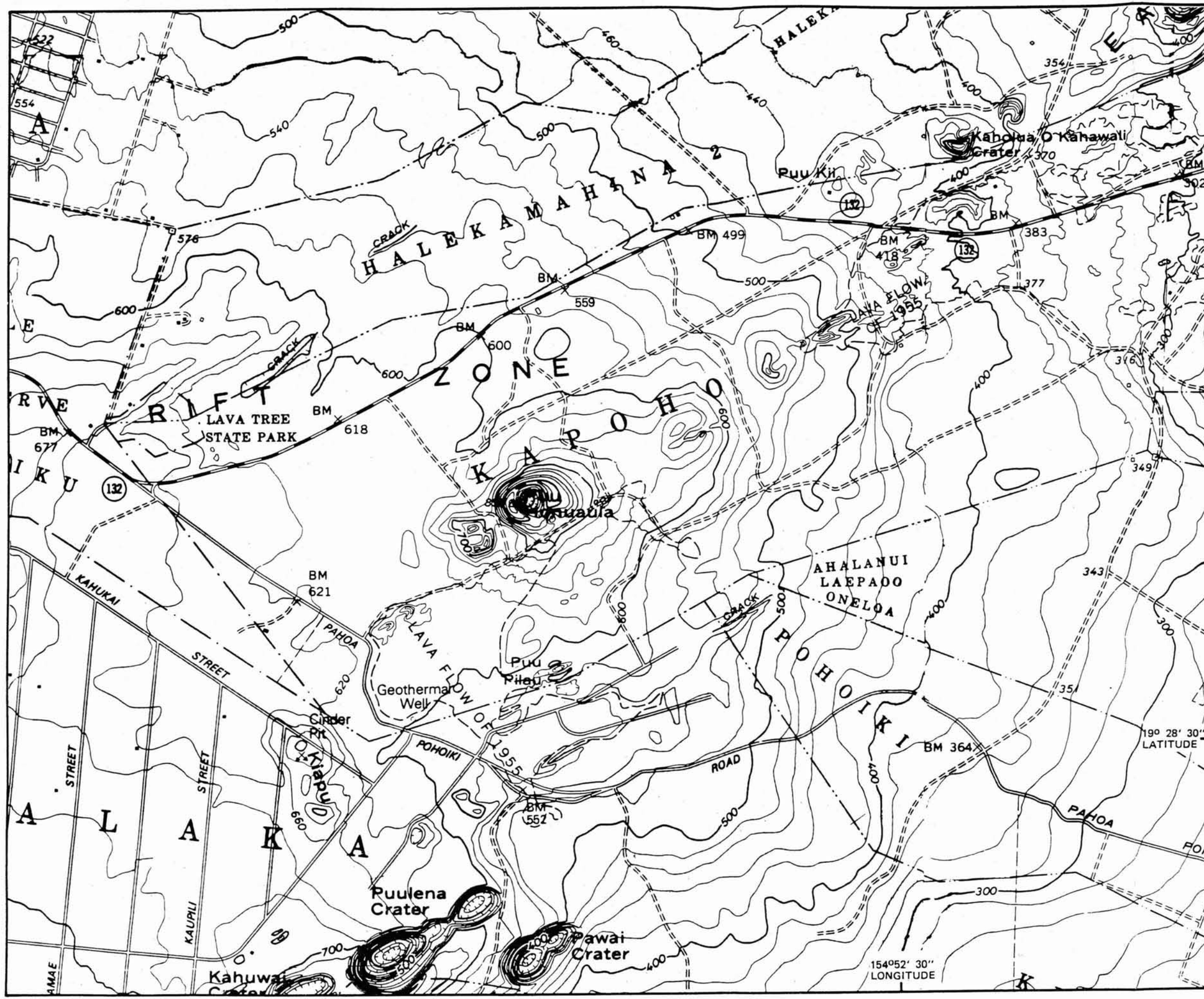
LOCAL AND SUBSURFACE GEOLOGY

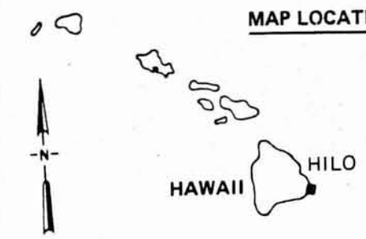
Major topographic features in the PGV project area are shown on Figure 3-2 and include four aligned prehistoric cones: Puu Honuaula, the unnamed puu immediately to the southwest of Puu Honuaula, and the spatter cones to the northeast of Puu Honuaula. These cones, together with the two surface breaks associated with the 1955 eruption (Figure 3-2), are in line along a northeast-southwest trend. This line of cones, breaks and eruptions probably represents a fissure or vent failure zone. Other topographic features in the site area include Puu Pilau and a number of cracks and minor eruptive features. The project site is underlain by basaltic aa and pahoehoe lava flows and associated ejecta from three main eruptive episodes: the Puna Volcanic Series, Historic Member, and Prehistoric Member.

Three eruptive events that represent the Prehistoric Member have occurred in the project region. The oldest events include the cinder and spatter cones of Kiapu, which is estimated to have erupted at least 1,500 years before present (BP). These features are located immediately to the southwest of geothermal well HGP-A. Spatter cones and lava flows of the Puu Kii fissure are dated at approximately 750 to 1,000 years BP and are exposed northeast of the project site. The Puu Kii flows are overlain to the south by flows from Puu Honuaula, which erupted an estimated 500 to 700 years BP.

The Historic Member is represented by flows of the 1790 and 1955 eruption. The 1790 flows erupted from fissure zones along both the northern and southern boundaries of the rift in the southern Puna District. The most recent lavas at the site erupted in 1955 from a discontinuous en echelon fissure system that longitudinally transects the project area. Flows from this event covered the southern portion of the project site (Moore, 1981; Moore, 1986).

Surficial basalt flows of the type common in Hawaii are highly vesicular, permeable and often fractured. The site area's subsurface is composed of layers of these subaerial flows with intercalated layers of tuffaceous material and minor soils to a depth of 1000 to 1800 feet below present sea level





SCALE
CONTOUR INTERVAL 20 FEET

0 — ½ MILE

0 — 1000 — 2000 FEET

0 — 1 KM

SOURCE: U.S.G.S., 1980, 1981a, 1981b

PUNA
GEOTHERMAL VENTURE PROJECT
HONOLULU, HAWAII

Figure 3-2
TOPOGRAPHIC FEATURES IN THE PGV AREA

FLUOR DANIEL	JOB. NO.	DRAWING NO.	REV.

(Slemmons et al., 1981). This is the approximate depth at which a transition from subaerial lava flows to submarine flows occurs. Submarine flows are more dense than subaerial flows and exhibit pillow structures and fracture porosity. Both types of basalt layers in the Puna subsurface profile have large compressive strengths due to the high density of basalt (up to 2.7 grams per cubic centimeter), interconnected fractures and vesicles, and lack of significant soil development. Fluid within the pore spaces of these rocks plays an insignificant role in overall substrata support.

Soils of the Keaukaha, Opihikao, and Malama series cover approximately 75 percent of the project site, while bare lava flows cover the remainder of the site. The Keaukaha Soil Series is present in the western section, southwest of Puu Honuaula. The soil is generally thin, ranges in depth up to 8 inches and overlays pahoehoe lava bedrock. It is very dark brown and mucky with a moderate to fine subangular blocky structure. The soil is highly permeable and strongly acidic. Runoff is minimal, and the erosion potential is slight. The Opihikao Soil Series is the most predominant soil type found in the western half of the site. Thick organic soils constitute this series, which are permeable with a slight erosion potential. The upper 3 inches are very dark brown, mucky, and friable with a medium to fine subangular blocky structure. The soil overlies pahoehoe lava bedrock and is strongly acidic. The Malama Soil Series extends across the center of the site to the northeast of Puu Honuaula. It consists of well-drained, extremely stony organic soils, ranging up to 1 foot in thickness and is underlain by aa lava flows. The upper 3 inches are very dark brown, contain extremely stony muck, and is underlain by fragmental aa lava. Runoff is minimal and the erosion potential is slight because the soil has a high permeability.

VOLCANIC AND SEISMIC CONDITIONS

Volcanically and/or tectonically active areas have associated levels of risk to property and life. Kilauea Volcano (and its associated rift zone) is one of the most seismically active areas in the world. The potential hazards associated with volcanism and seismicity can be largely mitigated with proper risk evaluation, planning, and structure design.

The most significant potential hazards associated with the LERZ include earthquakes, surface deformation, lava flows, eruptions and subsidence associated with faulting. The zones of overall relative risk from volcanic hazards were estimated and locations approximated relative to each of the five volcanos by the U.S. Geological Survey (Figure 3-3). The project site lies within an area that may be subject to high risk due to volcanic hazards (Mullineaux and Peterson, 1974).

Earthquakes

Earthquake activity in the LERZ has been attributed to two distinct mechanisms:

- Tectonically-related faulting such as that which has occurred in the Hilina Fault Zone on the south flank of the ERZ.

- Volcanically-related movements which are common in the ERZ and are especially concentrated in the northern middle ERZ and Kapoho areas.

The maximum historical magnitude for volcanically-related earthquakes on the ERZ is about Ms = 5.0. This type of earthquake is caused by magma movement in the shallow subsurface. Volcanically-related earthquakes represent the most frequent activity within the ERZ, but are of generally lower magnitude than tectonic earthquakes. High acceleration, displacement and velocity may occur along the LERZ, but only with a few high-frequency movement cycles of short duration (Slemmons et. al., 1981). This type of motion is likely to cause only minor structural damage to engineered structures (Slemmons et. al., 1981).

The relief of stress and strain by tectonically-related faulting, such as the type which occurs on the Hilina Fault System to the southwest of the site, results in potentially higher magnitude earthquakes than volcanically-related activity. The Hilina Fault Zone is the only proximal source of significant

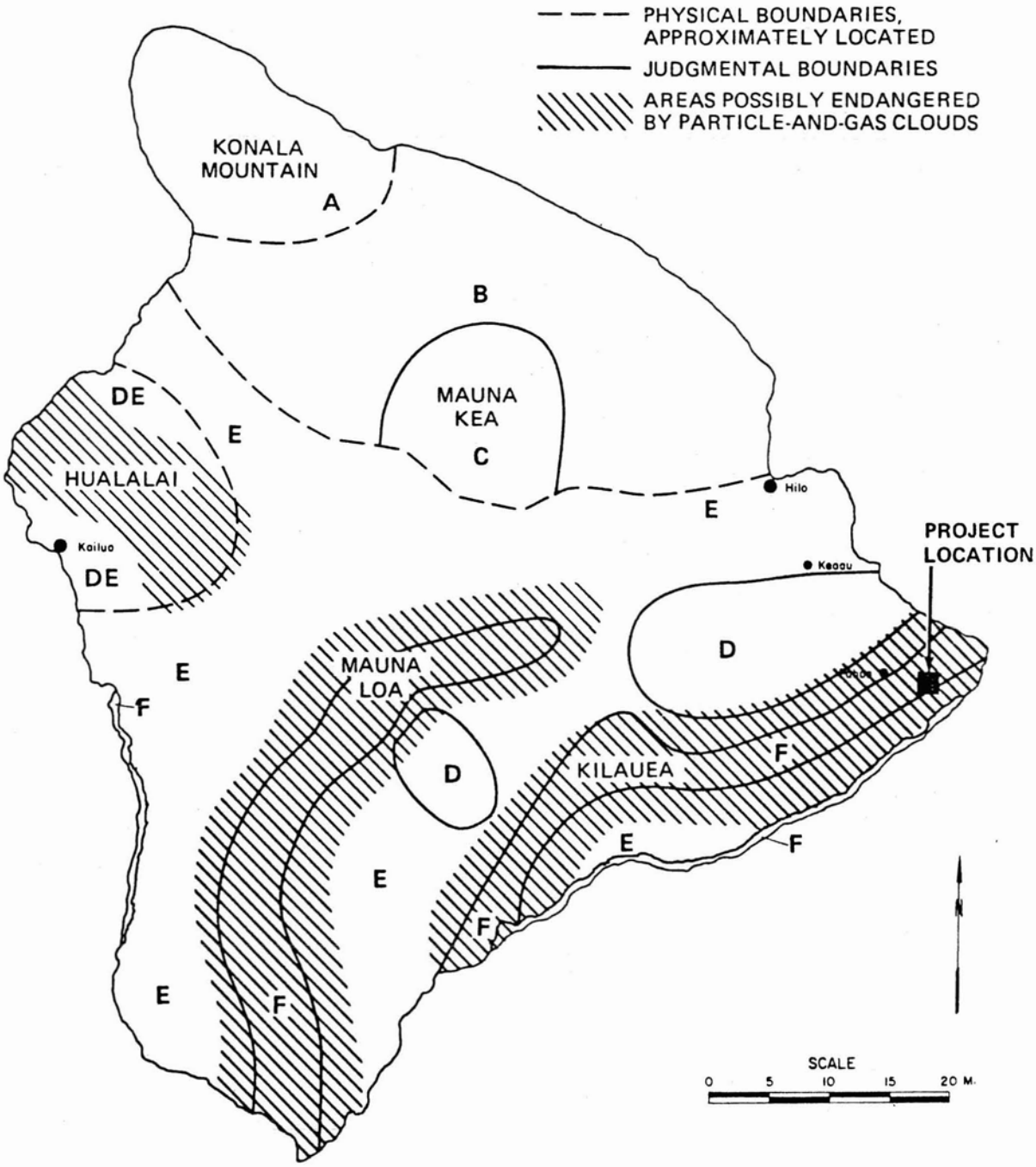


Figure 3-3 ZONES OF OVERALL RELATIVE RISK FROM VOLCANIC HAZARDS (RISK INCREASES FROM "A" THROUGH "F")
(After Mullineaux and Peterson, 1974)

earthquake damage of this type. Movement along this fault resulted in the Kalapaua earthquake of 1975 (Ms = 7.2). Smaller earthquakes occurred in 1954 (Ms = 6.5), in 1951 (Ms = 6.5 and 6.9), in 1929 (Ms = 6.5) and in 1868 (magnitude unknown). A maximum credible earthquake of about Ms = 6.75 with an epicenter within 15 miles from the project site may occur within the next 40 year period and should be assumed for planning purposes (Slemmons et. al., 1981). Little structural damage occurred associated with these historic earthquakes and accelerations rarely exceeded 0.4g despite their relatively large magnitudes. An acceleration of 0.22g was recorded at Hilo for the 1975 earthquake (Ms = 7.2). The magnitudes of earthquakes and resulting ground motion which can be expected at the project site are well within the range that can be mitigated through siting and appropriate design.

Surface Deformation

Surface deformation in the LERZ consists of ground swelling and horizontal extension associated with magma intrusion. This determination is often accompanied by fissuring and possibly normal faulting. Available data suggest that such deformation occurs prior to volcanic events including eruptions, magma intrusion at depth, and renewed eruptions during lengthy phases of activity.

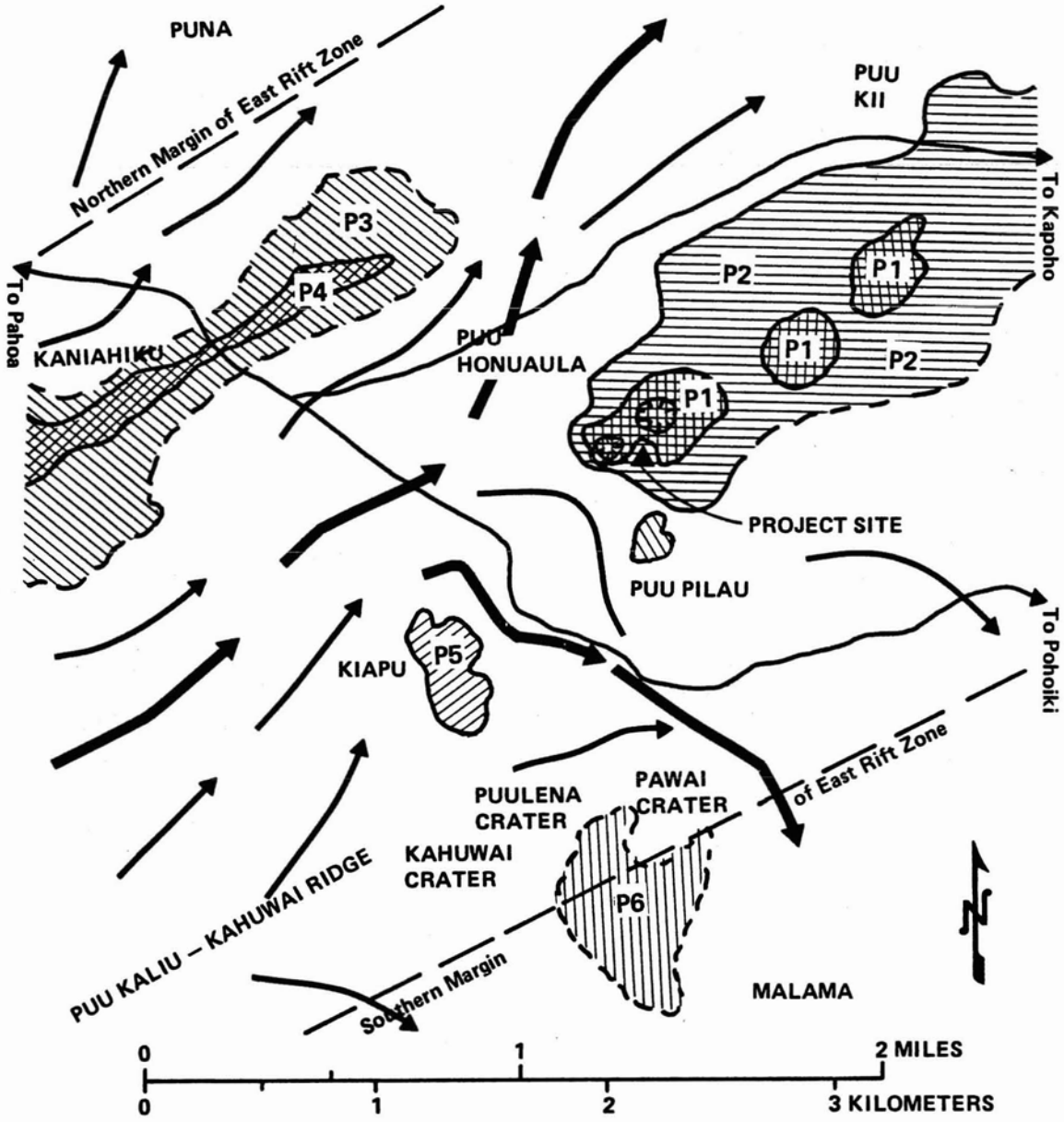
The broad arching, uplift and tilting that accompanies magma intrusion and extrusive events is not of sufficient magnitude or acceleration to constitute a significant hazard to property. Direct influence from fissuring and faulting are the chief threats to property. Sixteen individual fissure systems have been identified in the site area. The majority of these systems have formed en echelon fissures which are individually straight and parallel to the rift. There is an estimated 5 percent probability of damage to the primary structures within a given 40-year period using calculations based on the average width of the fissures (1 m), the width of the zone liable to fissuring (3,000 m), the frequency of occurrence (1 in 40 yr), and the dimensions of the engineered structure. Linear structures such as pipelines will have greater likelihood of surface damage. There is an approximately 60 percent probability of a linear fissure of average width 1 m intersecting a 2,000-foot length of pipeline trending normal to the rift zone within the 40-year life of the project

(Slemmons et al., 1981). Engineering practices, design, emergency response procedures and rapid repair of damaged areas will minimize any potential impact. If imminent danger to pipeline or other engineered structures exists, the facility can be shut down until the danger diminishes or until repairs are effected.

Volcanic Eruptions

Potential volcanic hazards consist of lava flows and ash falls, splatter falls, and their associated surface disruptions. Lava flows are of greatest concern for engineering and siting purposes. The risk of the site being overrun by lava from a vent located outside the project area is largely a function of topography. Lava flows from vents or fissures located uprift of the project site would most likely flow away from the site in the trough between Puu Kiapu and Lava Tree State Park. Flow may be directed between Puu Kiapu and Puu Pilau or Puulena Crater as shown on Figure 3-4 if ponding or damming should occur. Review of historical eruptive events shows an average lava thickness of approximately 18 feet with a range of 37 feet to a few feet (Slemmons et. al., 1981). The project site is situated on relatively level ground at an elevation of over 40 feet above the surrounding terrain. Lower-lying structures including three wellpads and associated pipelines will be at somewhat greater risk; engineered deflection berms and/or enclosed well heads can be used to greatly mitigate this concern. If an imminent threat of lava flow inundation of project facilities were to arise, production wells could be shut in and the plant shut down while emergency response procedures were enacted. Restriction or shutdown of surface access to the site from lava flow incursion is extremely unlikely due to deflection and other early warning and protective measures which would be utilized as part of the emergency response plan. However, should surface access to the site be cut off by lava flow, helicopter access would be employed to evacuate the main plant.

Hazards from eruptive vents or fissures which erupt in close proximity to the project site include ash falls, other ejecta and surface rupture. There is no instance in the historical record of a new eruptive fissure occurring over a previously existing fissure. The 1955 eruption was the last to occur in the site area and broke the ground surface at both ends of the Puu Honuaula chain



Map showing relative risk of lava flow incursions. Arrows show likely directions of flow of lavas in future eruptions. The most likely paths of flow are shown with thick arrows. P1 marks areas with lease risk of lava incursion and P6 marks areas of intermediate risk. Unshaded areas are those of greatest risk. (After Slemmons, 1981)

Figure 3–4

VOLCANIC RISK LEVELS, PUU HONUAULA AREA

of cones, outside the previous zone of weakness rather than within it. The PGV power plant was sited on high ground between two prehistoric cones to minimize the effects of potential volcanic eruption. Close coordination with the U.S. Geological Survey and the Hawaii Institute of Geophysics will be maintained to allow for possible early warning of eruptions and evaluation of preparatory measures.

SUBSIDENCE

Subsidence due to geothermal fluid withdrawal is not a significant concern in the LERZ. The zone at which geothermal fluid is withdrawn is composed of dense pillow basalts with interconnecting fracture and vesicle porosity. This rock type and the subareal flows above it are self-supportive. Fluid removal from the pores and fractures of these rocks will not affect their compressive strength. Reservoir formations with largely clays, sands or other sediment-dominated media are where subsidence has occurred on the mainland due to fluid removal. Removal of fluids from these formations lowers the mass volume of the unit resulting in a loss of compressive strength.

Four natural causes of subsidence are generally identified and should be addressed for the geothermal project:

- Settling of the island as a whole
- Downward movement of discrete blocks as a result of subsurface withdrawal of magma
- Relative downward and outward slumping of discrete blocks along the margins of the islands
- Local small-scale collapse of lava tubes.

Subsidence on a regional scale has been estimated to occur at a rate of approximately one foot per century. This type of subsidence does not significantly affect either lives or property and will pose little threat to the project site.

Settling of blocks because of magma withdrawal occurs in and near calderas and along rift zones. The maximum likely subsidence which could occur in the site area over the expected life of the project is on the order of a few feet. Subsidence related to magma withdrawal in the site area would likely happen in elongated blocks approximately parallel to the trend of the rift. Subsidence blocks are commonly bounded by faults that reach the surface.

The expected potential downward movement of the site area, on the order of a few feet due to magma withdrawal, will be accounted for in construction design. Plant and wellfield design will follow the specified Uniform Building Code, National Building Standards, and seismic zone specifications. Critical power plant structures will be built to Seismic Zone 4 specifications, which are greater than that required by the State of Hawaii. Any damage resulting from significant subsidence or differential subsidence related to magma withdrawal would be addressed and corrected in a timely, efficient and professional manner.

Relative subsidence due to slumping of blocks occurs along the coastal margin of the island where discrete normal, listric faulting associated with magma intrusion occurs, and steep, unstable, natural or constructional slopes occur.

Neither of these two situations exists in the vicinity of the project site. The closest significant slump block occurs approximately 10 to 15 miles southwest of the site along the Hiliua Fault Zone.

Lava tubes occur sporadically on the Island of Hawaii. These tubes are small and random and should not pose a significant threat to the operation and safety of the geothermal project. Other hazards, such as falling rock fragments, volcanic fumes, and Tsunamis, are much less serious and pose little threat to the project site.

3.2 ENVIRONMENTAL IMPACTS OF THE PROPOSED ACTION

The primary geological impacts on the project site consist of two types: construction impacts and operation impacts. Construction impacts are impacts on the topography, surface geology, and soils associated with earthwork and excavation activities during the clearing and construction phase. Operation impacts are ground changes related to wellfield production and injection activity.

CONSTRUCTION IMPACTS

Grading, grubbing, and stockpiling of soil, cinders, and rock will be required at the project site to support the planned activities. These alterations could change surface drainage. The impact will be minimal since the ground alterations planned are limited in scope and ground percolation rates are high.

Removal and disruption of soils during clearing and construction could result in changes to the soil structure, density, and moisture content. These changes could potentially increase erosion and alter groundwater percolation rates and vegetative support. These effects are considered negligible at the project site because the soils are poorly developed, generally have rapid percolation rates, and are not very susceptible to erosion.

OPERATION IMPACTS

Experience with geothermal developments worldwide shows that, in certain regions, a relationship exists between geothermal wellfield development and increased seismicity and subsidence. Increased seismicity is of magnitudes less than 4.0 on the Richter scale when it does occur coincident with geothermal development. Such levels of seismicity are minor events compared to the November 1975 earthquake (Ms = 7.2), the largest in recorded history in the southern Puna District. No damage was reported in the Pahoa and Kapoho areas as a result of this earthquake. Seismic events, which are caused by changes in the hydrologic and tectonic balance in and around the geothermal reservoir, are

not of a sufficient magnitude to cause significant surface damage. Seismic effects are not considered a significant environmental concern for this project.

Subsidence due to geothermal production is not expected in the project area because the dense, basaltic lava flows and dikes that make up the rock of the geothermal reservoir are self-supporting and because the reservoir is located at depths greater than 4000 feet.

3.3 PROPOSED MITIGATION MEASURES

Grading activities during construction will cause minor surface changes within the project site. These activities will be kept to a minimum, in order to maintain natural topography. Construction vehicles will be limited to those areas under development to minimize soil disturbance. On-site materials will be used for fill to reduce the need for imported construction materials when possible. Excess earth unsuitable for use in construction will be stockpiled and stabilized according to building regulations to avoid any increased erosion potential. The planned surface changes will not result in significant impacts.

Fluid pipelines have the greatest vulnerability to disruption from geologic hazards. Judicious and timely on-site field evaluations are required to minimize wellfield disruptions and environmental impacts. Shutdown of the wells and power plant will take place under extreme conditions. Wellfield damage will be repaired in the shortest period of time possible. Close coordination is planned between the Hawaii Volcano Observatory (U.S. Geological Survey) and the Hawaii Institute of Geophysics to further reduce risks and ensure timely warnings of impending geologic hazards.

EARTHQUAKES

Abatement of potential earthquake damage is primarily achieved through proper design of the engineered structures. The maximum predicted acceleration due to ground movement is 0.4g (at 4 Hz). Critical structures will be designed to withstand movement of this magnitude plus a 10 percent safety factor.

Critical equipment will be designed to Seismic Zone 4 requirements. Zone 4 is the highest seismic level and exceeds the State of Hawaii Zone 3 requirements. The turbine will be automatically shut down until evaluation of the cause can be obtained if abnormal vibrations occur within the turbine generator system.

SURFACE DEFORMATION

Broad ground movements associated with magma intrusion do not pose a significant threat to property or life. Fissuring or faulting, as they occur within the LERZ, are commonly en echelon and parallel to the rift axis. The estimated probability of a ground rupture affecting the building structures at the PGV site is estimated at 5 percent over a 40-year period. The probability of ground rupture affecting piping, especially longer segments oriented perpendicular to the trend of the rift zone, is higher than that of primary structures. Several factors combine to mitigate any threat of damage to pipelines: Pipelines are built to withstand a wide range of thermal expansion resulting in a large element of built-in flex; pipelines and other structures will be built to strict seismic standards of safety; pipelines will be designed to accommodate projected average fissure widths as defined by Slemmons et al. (1981) with no damage. Should any sudden seismic event exceed piping design allowances and result in damage, emergency response procedures would include shutdown and depressurization of affected pipelines within one hour. Repairs will be conducted in a timely and efficient manner whenever needed. The plant can be shut down while an evaluation of the damage is made and repairs are effected if damage is found to be a serious threat to either life or property.

VOLCANIC ERUPTION

Abatement measures which will be used to minimize volcanic hazards include:

- Major facility structures located on elevated ground in a previous zone of weakness

- Wellheads placed in cellars that can be filled with cinders in the event of a lava flow

- Deflection barriers constructed around the wellpads and pipelines

- Close and continued coordination with the U.S. Geological Survey and the Hawaii Institute of Geophysics to ensure early warning of impending volcanic activities

SUBSIDENCE

The dense, basaltic lava flows and dikes that make up the substrata of the geothermal reservoir are self-supporting; the top of the reservoir is nominally at a 4,000-foot depth. These factors make subsidence due to geothermal production highly unlikely. Natural subsidence will be largely abated by proper design to include Seismic Zone 4 standards, and construction and building orientation. Power plant design will provide for leveling correction of the turbine and adequate end thrust bearings to further mitigate uneven and moderate ground movement.

Section 4

HYDROLOGY

This section discusses surface and subsurface hydrology, as well as the injection impacts on shallow and deep aquifer systems. The material provided in this section identifies the potential effects that the PGV operation may have on groundwater.

4.1 ENVIRONMENTAL SETTING

The Puna geothermal reservoir is located in the southeastern portion of the Island of Hawaii within the Lower East Rift Zone (LERZ) of Kilauea Volcano. The area is characterized by vesicular, young subaerial basalt lava flows and high annual rainfall. The very high permeability of the lava flows allow rapid percolation of almost all the precipitation into the subsurface.

The typical occurrence of groundwater in the Hawaiian Islands follows the Ghyben-Herzberg principle where a lens of fresh (basal) water floats on, and displaces, denser saltwater. This lens of basal water progressively thickens from the coast to the center of the island. Rift zones of Hawaiian volcanos impose two major modifications on the Ghyben-Herzberg principle. First, the abundant faults and dikes within the rift zone result in basal water occurring at higher elevations and to greater depths than otherwise predicted. Second, the strong structural grain imposed by rifts and the impermeable nature of the associated dikes causes groundwater, both upgradient and within the rift, to flow primarily parallel to it. These conditions occur in the vicinity of the project site in the LERZ.

The geothermal reservoir is largely separated from overlying strata and groundwater by a 1500 foot thick, relatively impermeable seal. Some leakage of fluids from the Puna geothermal reservoir into the overlying shallow and intermediate depth groundwater aquifer system is documented. Consequently, the

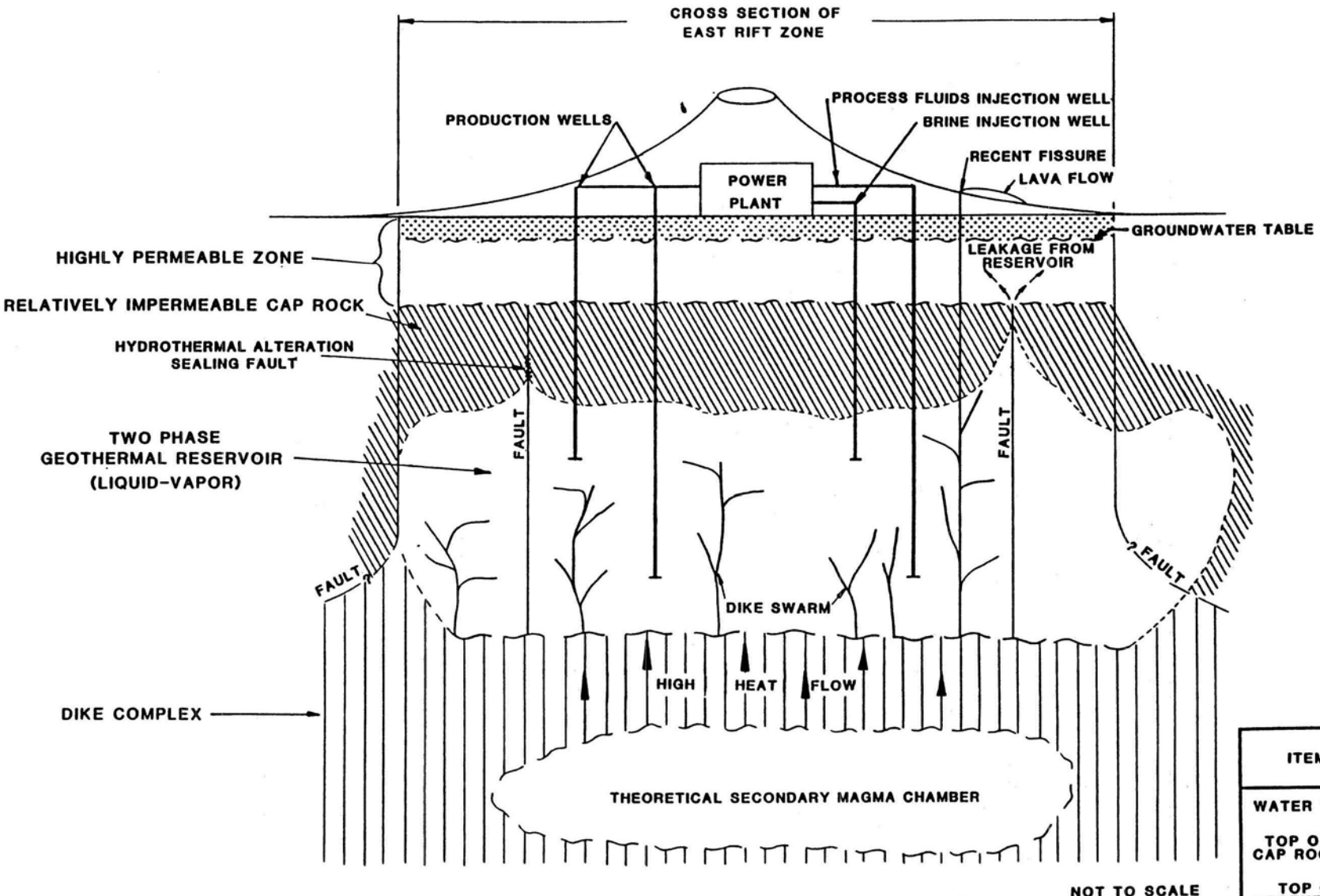
high volume of fresh water that should exist within this aquifer has been chemically and thermally altered by the geothermal fluid leakage. As a result of this leakage, no fresh water is present within the immediate project site region.

Reinjection of the brine into the reservoir has the benefit of replacing reservoir liquid supply and assisting in effective heat extraction. The brine reinjection process should extend the life of the producible reservoir. Process fluids reinjection into the reservoir has the advantage of avoiding potential hydrogen sulfide (H_2S) air quality impacts. Reinjection will not impact any fresh drinking water sources both because there is no geothermally-unaffected groundwater in the project site area and because the relatively small volume of process fluids and brine are being returned to the same environment from which they were taken.

SURFACE GEOTHERMAL MANIFESTATIONS

The reservoir is believed to be maintained by very high heat flow within the rift generated by partially or fully penetrating dikes and possibly by localized secondary magma chambers. This heat process is made more efficient by the overlaying seal that inhibits significant venting. The reservoir is confined to the rift, except where faults and/or fractures allow lateral extension into nonrift areas. Where the overlying relatively impermeable seal is locally broken by faulting or fracturing, leakage of geothermal fluids to areas above the reservoir occurs. A cross section of the geothermal reservoir is shown on Figure 4-1.

Tremendous heat flux is generated by the rift zone environment; nevertheless, no marked geothermal surface manifestations (e.g., Yellowstone type) are present in the LERZ. Several hot springs discharging along the southeastern Puna coast appear to be related to geothermal leakage in the rift.



ITEM	DEPTH BELOW GRADE
WATER TABLE	~ 600'
TOP OF CAP ROCK	~2500'
TOP OF GEOTHERMAL RESERVOIR	~4000'

Figure 4-1 CONCEPTUAL MODEL OF THE PUNA GEOTHERMAL RESERVOIR

Isolated steam vents that exist within the rift are more closely related to recently active fissures. The lack of surface manifestations of the geothermal reservoir is attributed to the relatively impermeable seal above the reservoir and a vigorous, high volume, cool groundwater system which "hydraulically masks" the geothermal reservoir.

FLUIDS INJECTION

The project's wellfield development plan provides for the subsurface disposal of geothermal brine and process fluids (noncondensable gas dissolved into steam condensate) through reinjection into the geothermal reservoir. This procedure is a virtually closed system whereby the majority of extracted geothermal fluids are returned to the geothermal reservoir beneath the relatively impermeable seal. Reinjection of fluids into the subsurface is a well-established practice in the geothermal and oil-gas industry throughout the world. Hydrogen sulfide and other gas abatement through absorption and injection is being utilized or has been demonstrated in a number of geothermal fields. Readily available technology will be utilized in the PGV project.

Geothermal brine and process fluids (i.e., noncondensable gases dissolved under pressure into cooling tower water) will be separately reinjected into the geothermal reservoir below the seal. Reinjection of geothermal brine into the reservoir should help to conserve the reservoir's heat and water balance, thereby prolonging the life of the geothermal resource. Reinjection of process fluids should eliminate otherwise potential environmental concerns such as air emissions of hydrogen sulfide or the handling of treatment chemicals. The groundwater aquifer system that overlies the reservoir will not be further impacted by the injection process because of the relatively impermeable seal that separates the two, the relatively small volume of injectate, and because the aquifer system is already degraded by natural leakage (Figure 4-1).

SURFACE HYDROLOGY

No known surface drainage (runoff) exists in the PGV site area. The only standing body of water known to exist in the Puna area is Green Lake near Kapoho. The unweathered, highly permeable lavas and well-drained soils that comprise the site region allow much of the high volume of rainfall to percolate to the water table. The surface runoff that occurs elsewhere on the Island of Hawaii fluctuates considerably with variations in rainfall. The largest streams are located on the northeast (windward) side of the island in areas of high rainfall. These areas are often underlain by cemented tuff units which inhibit downward percolation of rainwater.

GROUNDWATER HYDROLOGY

Due to the lack of surface runoff in the site area, a large percentage of rainwater is available for recharge to the aquifer system. Rainwater percolates readily through the highly permeable overlaying rock and reaches the water table which is located at a depth of approximately 600 feet below ground surface. An average of about 120 inches of precipitation falls annually at the site, resulting in a recharge rate of 6,080 acre-ft/yr/mi^2. Recharge loss due to evapo-transpiration is estimated to be about 30 inches, leaving about 4,440 acre-ft/yr/mi^2 to infiltrate to groundwater (Weiss Associates, 1983).

Regional Groundwater Occurrence

Based on occurrence, groundwater aquifers on the Island of Hawaii fall into three general categories:

1. Basal (fresh) water floating on salt water (Ghyben-Herzberg lens)

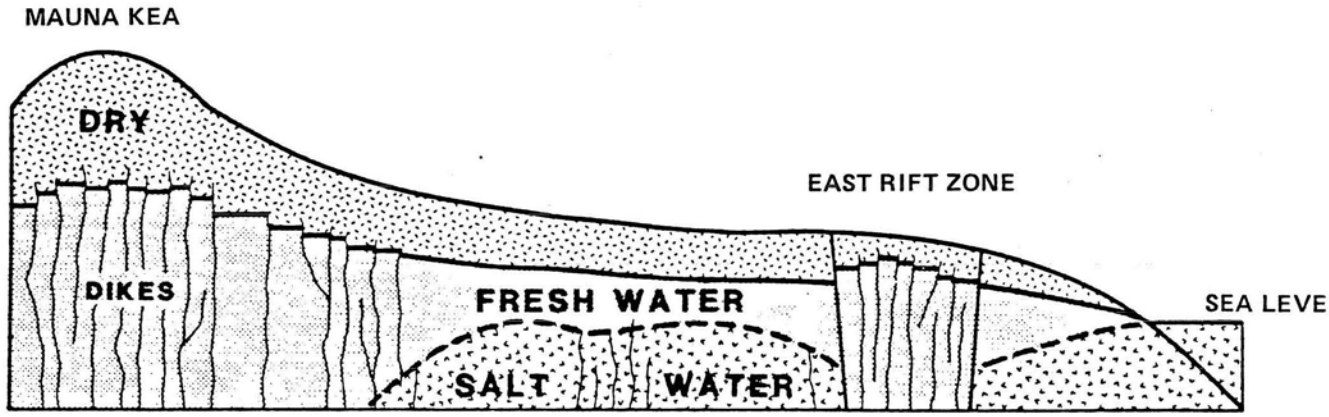
2. Water perched on relatively impervious soil or rock formations

3. Water confined by dikes

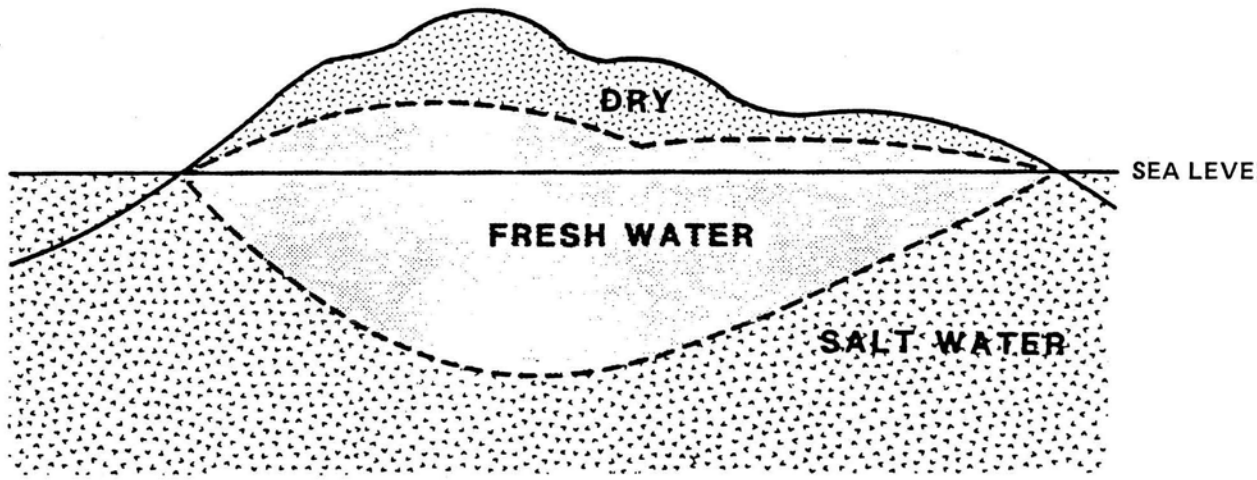
The majority of the groundwater aquifers outside the ERZ follows the Ghyben-Herzberg model of fresh water (from rain recharge) floating on denser salt water (ocean water). This model, shown on Figure 4-2, approximates many island aquifer systems throughout the world. The general principle on which the model is based states that the elevation of the fresh water table (termed "basal water") above Mean Sea Level is 1/41 of the total thickness of the fresh water aquifer. Groundwater wells in the Pahoa area draw from high-quality basal water that fits this model. Water levels in these wells are approximately 15 feet above MSL, which suggest a total aquifer thickness using the Ghyben-Herzberg principle of 615 feet in the Pahoa vicinity north of the LERZ. The Puna District, except for the area within the East Rift Zone (ERZ), is underlain by predominantly basal water.

Recharge waters can accumulate as perched aquifers of varying significance where impermeable or semi-permeable layers (usually ash or other tuff units) are encountered above the main groundwater aquifer. Where these layers intercept cliffs or sea walls, waterfalls can occur as is found at Waipio Bay. Perched aquifers are virtually unknown in the Puna area and are considered to be of only minor significance as a source of usable groundwater. An ash formation occurs in the vicinity of Kapoho Crater where the only standing body of water (Green Lake) is found. This ash formation forms a perched aquifer system which partially feeds a drinking water well at Kapoho Crater.

Groundwater within the ERZ is affected by the dike system that characterizes this rift feature (Figure 4-2). Groundwater affected by the dike system is at generally higher elevations than the basal water outside the ERZ. The individual dikes of the ERZ act as relatively impermeable barriers to transverse water migration and cause the dominant flow direction to be parallel to the rift. These conditions have resulted in a groundwater aquifer system that does not follow the Ghyben-Herzberg model. The composition of fluids within the geothermal reservoir in the PGV project area represents much fresher water than would be predicted by the Ghyben-Herzberg principle. Fresher water occurs at depths far greater than predicted by the Ghyben-Herzberg principle. Groundwater to the north of the rift zone is at somewhat higher elevations than



A. Schematic cross-section from the rift zone of Mauna Kea through the East Rift Zone of Kilauea showing the distribution of fresh water and salt water (modified after Stearns and Macdonald, 1946). Two types of ground water occurances are illustrated: dikecontroled and basal water within and outside the rift zone, respectively. Only two water chemical categories are shown.



B. The Ghyben-Herzberg Principle showing the lens of fresh (basal) water floating on salt water (modified after Stearns, 1966).

Figure 4-2 GENERALIZED MODEL OF THE GEOHYDROLOGIC SETTING OF THE EAST RIFT ZONE

elsewhere outside of the rift zone, suggesting that the rift may be producing a damming effect. Water quality data across the rift also suggest that groundwater circulation is restricted. The dike-confined groundwater within the LERZ eventually discharges to the basal supply outside of the rift through faults and/or fractures.

Regional Water Quality

The chemistry of Hawaiian groundwater varies greatly with location. Although the surrounding sea significantly influences shoreline groundwater chemistry, inland groundwater quality is controlled by aquifer type, soil cover, surface land usage and recharge-discharge rates (Imada, 1984). On the Island of Hawaii, the high net groundwater recharge and basal discharge to the ocean result in minimal rock/water interaction and a further seaward seawater/-fresh water interface than would otherwise be expected.

The density difference between fresh and salt water allows migrating fresh groundwater to float on salt water. However, tidal fluctuations and other head variations tend to create a zone of mixing near the interface which results in a transition zone between fresh and saline water. These conditions add to variations in TDS concentrations of the groundwater with location and depth.

Groundwater quality, inland from shore areas (mixing zones) and away from areas of geothermal influence, is generally very good on the Big Island. Wells in the Pahoa area have been producing high quantities of excellent quality drinking water for many years.

Local Groundwater Occurrence

The mechanisms controlling groundwater occurrence in the Puna area are more complex than the Island as a whole. Groundwater resources in this area occur in both dike-confined and unconfined aquifers. Dike-confined aquifers are aquifers that are highly influenced by proximal dikes; either in water table elevation, flow direction, or both.

The dikes within the LERZ control the water table elevations, flow direction, and to some extent, the quality of groundwater at the PGV site area. The main aquifer beneath the site area occurs at a depth of approximately 600 feet below grade. Groundwater within the LERZ flows roughly parallel to the rift to the northeast, except where structural leakage of this water to the southeast occurs. According to Imada (1984), groundwater to the south of the LERZ flows at relatively high velocities to the south. Groundwater to the north of the rift (i.e., the Pahoa area) flows sub-parallel to the rift to the northeast. Generally, flow occurs perpendicular to topographic contours, except where dikes and faults within the rift affect flow.

The permeable nature of the rocks containing the aquifers in the LERZ area, coupled with high recharge rates, results in high groundwater flow velocities. The volume of water that is contained in, and moves through, the local aquifer system (depths of 600-2,500 feet), is extremely large. Mean groundwater residence time within the LERZ, shown by oxygen and hydrogen isotope concentrations ($\delta^{18}O$ and ^{3}H [tritium], respectively) is on the order of a few years (Kroopnick et. al., 1978). This short residence time coupled with high annual rainfall confirms the existence of a vigorous groundwater flow system. The volume and dynamic nature of this aquifer system, along with the natural chemical makeup of the water, are important factors in evaluating any impact that a reinjection process may have on the system.

The only known exception to high aquifer permeabilities in the LERZ is found near Kapoho Crater. The flow velocities which exist within the ash layer of this area are certainly much less than surrounding rock types. Evidence suggests that, due to the high groundwater table in this area (which exists primarily because of the low topographic elevation of this portion of the LERZ), volcanic eruptions and/or lava flows were more water-influenced at the time of this ash formation. This factor produced more explosive eruptions in the area due to expanding gases and, therefore, more fine-grained, tuffaceous material fell on the paleolandscape. One well (Kapoho shaft) produces water from the aquifer in this vicinity. This well probably draws water from both the tuffaceous rock (that which Green Lake is "perched" upon) and the surrounding, more permeable aquifer.

Local Groundwater Quality

The ERZ acts as a divide for groundwater salinity. Chloride concentrations north of the ERZ are relatively low, while concentrations greater than 1000 parts per million (ppm) are common within, and south of, the ERZ (Davis and Yamanaga, 1968).

Cox and Thomas (1979) conducted a chemical review of approximately 400 groundwater samples in the State of Hawaii and have determined three parameters which define the chemical and temperature characteristics of geothermal water (groundwater affected by geothermal influences): temperature in excess of 84°F; chloride to magnesium (Cl/Mg) ratios greater than, or equal to, 15; and silica content exceeding 30.85 mg/l depending on locality. Groundwater data for samples collected from various depths in the LERZ region generally show that TDS and temperature increase significantly with depth in the aquifer system. TDS and temperature values for samples collected from depths of about 2000 feet (eg., at the HGP-A well) were found to be approximately three times higher than for samples collected near the water table at depths of about 600 feet (eg., at the KS-1 well). This depth relationship is expected, given that the source of the chemical and thermal contamination is located directly below the groundwater aquifer.

Iovenitti (1986) classified groundwater near the top of the aquifer system in the southeastern portion of the Island of Hawaii into three types: geothermal, fresh and mixed (Figure 4-2) on the basis of more conservative temperature and chemical criteria than those proposed by Cox and Thomas (1979). Geothermal groundwater is defined as having two of the following three characteristics: a total dissolved solids content equal to or greater than 2,000 mg/l; a temperature equal to, or exceeding, 100°F; and/or (Cl/Mg) ratio in excess of 15. The Federal maximum tolerance limit for TDS in drinking water is 1000 ppm, while 500 ppm is the recommended level. The term "geothermal water" was chosen because of the profound effect that leaking geothermal fluid has had on the chemistry of this water. Fresh groundwater is defined as having two of the following three characteristics: a total dissolved solids content

of 500 mg/l or less, temperature not greater than 84°F, and/or a (Cl/Mg) ratio less than 15. Mixed groundwater is defined on the basis of location and has characteristics intermediate to fresh and geothermal groundwater.

As shown on Figure 4-3, geothermal groundwater is encountered in the vicinity and downgradient of the major structural break of the LERZ (transverse fault). Sampled groundwater in the area was found to have temperatures ranging from 100 to 199°F, Cl/Mg ratios of 18 to 3200, silica content of 24 to 105 ppm, and TDS concentrations of 762 to 11,700 ppm. This chemical signature is undoubtedly caused by leakage of geothermal fluid from the reservoir below. Figure 4-1 shows the relationship of the geothermal reservoir to the overlying "cap" rock and aquifer system. Leakage occurs where faulting allows geothermal fluids, which are under great temperature and pressure, to escape through the impermeable seal. Upward leakage of geothermal fluid into the shallow subsurface is most likely occurring along the transverse fault as shown on Figure 4-3. The upwelling fluid migrates laterally following the topography to the sea as it reaches shallower depths. Two plumes of geothermal groundwater have been identified. One plume flows parallel to the rift, progressively interacting with meteoric water recharge (from rainfall) to form the mixed groundwater region at Kapoho Crater. The other plume, being unconfined by the structures of the rift, forms a relatively broad plume discharging as warm springs and seeps along a portion of the southern Puna coast.

The only "fresh" water known to occur in the LERZ area depicted on Figure 4-3 is found north of the LERZ (recharged from the Mauna Loa area) and south of the rift in an area southwest of the project site. Fresh water is the only groundwater type considered suitable for human consumption based on temperature and chemistry.

The fresh water occurrences are either outside the rift zone or upgradient from the transverse structural break area. All groundwater areas within the rift or downgradient to the south of the transverse break are geothermally affected.

Mixed groundwater is located within the rift zone near Kapoho Crater. This water type lies hydrologically downgradient of the upwelling geothermal fluids and is quite possibly a mixture of fresh (possibly recharge from Green Lake), geothermal and sea water. Water from the Kapoho shaft near Green Lake contains elevated TDS concentrations (of the calcium magnesium sodium bicarbonate type) without the temperature signature evident further up-rift. The high bicarbonate nature of the water is reported by Imada (1984) to be of volcanic origin. This water approaches the low-quality end of drinkable water and is considered of limited use. Continued pumping in this area will probably draw increasingly from the seawater and geothermally altered water which surrounds Kapoho Crater.

4.2 ENVIRONMENTAL IMPACTS OF THE PROPOSED ACTION

CONSTRUCTION IMPACTS

No surface water drainages exist at the site; however, clearing and construction activities may create minor surface water drainage. These activities are not expected to affect the occurrence of groundwater.

Minor spills of oil, gasoline, and other materials may occur during routine clearing and construction. Procedures will be implemented to minimize such accidental spills, and mitigation measures will be established.

Drilling fluids ("mud") will consist of a nontoxic mixture of fresh water, bentonite and sepiolite clays, biodegradable detergents, and special additives used to control pH, viscosity, flocculation and foaming. These nontoxic drilling fluids will be discharged to unlined sumps under normal drilling operations and will percolate into the groundwater. In addition, some loss of drilling fluid in the subsurface during drilling is expected. Toxicity tests of drilling fluids previously placed in the Wellpad A sump show no EPA-defined toxicity levels. Arsenic, lead and mercury were among the metals measured in these 1985 tests. Neither wellbore fluid losses while drilling or drilling sump residues are expected to approach toxic levels or to contaminate the existing geothermally-contaminated groundwater in the project area.

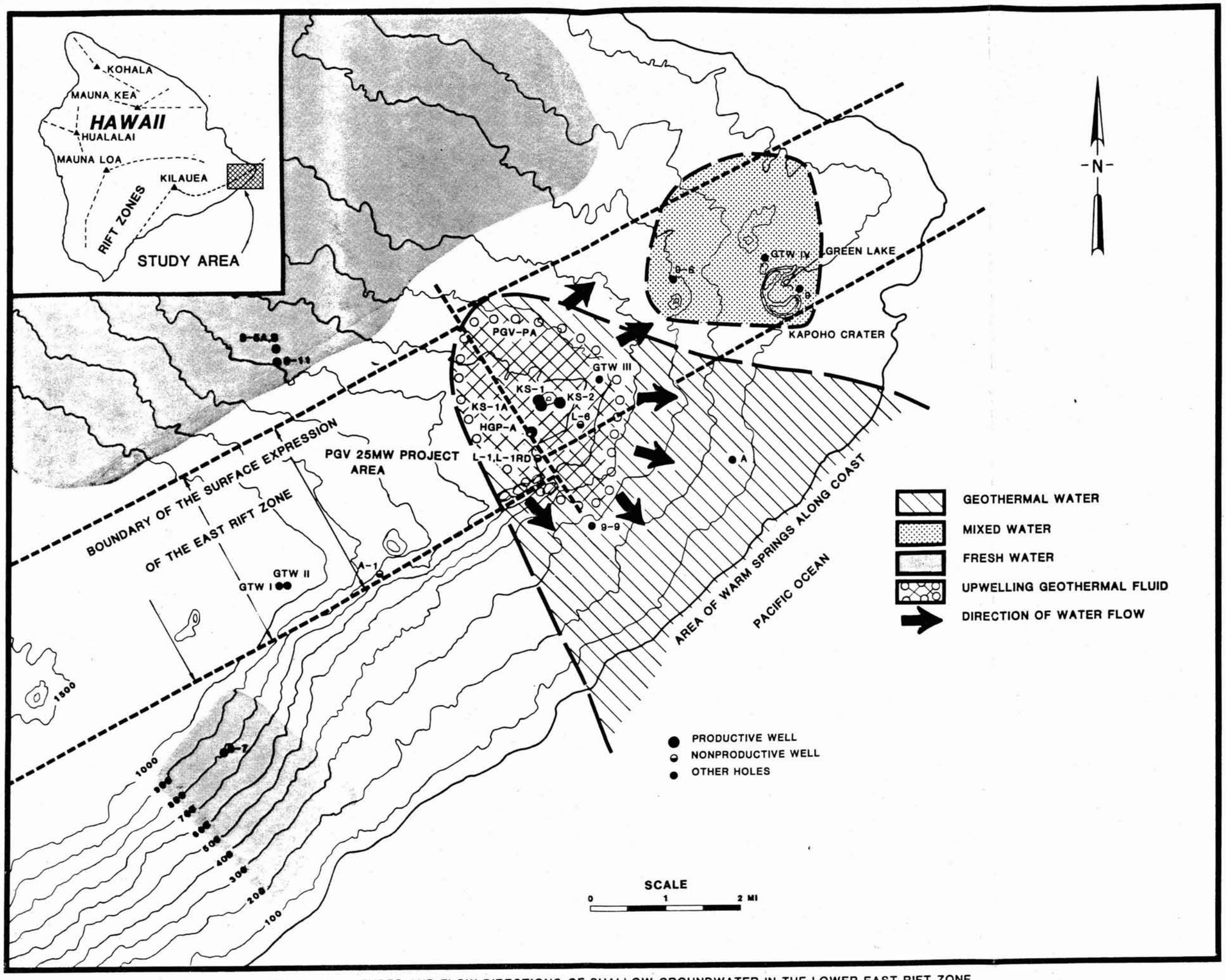


Figure 4-3 TYPES AND FLOW DIRECTIONS OF SHALLOW GROUNDWATER IN THE LOWER EAST RIFT ZONE

Geothermal brines will be discharged to a rock muffler at the test site during well flow testing. The rock muffler will discharge to an unlined sump and the brines will percolate into the most shallow, naturally-degraded groundwater. The small volume of geothermal brine relative to the very large volume of existing degraded groundwater will result in an insignificant impact.

Geothermal reservoir fluids will be precluded from migrating into the overlying groundwater system by sealing the wellbore with casing and cement before drilling into the geothermal reservoir. Casing design requirements, casing materials, and cementing operations and procedures established for geothermal wells will be used on this project (Nicholson, 1984 a, b, c). Drilling permit requirements will be stringently enforced and maintained.

PGV is very interested in obtaining background information pertaining to underlying formations and water quality. Well drilling logs are required by the State of Hawaii during drilling. These logs will include such items as the composition of the "mud", well bore resistivity, drilling rates and speeds. It is anticipated that a compilation and analysis of the data will assist in further characterizing the "groundwater zone." In addition, water samples will be collected at the water table and analyzed to determine chemical and physical characteristics.

OPERATION IMPACTS

The power plant, production wells, brine injection well, and process fluid well operation will not impact surface hydrology. They are cased in steel and cemented throughout the more shallow, unproductive depths.

The power plant and production well operations will have minimal impact on site groundwater. Operation of the geothermal wellfield will include the reinjection of fluids consisting of brine and process fluids. The geothermal brine and process fluids will be returned to the geothermal reservoir from which they came by reinjection below the 4,000-foot level and will not be expected to have an impact on groundwater (Figure 4-1).

The relatively small volume of brine being reinjected into the geothermal reservoir is expected to be reheated quickly by the high temperatures prevailing in the reservoir environment. This process will help to prolong the life of the project by resupplying some of the finite resource. Brine reinjection will have an insignificant impact on leakage of geothermal fluids to the overlying groundwater aquifer(s).

The noncondensable gases, consisting primarily of CO_2 and H_2S, will be combined with the clean blowdown water in an absorption vessel at a pressure of about 200 pounds per square inch (psi). This pressure is required for the H_2S and CO_2 to dissolve into the blowdown water and remain in solution. The calculated compressive force which will exist at the minimum reinjection depth (4,000 feet) is 1,500 psi. These engineered and calculated values show that all but trace amounts of the H_2S and CO_2 gases, once combined and dissolved in the blowdown water, will be in solution with the blowdown water and will remain in solution after being reinjected into the geothermal reservoir. If bubbling of the gases occur within the reservoir, the great depth, overlying impermeable seal, and high iron content of the host rock will help to ensure that no harmful gas (i.e., H_2S) reaches the surface.

Silica precipitation is a potential concern in any system which handles brines containing high concentrations of silica and dissolved salts. There are three main factors which will be used to minimize silica precipitation from the brine in the piping and reservoir of the project site:

- Maintain a relatively high temperature in the brine (>300°F).
- Minimize above-ground residence time (less than one hour).
- Use conservative assumptions for silica concentration (1500 ppm).

Past testing has shown that if temperature is maintained and above-ground residence time is kept to a minimum, even when supersaturating conditions are present, no appreciable silica precipitation occurs. Silica precipitation in the geothermal reservoir should not pose a significant threat due to the very high temperature of the reservoir environment (600°F). However, should silica

precipitation threaten the efficiency of the injection process, alternate injection well siting or above-ground treatment methods would be employed. Aboveground treatment may include dilution, chemical treatment or the utilization of a straining system while maintaining high temperature and short residence time. The subject of silica precipitation kinetics is difficult to assess without extensive field tests. A period of close chemical, physical, and efficiency monitoring will follow initial start-up of the injection process.

Kindle, et al. (1984) have developed methodology to calculate silica precipitation rates (scaling) in above-ground piping. Using these methods to calculate potential silica scaling rates at the Puna site suggests that a maximum build up of about 2 mm/yr could occur. An allowance for this buildup will be provided for and mitigated through appropriate piping design. Should silica scaling progress to the point of significantly restricting piping diameters, pipes would be cleaned periodically by chemical or mechanical means.

The total volume of the process fluids injectate will be approximately 240 gallons per minute. This small volume should be insignificant when combined by reinjection with the high volume of the reservoir fluids. In the event that a malfunction occurs or a determination is made to temporarily stop process fluids reinjection, the process fluids will be rerouted to a surface abatement system.

No fresh water exists beneath, or downgradient of, the project site.

A petition to amend the Underground Injection Control (UIC) line was submitted on June 10, 1986, to the Hawaii State Department of Health (DOH). This amendment proposes to move the UIC line to the north of the LERZ, thereby reclassifying the geothermally affected aquifers beneath, and downgradient of, the site as exempt and non-underground sources of drinking water (USDW). The evidence presented in this EIS is based, in part, on the petition. Underground injection is regulated by Chapter 340E in the Hawaii Revised Statutes; Title 11, Chapter 23 of the DOH Administrative Rules; and by Federal standards contained in the Code of Federal Regulations (CFR; 40 CFR 122 and 146). A

public hearing on the UIC permit will be held once appropriate data have been filed. Processing time needed for permit approval is estimated at 6-9 months. UIC permits are granted for 5 year terms and are continuously enforced and monitored.

The closest source of groundwater currently providing limited use is near Kapoho Crater in the LERZ. The following factors minimize the risk of impacting on the groundwater in the Kapoho area:

- The intended depth of process fluid reinjection and natural abatement of H_2S by the iron (Fe) containing water and substrata
- The indicated groundwater dispersion pattern which directs large amounts of groundwater to the south
- The three-mile distance between the project site and the Kapoho Shaft
- The insignificant impact that reinjection should produce in the site area
- The overlying relatively impermeable seal which restricts upward migration of fluids within the geothermal reservoir
- The relatively small volume of injectate compound to the fluids naturally existing within the reservoir and the "closed system" nature of the extraction and reinjection process

4.3 PROPOSED MITIGATION MEASURES

CONSTRUCTION

Clearing and construction activities will be limited and are not expected to significantly affect surface drainage or erosion. Facility construction is not anticipated to have any adverse effects on the surface hydrology.

No adverse impacts on groundwater quality are expected to occur during drilling. Nevertheless, the geothermal wells will be drilled according to stringent Federal and State regulations designed to prevent discharge of reservoir fluid. The wells will be cased and cemented at multiple depths during drilling operations to prevent produced reservoir fluid from escaping into the groundwater. Geothermal fluids tapped at lower depths will be prevented from migrating upward in the wellbore by carefully controlling the weight of the drilling fluid.

Precautions will be taken during storage and handling of petroleum and chemicals to avoid accidental spills. Any accidental spill will be contained and cleaned up immediately in accordance with site emergency preparedness plans.

OPERATION

No adverse impacts are anticipated on surface or groundwater hydrology during operation of the plant. Accepted procedures will be followed by all maintenance, operating, testing, and management personnel during operation of the geothermal wells. Strict adherence to geothermal development regulations, including State of Hawaii Department of Health and Department of Land and Natural Resources regulations, as well as permit conditions for design and operation of production and injection wells will be maintained. Injection wells will be monitored for operating parameters including pressure, temperature, flow rate, annulus pressure, and chemistry of injectate. This monitoring procedure will provide information on the efficiency of the injection process as well as early warning in the event of a malfunction or change in reservoir parameters.

Geothermal brines and process fluids will be reinjected back into the geothermal reservoir system from which they were extracted. The relatively small volume of injectate, the extreme depth of reinjection (greater than 4,000 feet), the existence of a relatively impermeable seal above the reservoir, and the conservative nature of the reinjection process should result in no negative impact. A petition for movement of the UIC line northward of the LERZ has been

submitted and is being considered by the appropriate regulatory agencies. Strict underground reinjection control regulations and guidelines will be followed during construction and operation of the reinjection program.

DECOMMISSIONING

No impacts on surface or groundwater hydrology from power plant and wellfield decommissioning are expected. Therefore, no mitigation measures will be necessary. Geothermal wells will be abandoned and plugged in accordance with regulatory requirements.

Section 5

METEOROLOGY AND AIR QUALITY

The regional climate, site meteorology and baseline air quality in and around the Puna Geothermal Venture (PGV) project site are described in this section. Air emissions are controlled through a total reinjection concept to minimize release of the hydrogen sulfide (H_2S) and total suspended particulates (TSP) and trace elements from the facility.

The noncondensable gases are retained in an essentially closed loop system and reinjected into the geothermal reservoir. These noncondensable gases are a component of the geothermally produced fluid which separates from the brine and flows through the power plant with the steam. The gases are evacuated from the steam condenser, dissolved into the cooling tower blowdown in a contact absorber, and subsequently reinjected back into the geothermal reservoir with the process fluids. The major source of potential H_2S emissions during normal operation of the PGV Plant is the small fraction that may remain in solution with the steam condensate. This H_2S fraction may be released to the atmosphere at the cooling tower. Total H_2S emissions from the project are anticipated to be at or below 4 lb/hr. This quantity is less than one-half of the proposed State H_2S limit from a geothermal facility of this size. Short duration release of noncondensable gases will occur during well testing, steam stacking, and well venting, as well as from a rupture disk event.

5.1 ENVIRONMENTAL SETTING

REGIONAL CLIMATE

The Hawaiian Islands lie within the trade winds belt. The trade winds (trades) are an outflow of air from the central North Pacific high pressure region located generally to the north and east of the Hawaiian Island chain. The trades flow is generally from the northeast on the island of Hawaii. The Pacific High moves north and south with the sun; in summer, it is at its

northernmost position and brings the heart of the trades directly across the island. The local ruggedness of the terrain results in markedly different wind flow patterns and local climates on the island.

The trades are prevalent 80 to 95 percent of the time in summer (May through September). The trades are more northerly and are prevalent 50 to 80 percent of the time in average monthly values from October through April (Ruffner, 1985). The trades exert a dominant influence on the general climate of the Islands. Clear skies are rare on the east coast of Hawaii, as clouds frequently form on the upslope sides of the mountains. The sky at Hilo is clear from sunrise to sunset an average of 34 days per year, partly cloudy 128 days per year, and cloudy 203 days per year. Showers are frequent, varying from sudden sprinkles to heavy downpours. The trades are generally constant movements of mild marine air and the range of diurnal temperature change is narrow. The days are approximately the same length throughout the year because of the 21 degrees north latitude.

Major storms occur in Hawaii most frequently between October and March, bringing heavy rains that are sometimes accompanied by high winds. The storms may be generated by the passage of cold fronts moving to the east or southeast or by low pressure regions of warm, moist air that produce clouds and torrential rains.

Other smaller local air movements also occur and range in scale from a few to many square kilometers. These movements are most commonly found on lands to the south and west of the mountains in their aerodynamic shadow. The topography is important in determining these local wind occurrences. Some of these air flows occur diurnally and are either upslope/downslope flows or onshore/offshore flows. Both flows are driven by radiative thermal gradients.

The site of the PGV project is about 21 miles from Hilo, Hawaii. Long-term climatic data are available from the National Weather Service (NWS) station at General Lyman Field (Hilo Airport). Table 5-1 shows the climate normals, means, and extremes for the Hilo Airport NWS data which are generally comparable to actual measurements of meteorological conditions at the PGV site.

TABLE 5-1
REGIONAL CLIMATE NORMALS, MEANS, AND EXTREMES
(SOURCE: RUFFNER, 1985)

Month	Temperatures, degrees F: Normal: Daily Max.	Daily Min.	Monthly	Extremes: Record High	Year	Record Low	Year	Normal Degree days Base 65 degrees: Heating	Cooling	Precipitation in inches: Water equivalent: Normal	Monthly Max.	Year	Monthly Min.	Year	Maximum in 24 hrs	Year	Snow, Ice pellets: Monthly Max.	Maximum in 24 hrs	Relative Humidity, pct. (Local time): 02 Hour	08 Hour	14 Hour	20 Hour
(a)				37		37					41		41		41		41	41	34	34	34	34
J	79.5	63.2	71.4	91	1979	64	1980	0	186	9.42	32.24	1979	0.36	1963	9.94	1949	0	0	83	79	66	82
F	79.0	63.2	71.2	92	1968	63	1962	0	176	13.47	45.55	1979	0.83	1963	22.30	1979	0	0	84	79	66	82
M	79.0	63.9	71.5	93	1972	64	1963	0	202	13.55	49.93	1980	0.88	1972	17.05	1980	0	0	86	81	67	83
A	79.7	64.9	72.4	89	1978	66	1949	0	222	13.10	31.94	1963	2.93	1962	11.07	1971	0	0	88	82	69	83
M	81.0	66.1	73.6	94	1966	68	1947	0	267	9.40	25.01	1964	1.18	1945	10.26	1965	0	0	88	80	68	82
J	82.5	67.1	74.8	90	1969	60	1946	0	294	6.13	15.50	1943	2.43	1961	4.21	1978	0	0	87	78	65	81
J	82.8	68.0	75.4	89	1980	62	1970	0	322	8.68	28.59	1982	3.83	1975	7.11	1982	0	0	86	81	68	82
A	83.3	66.4	75.9	93	1960	63	1955	0	338	10.02	26.42	1957	2.06	1971	9.65	1970	0	0	88	81	69	83
S	83.6	68.0	75.8	92	1951	61	1970	0	324	6.63	13.70	1980	1.59	1974	6.69	1981	0	0	87	80	68	83
O	83.0	67.5	75.3	91	1979	62	1980	0	319	10.01	28.10	1961	2.40	1963	8.88	1961	0	0	87	80	69	85
N	80.9	66.3	73.6	88	1978	58	1948	0	258	14.88	27.03	1959	2.33	1963	15.59	1959	0	0	86	81	70	85
D	79.5	64.3	71.9	83	1980	55	1977	0	214	12.86	50.82	1954	0.28	1980	10.50	1946	0	0	85	81	69	84
					MAY		FEB					DEC		DEC		FEB						
TR	81.2	65.9	73.6	94	1966	53	1962	0	3134	128.15	50.82	1954	0.28	1980	22.30	1979	0	0	86	80	68	83

Month	Wind: Mean Speed m.p.h.	Prevail. direct. thru 1963	Fastest mile (b): Speed m.p.h	Direct	Year	Percent of possible sunshine	Mean sky cover, tenths, sunrise to sunset	Mean number of days: Sunrise to Sunset: Clear	Partly Cloudy	Cloudy	Precip. .01 inch or more	Snow, ice pellets 1.0 inch or more	Thunder-storm	Heavy fog, visibil'y 1/4 mile or less	Temperatures, degrees F: Max.: 90 and above	32 and below	Min.: 32 and below	0 and below	Average station pressure, mb
(a)	34	14	13	13		33	37	37	37	37	41	41	38	38	38	38	38	38	11
J	7.4	SW	30	SE	1968	47	6.4	6	12	13	17	0	1	0	(c)	0	0	0	1014.1
F	7.7	SW	26	E	1976	45	6.7	5	10	13	18	0	1	0	(c)	0	0	0	1015.2
M	7.5	SW	29	SE	1972	39	7.6	2	10	19	24	0	2	0	(c)	0	0	0	1016.9
A	7.3	WSW	26	SE	1979	38	8.2	1	8	21	25	0	1	0	0	0	0	0	1016.8
M	7.2	WSW	23	SE	1978	36	7.9	1	10	20	25	0	1	0	(c)	0	0	0	1016.8
J	7.0	WSW	21	E	1968	43	7.5	2	10	18	24	0	(c)	0	(c)	0	0	0	1016.4
J	6.8	WSW	26	SE	1974	42	7.7	1	12	18	27	0	(c)	0	0	0	0	0	1015.8
A	6.7	WSW	25	NW	1972	42	7.5	1	12	18	27	0	(c)	0	(c)	0	0	0	1015.2
S	6.7	WSW	23	SE	1976	43	7.0	3	12	15	23	0	(c)	0	(c)	0	0	0	1014.5
O	6.6	SW	24	SE	1972	39	7.3	3	11	17	24	0	1	0	(c)	0	0	0	1014.7
N	6.7	WSW	22	SE	1975	35	7.2	4	10	16	23	0	1	0	0	0	0	0	1014.7
D	7.2	SW	30	NW	1973	37	6.8	5	11	15	21	0	1	0	(c)	0	0	0	1014.9
					DEC														
TR	7.1	WSW	30	NW	1973	40	7.3	34	128	203	279	0	9	0	1	0	0	0	1015.5

Notes. (a) Length of record, years, through the current year unless otherwise noted, based on January data.
(b) Fastest mile wind data is through 1979.
(c) Less than one half.

NORMALS - Based on record for the 1951-1980 period
MEANS - Length of record in (a) is for complete data years.
EXTREMES - Length of record in (a) may be for other than complete or consecutive data years. Date is the most recent in cases of multiple occurrence.

Temperature

The difference between the normal monthly mean temperature of 75.9°F for the warmest month, August, and 71.2°F for the coolest month, February, illustrates the steadiness of the climate. The difference is a small annual mean variation of 4.7°F. The record high temperature of 94°F was recorded in May 1966, while the record low temperature of 53°F was recorded in February 1962.

Precipitation

Precipitation is a function of elevation above mean sea level (MSL). The average annual rainfall for the 1951 to 1980 base period at Hilo Airport was 128.2 inches. The mean annual rainfall can exceed 200 inches in the mountains. The mean annual rainfall at the PGV project site was estimated to be 120 inches for the 1931 to 1955 base period (Ruffner, 1985).

Nearly 70 percent of the rain for the 1951 to 1980 base period at Hilo Airport occurred during the cooler months (October through April), the Hoo-Ilo season. Temperatures are slightly cooler during the Hoo-Ilo season when the sun is in the south and the trades are less steady and more frequently interrupted by stormy periods. The maximum monthly rainfall was 50.82 inches in December 1954. The minimum monthly rainfall was 0.28 inches in December 1980. The maximum 24-hour rainfall was 22.3 inches in February 1979. No occurrences of snow or sleet have been recorded at lower elevations.

Winds

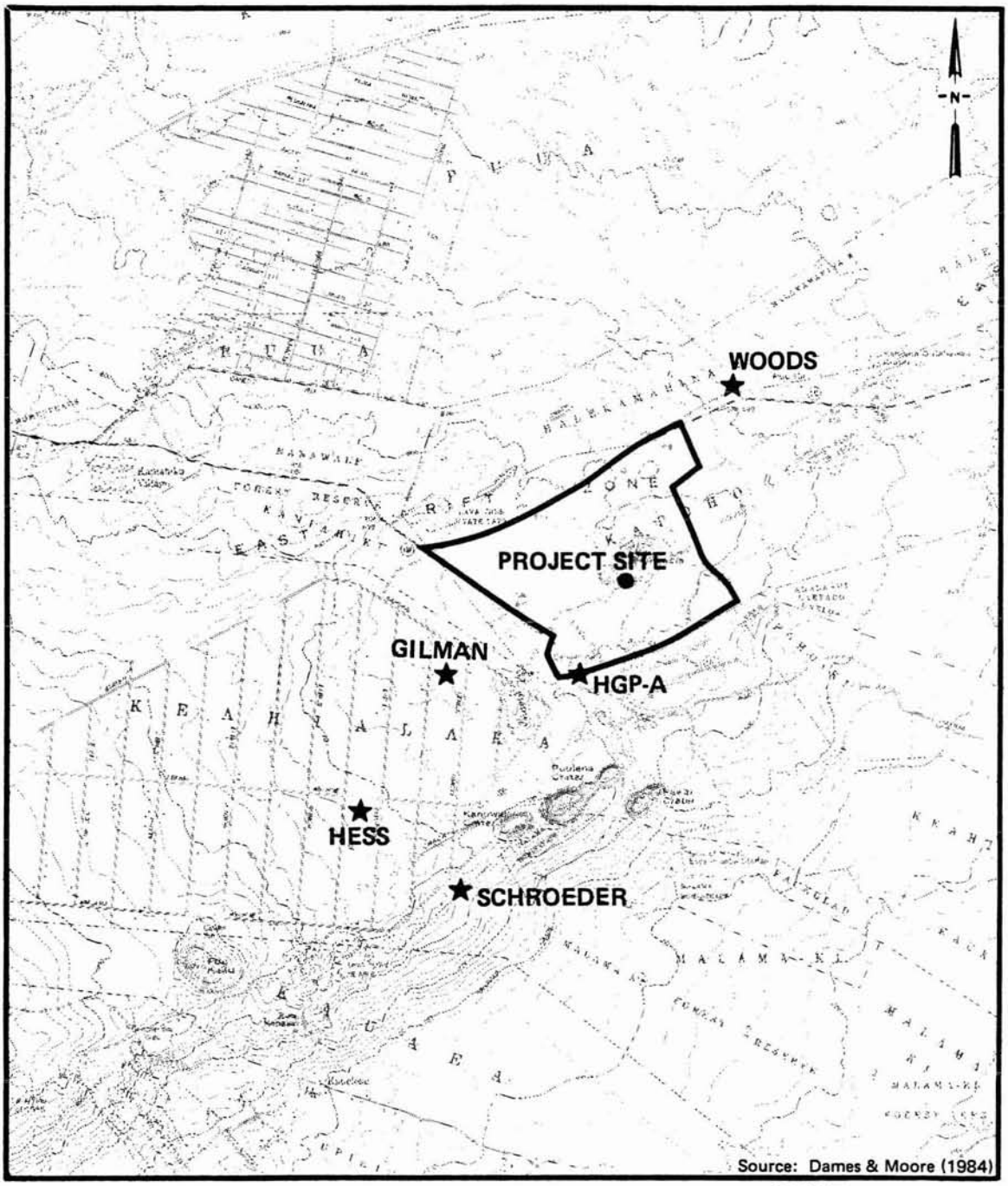
Winds at Hilo average 7.1 mph, with a mean maximum month (February) average of 7.7 mph and a mean minimum month (October) average of 6.6 mph. The annual resultant direction of the winds is from the west-southwest. Monthly directions of winds are from either the west-southwest or southwest. The wind direction at Hilo is about 180 degrees counter to the expected trades flow. This condition is attributed to the special situation at Mauna Loa where the onshore flow is lifted to provide an upslope wind by day while a drainage flow with a counter downslope wind develops at night and in the early morning hours.

The drainage flow predominates (Ramage, 1978). Local terrain features tend to define the wind flows and their influence predominates over the synoptic flow of the trade winds. The wind flows specific to the project site are discussed in the next subsection.

The ability of air in the surface layers to disperse contaminants varies diurnally and seasonally. One measure of this dispersal capability is the mean maximum mixing depth (MMD). MMDs can be estimated with the method of Holzworth (1964) using the daily radiosonde observations and normal maximum surface temperatures. Daily morning and afternoon mixing heights reported at Hilo (Dames & Moore, 1984) indicate that afternoon mixing heights are higher (average 5,420 feet) than mornings (average 4,144 feet) except for February. Summer heights are higher than those in winter. A higher mixing height allows greater dispersion of air pollutants which favors better air quality. Lower pollutant concentrations would be expected in summer than in winter and during daytime than at night.

SITE CLIMATE

PGV has conducted meteorology and air quality monitoring studies in the Puna region since 1981. Observations made at the Woods Site include wind speed and direction, standard deviation of wind direction fluctuation (sigma theta), temperature, relative humidity, precipitation, and insulation. The Woods Site is located about 1.1 miles north of the power plant site, as shown on Figure 5-1. Recent meteorological data from the Woods Site is presented in Table 5-2. Annual wind roses for the period of May 1981 to May 1982 are presented on Figures 5-2, 5-3 and 5-4 for all hours, daytime hours and nighttime hours, respectively (W. Burkhard, 1986). The wind flow is from the north to northeast during the daytime and from the west during the nighttime. The nighttime westerly winds derive from downslope flows. The north-to-northeast daytime winds derive from the trades. The average annual wind speed for all hours is 7.4 mph with daytime and nighttime annual average wind speeds of 8.5 mph and 6.3 mph, respectively. The Woods Site meteorological data, which represent the most complete information for the site, were also summarized for October 1982 to September 1983 (Dames & Moore, 1984). This 1982-1983 data set was used for the air quality impact calculations.



★ – Stations

SCALE
CONTOUR INTERVAL 20 FEET

.5 0 1 MI

1000 0 2000 4000 6000 FT

1 .5 0 1 KM

Figure 5–1 AIR QUALITY MONITORING STATIONS

Table 5-2

WOODS SITE

MONTHLY METEOROLOGICAL DATA SUMMARY

	Temperature, °F			Wind				Precipitation[a]			Relative Humidity
				Prevail	Speed, mph			Inches	In./Day		
Mo/Yr	Avg.	Min.	Max.	Direct.	Avg.	Min.	Max.	Total	Min.	Max.	Percent
Oct 87	74.3	70.0	76.6	NW	4.0	3.2	4.9	4.65	0	2.35	94
Sep 87	76.6	74.3	79.2	NW	5.0	3.1	7.2	4.06	0	2.32	95
Aug 87	75.9	75.4	80.2	NW	5.2	3.8	6.8	2.80	0	0.53	94
Jul 87	73.8	72.9	77.2	NNW	5.3	4.0	6.5	14.99	0.01	7.65	96
Jun 87	73.6	71.6	77.4	N	5.6	4.4	7.8	5.72	0	0.79	95
May 87	73.4	64.8	76.1	NW	6.1	2.5	9.3	6.90	0	1.86	93
Apr 87	69.1	66.9	74.8	WNW	6.0	4.5	10.0	6.32	0	1.65	88
Mar 87	68.4	66.6	74.3	NW	6.4	2.3	10.2	3.53	0	1.43	82
Feb 87	68.2	65.1	73.0	NNW	6.0	3.7	10.6	3.61	0	0.98	89
Jan 87	68.4	65.5	73.9	NW	6.6	3.2	13.6	5.46	0	2.05	93
Dec 86	68.9	65.7	69.4	NNW	5.3	3.2	10.6	3.90	0	0.52	88
Nov 86	72.3	67.6	76.6	N	6.1	4.2	9.3	19.64	0	3.71	89
(b)	71.9	64.8	80.2	NNW	5.7	2.3	13.6	81.58	0	7.65	91

(a) Possible malfunction of rain gage during measurement period. Rain gage sensor cable replaced October 28, 1987.

(b) Average values for 12 months (November 1986 through October 1987).

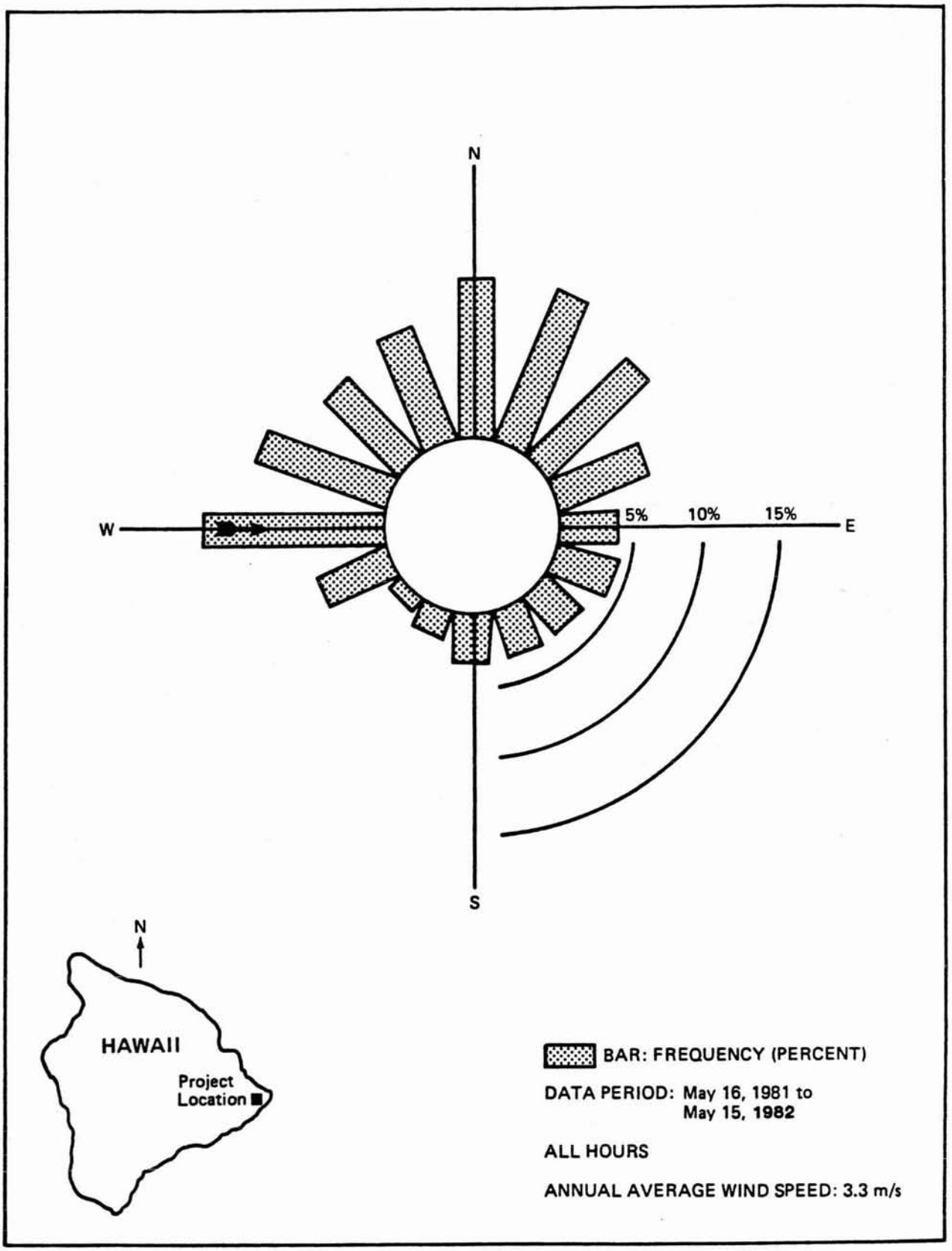


Figure 5–2 ANNUAL WIND ROSE FOR THE WOODS SITE MAY 1981 TO MAY 1982

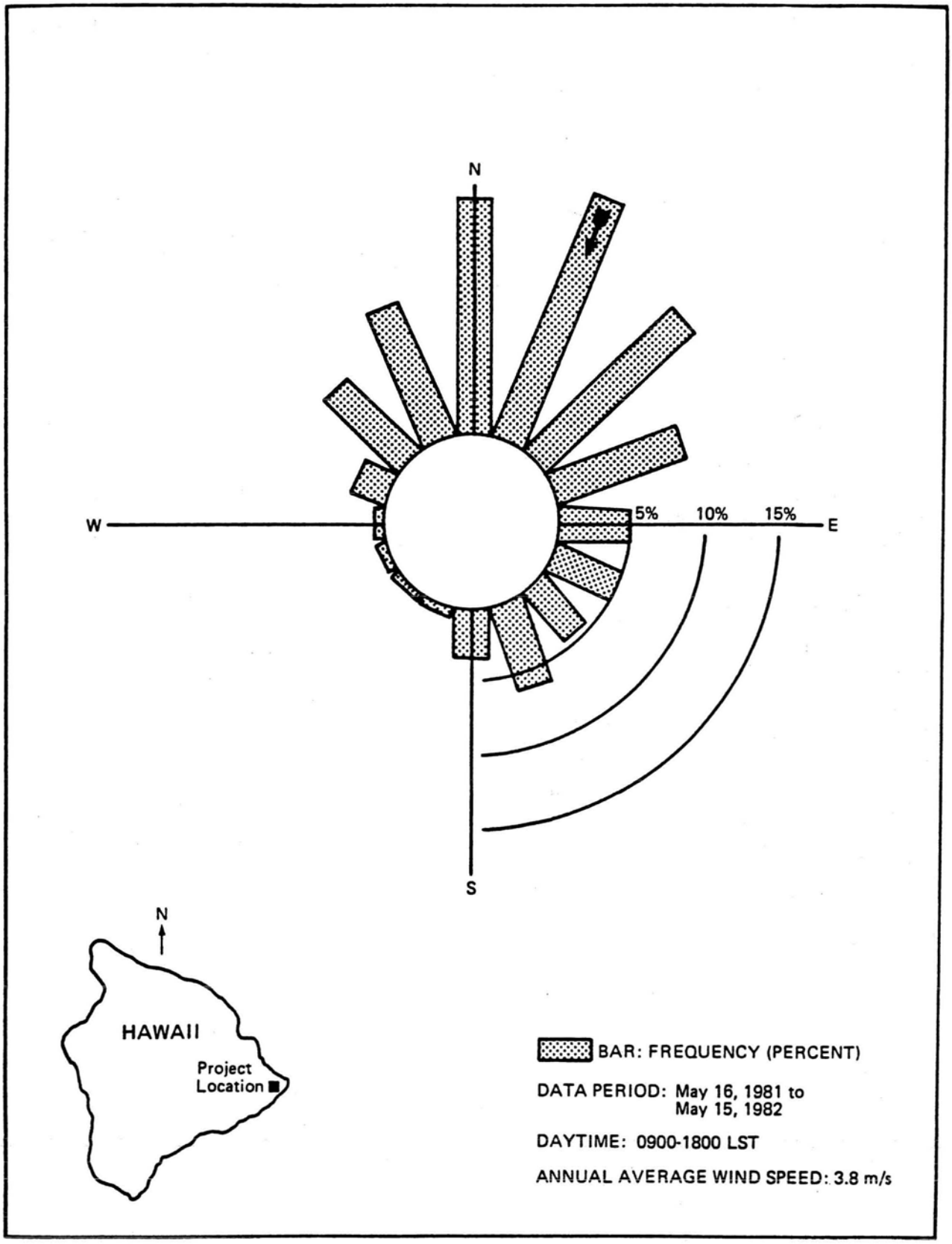


Figure 5–3 ANNUAL DAYTIME WIND ROSE FOR THE WOODS SITE MAY 1981 TO MAY 1982

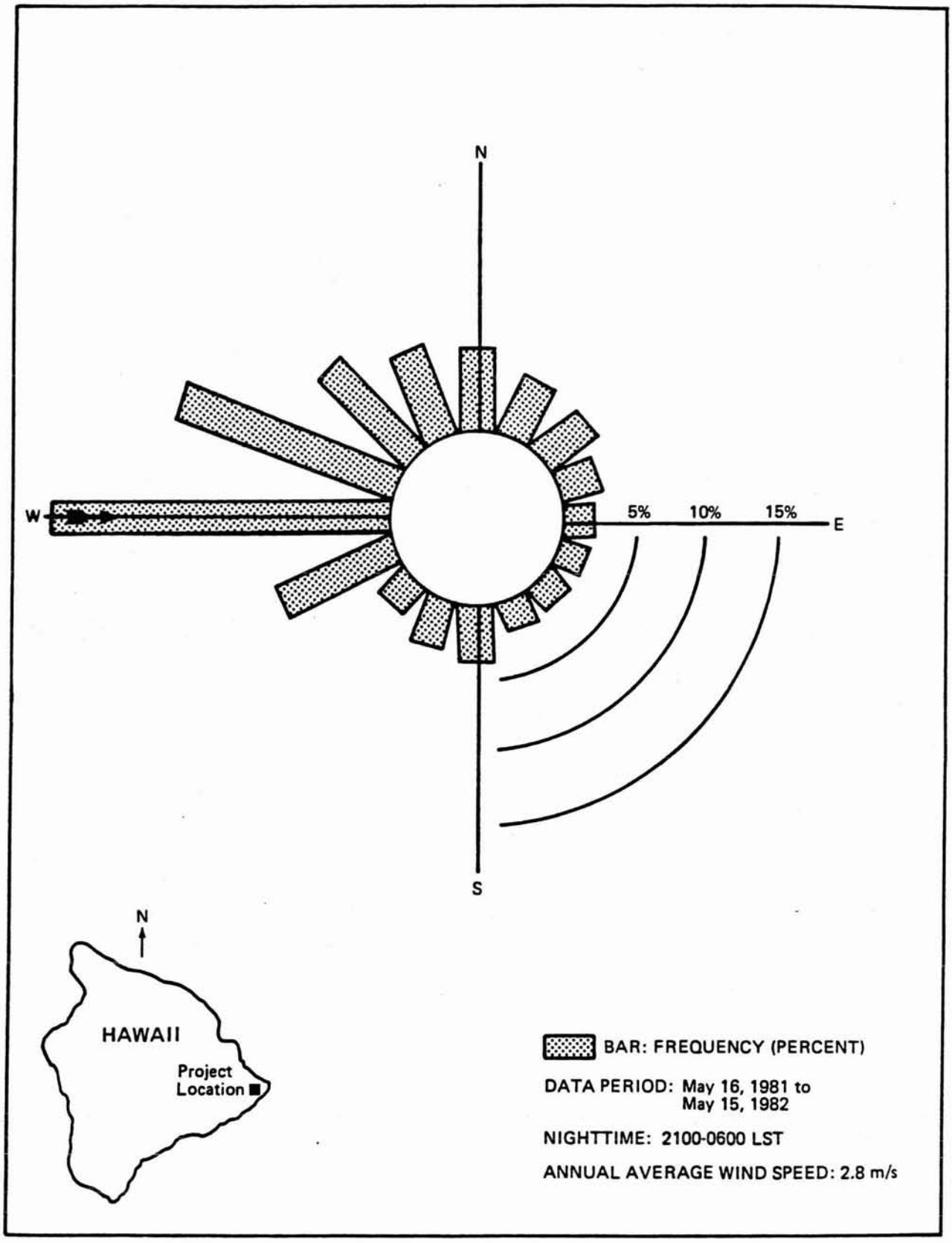


Figure 5-4 ANNUAL NIGHTTIME WIND ROSE FOR THE WOODS SITE MAY 1981 TO MAY 1982

An annual wind rose summary of these data is shown on Figure 5-5. This wind rose is very similar to that for the period of May 1981 to May 1982, shown on Figure 5-2. The average annual wind speed is 6.5 mph, which is similar to the value reported for the period of May 1981 to May 1982. The strongest winds, 8.3 mph, are from the southwest. Daily mid-afternoon winds are strongest (9 mph), and evening hour winds are the lightest (4.5 mph).

Measurements of wind direction variation yield estimates of the atmosphere's dilution capability or stability. Stability, which is a measure of turbulence, is used to estimate diffusion of releases into the air. Stability varies from category A (very unstable), B (unstable), and C (slightly unstable), to D (neutral), E (slightly stable), and F (stable). Atmospheric mixing and dispersion are greatest during unstable conditions, which occur most frequently during daylight hours. Table 5-3 shows the typical annual frequency of each stability category at the site.

Table 5-3

FREQUENCY OF ATMOSPHERIC STABILITY CATEGORIES AT THE WOODS SITE

Category	Percent of Time
A (very unstable)	<2.5
B and C (unstable to slightly unstable)	25.0
D (neutral)	>50.0
E (slightly stable)	20.0
F (stable)	<2.5

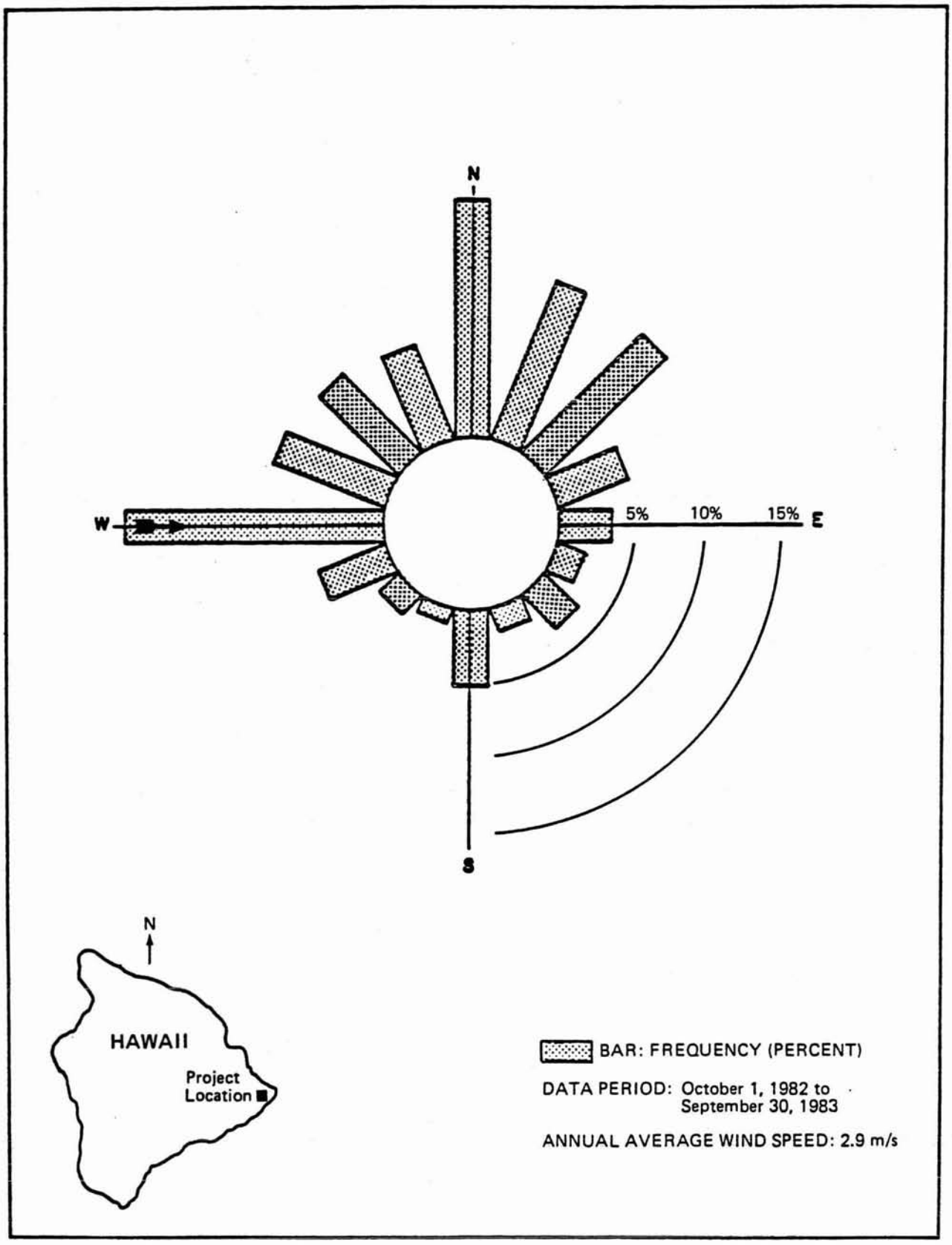


Figure 5–5 ANNUAL WIND ROSE FOR THE WOODS SITE OCTOBER 1982 TO SEPTEMBER 1983

BASELINE AMBIENT AIR QUALITY

PGV and HGP-A monitoring stations include:

- Schroeder Site located about 1.6 miles south southwest of the power plant site. Data collection began in March 1981.

- Hess Site located about 1.6 miles southwest of the power plant site. Data collection began in July 1982.

- Gilman Site located about 0.9 miles west of the power plant site. Data collection began in July 1982.

- Woods Site located about 1.1 miles north-northeast of the power plant site. Data collection began in 1981. Comprehensive meteorological data collection began in April 1982.

NEA, Inc. recorded ambient H_2S concentrations for the Hawaii Department of Planning and Economic Development (Dames & Moore, 1984). Data collected and reported through 1983 for the first three sites and through August 1986 for the Woods Site are shown in Table 5-4. These data indicate that H_2S ambient levels are below 0.010 ppmv (14 ug/m^3) about 98 percent of the time. H_2S levels exceeded 0.020 ppmv (28 ug/m^3) less than 1 percent of the time. The maximum H_2S level reported was 0.048 ppmv (67 ug/m^3) at the Schroeder Site. This site is located southwest of the HGP-A well site. These H_2S ambient levels can be compared with the ambient 1-hour standard of 139 ug/m^3 (0.1 ppmv) proposed by the Hawaii Department of Health (HAR. Chap 11-59).

Particulate matter (PM) has also been monitored using hi-vol samplers at two locations in Puna. The first location is the Bishop Estates Leasehold, about 3 miles southwest of the power plant site; the second is the visitor center of Hawaii Volcanoes National Park about 13.2 miles northwest of the power plant site. Data from the Bishop Estates Leasehold showed that the 14 biweekly samples at each site between December 1982 and March 1983 averaged a 24-hour PM level of 20 ug/m^3 at the leasehold. The highest value at the

Table 5-4

ONE-HOUR AVERAGE HYDROGEN SULFIDE CONCENTRATIONS
IN THE HGP-A WELL AREA (1981-1983)

Site	H_2S Concentration Range (ppmv)	Number of Observations 1981	1982	1983
Schroeder[a]				
	0-0.01	4,464	6,476	NA[b]
	0.011-0.02	233	225	0
	0.021-0.03	25	12	0
	0.031-0.04	2	5	0
	0.041+	2	2	0
Total number of observations		4,726	6,720	NA
Maximum H_2S concentration (ppmv)		0.045	0.048	0.007
Average H_2S concentration (ppmv)		0.0042	0.0044	0.0014
Gilman[c]				
	0-0.01	(d)	3,924	NA
	0.011-0.02	--	4	0
	0.021+	--	0	0
Total number of observations		--	3,928	NA
Maximum H_2S concentration (ppmv)		--	0.016	0.008
Average H_2S concentration (ppmv)		--	0.0030	0.0012
Hess[c]				
	0-0.01	--	3,635	NA
	0.011-0.02	--	90	0
	0.021+	--	0	0
Total number of observations		--	3,725	NA
Maximum H_2S concentration (ppmv)		--	0.014	0.004
Average H_2S concentration (ppmv)		--	0.0035	0.001

Table 5-4 (Cont'd)

Site	H_2S Concentration Range (ppmv)	Number of Observations 1981	1982	1983	1984	1985	1986[f]
Woods[e]	0-0.01	NA	5,633	3,512	NA	NA	NA
	0.011-0.02	NA	0	0	NA	0	NA
	0.021+	0	0	0	0	0	0
Total number of observations		NA	5,633	3,512	NA	NA	NA
Maximum H_2S concentration (ppmv)		0.013	0.007	0.004	0.013	0.009	0.015
Average H_2S concentration (ppmv)		0.0026	0.0019	0.001	0.0016	0.0018	0.0024

(a) Data from May 1981 through September 1983 (missing June 1982 data).
(b) Data not available.
(c) Data from July 1982 through September 1983.
(d) Station not operating during this time.
(e) TPC has been monitoring H_2S at the Woods Site continuously since 1981. Comprehensive data were obtained from April 1982 through August 1986(missing April 1983 data).
(f) Through August 1986 only.
NA = Data not available

Sources: Dames & Moore, 1984; W. Burkhard, 1986.

visitor center was 39 ug/m^3. These PM values can be compared to the State of Hawaii Ambient Air Quality Standard (AAQS) of 150 ug/m^3 for a 24-hour period.

In addition to air quality monitoring, several local residential water catchment systems have been sampled before and after unabated geothermal discharges (venting) to the atmosphere. The analyses of these samples have not indicated a significant impact on catchment water due to geothermal emissions. Lead, arsenic and mercury are of particular concern for health reasons, but concentrations in the samples were below detectable limits or showed no change from baseline concentrations. Therefore, unabated geothermal discharges to the atmosphere are not anticipated to significantly impact catchment water quality. Copies of catchment water analyses are on file with the County.

5.2 ENVIRONMENTAL IMPACTS OF THE PROPOSED ACTION

The air quality impacts of the various phases of the proposed project are evaluated in this subsection. The three phases that are considered include: clearing and construction activities, operation of the geothermal power plant, and decommissioning of the facility.

DISPERSION MODELING

The analyses of air quality impacts were based on recommendations specified in the "Guideline on Air Quality Models" (U.S.EPA, 1986) as required by Hawaii Administrative Rules, Title 11, Chapter 60, Section 17. Air quality impacts were assessed by dispersion modeling techniques using the EPA approved models. These models included ISCST, MPTER and COMPLEX I. ISCST is designed for multiple point sources, area sources and volume sources with relatively flat terrain. The model is also designed to account for aerodynamic downwash effects of stacks and buildings. The model requires hourly meteorological data as input to calculate the highest ground-level concentrations (GLCs) at receptors. The GLCs may be calculated for averaging times ranging from 1 to 24 hours and for the entire year. MPTER is designed for multiple sources with relatively flat terrain and land elevations no higher than the shortest stack modeled. The model calculates highest ground-level concentrations (GLCs) at

receptors for averaging times ranging from 1 to 24 hours and for the entire period of meteorological data. The COMPLEX I model, which is designed for complex (hilly) terrain, is similar to the EPA Valley model, but is more sophisticated. This model requires hourly meteorological data for a year as input to calculate the highest GLC for 1 to 24 hours as well as an annual average GLC.

Meteorological data from the Woods monitoring site were used for the model inputs. The data from February 1982 through January 1983 were reported as 3-hour averages. The data were reported as 1-hour averages for each hour of the day from February 1983 through September 1983. The designated "data year" consisted of the 3-hour data of October 1982 through January 1983 combined with the 1-hour data of February 1983 through September 1983 to give 1 year of data for October 1982 through September 1983. Each hour the 3-hour data was assumed to be representative of the 3 hours. The models used require 24 observations per day to correctly model for short-term (1- to 24-hour) atmospheric diffusion.

IMPACTS OF CLEARING AND CONSTRUCTION ACTIVITIES ON AIR QUALITY

Clearing and construction activities include drilling and testing of the geothermal wells as well as site clearing and construction of the power plant and wellpads.

Well Drilling, Well Venting, Flow Testing and Well Workover

The atmospheric impact of wellfield construction will derive principally from the rotary drilling rig emissions. Only one drilling rig will be on the site at any one time. It is anticipated that nine geothermal wells will be required initially to provide steam and reinjection capacity for the power plant. The first six wells will support the start-up of the first unit. Three additional wells will follow for start-up of the second unit. Drilling time per well is approximately two months. An additional eleven wells may be drilled over the 35-year life of the project.

Drilling fluid (mud) is pumped down through the center of the drill pipe during well drilling and comes back up around the pipe carrying the cuttings produced by the drilling. Mud effectively prevents the discharge of air contaminants from the hole. The estimated emissions for carbon monoxide (CO), hydrocarbons (HC), oxides of nitrogen (NOx), sulfur dioxide (SO_2) and total suspended particulates (TSP) from the drill rig engines during well field construction are listed in Table 5-5. Emissions of H_2S and TSP are listed on Table 5-6 and will be negligible during mud drilling operations.

A well is vented directly to the atmosphere upon completion to clean the well of dirt and debris prior to well testing. Two periods of up to 4 hours each are usually necessary for well venting. Well venting is a one-time activity that occurs when the well is first drilled. H_2S emissions cannot be controlled during well venting and are estimated to be 292.5 lb/hr based on 150,000 lb/hr steam flow and 1950 ppm(w) steam H_2S concentration. H_2S emission rates during well venting are specifically exempted from meeting the proposed State emission limits, provided that the State director of health is informed and the public is notified. TSP emissions are estimated to be 43.1 lb/hr for well venting.

Flow testing consists of separating the liquid and vapor phases, and measuring the flow rate of each phase. A portable chemical injection unit will be brought to each wellpad rock muffler for H_2S abatement. This method of abatement will remove 95 percent of the H_2S in the steam. Testing will average up to 240 hours per well. The duration of testing may be reduced for subsequent wells as experience is gained on the wellfield. Flow testing is usually necessary at completion of drilling and is normally performed only when a well is first completed. Emissions and ground-level impacts of H_2S and TSP during well testing are presented in Table 5-6.

Table 5-5

DRILLING RIG EMISSIONS DURING WELLFIELD CONSTRUCTION[a]

Item	Emission		
	Grams/hour[b]	Kilograms/day[c]	Metric tons/year[d]
CO	188	4.50	1.37
HC	71	1.71	0.52
NO_x	1,030	24.72	7.51
SO_2	65	1.56	0.47
TSP	63	1.50	0.46

(a) Based on EPA document AP-42, Sppl. 14, May 1983, pp. 3.2.7-2,3. These values pertain to oil well drilling rather than geothermal well drilling. However, rigs are generally similar for oil and geothermal well drilling, and these emissions are good approximations of the emissions for the proposed project.

(b) Based on one drilling rig.

(c) Based on a 24-hour day.

(d) Based on a 10-month (304-day) period for Phase I (five wells).

Table 5-6

WELL DRILLING, TESTING AND WORK OVER: ESTIMATED AIR POLLUTANT EMISSIONS AND CORRESPONDING MAXIMUM AMBIENT CONCENTRATIONS

	H_2S			TSP[a]		
	Estimated Emissions Per Well		Maximum Incremental Ground-Level Concentrations	Estimated Emissions Per Well		Maximum Incremental Ground-Level Concentration,
Operation	lb/hr	g/s	ug/m^3 (ppmv)	lb/hr	g/s	(ug/m^3)
Drilling[b]	trace	trace	trace	trace	trace	trace
Flow Testing[c]	14.6	1.84	47(0.034)	43.1	5.43	63
Well Workover[d]	7.0	0.89	26(0.019)	34.5	4.34	50

(a) The emission rates of particulate matter (Y) were estimated from the steam flow rate (X) according to the following equation: $Y = 0.00029 X - 0.42$, where X and Y are in lb/hr (Dames & Moore, 1984)

(b) Emissions of H_2S and TSP from mud drilling are typically below detectable limits.

(c) Impacts are evaluated on a per well basis assuming 150,000 lb/hr stream flow, maximum H_2S content of 1,950 ppm(w), 95 percent H_2S removal by chemical treatment, and no control of TSP emissions.

(d) Impacts are evaluated on a per well basis assuming 150,000 lb/hr stream flow, drill pipe flow restriction of 20 percent, maximum H_2S content of 1,950 ppm(w), 40 percent H_2S removal by water injection, additional 95 percent H_2S removal by chemical treatment, and no control of TSP emissions.

A well will typically require some remedial workover to improve flow rates during its life time. The technique used for well workover is anticipated to be air drilling. Air, instead of mud, is forced down through the center of the drill pipe and comes back up around the pipe carrying cuttings produced by the drilling. The time required for a well workover will normally range up to 120 hours per well. Water injection and chemical treatment will be used to control H_2S emissions during workover operations. Estimated H_2S and TSP emissions and ground-level impacts are presented in Table 5-6 for well workover operations.

MPTER and COMPLEX I were used to model H_2S and TSP emissions from flow testing and well workover operations. Modeling results for flow testing indicate a maximum incremental 1-hour H_2S GLC of 47 ug/m^3 (0.034 ppmv) and a maximum incremental 24-hour TSP GLC of 63 ug/m^3. Well workover modeling indicates a maximum incremental 1-hour H_2S GLC of 26 ug/m^3 (0.019 ppmv) and a maximum incremental 24-hour TSP GLC of 50 ug/m^3. Modeling results indicate that maximum H_2S and TSP GLC locations were generally found approximately 1 km south-southwest of the PGV site. H_2S emissions from geothermal wells during testing and routine maintenance are specifically exempted from meeting the proposed State emission limits. It is important to note that the GLC values were obtained with worst-case assumptions and that the maximum GLC of 26 ug/m^3 (0.018 ppmv) for well workover is below the proposed State increment of 35 ug/m^3 (0.025 ppmv). Flow testing and well workovers will be short in duration, which reduces the likelihood that the highest H_2S GLCs would be attained.

The 1-hour ambient H_2S concentrations for flow testing and well workover, assuming worst case background H_2S concentrations, will not exceed the proposed State H_2S AAQS of 139 ug/m^3. Maximum 24-hour ambient TSP concentrations will not exceed the State AAQS of 150 ug/m^3 for flow testing and well workover. Modeling results indicate that maximum H_2S and TSP GLC locations generally occur 1 km south-southwest of the PGV site.

Clearing and Construction

Clearing and construction activities will impact air quality due to construction equipment emissions, emissions from the general ongoing surface activity, and pipeline cleanout emissions. These activities and the associated

air quality impacts will be temporary. Table 5-7 presents equipment emissions from clearing and grubbing activities. The principal equipment items are listed, together with the estimated contaminant emissions. The schedule is based on an 8-hour day. The total time required for site development including excavation and backfill is estimated to be 5 months.

Power plant construction will include foundations and structures, installation of turbine-generators, electrical switchgear, and support structures. The construction time is estimated to be 12 months and can begin approximately one month after the start of site preparation. Estimates of gaseous engine exhaust emissions from construction equipment used during power plant construction are shown in Table 5-8. These emissions should not lead to any air quality impacts exceeding the standards.

Fugitive dust emissions result from heavy construction activities, including building and road construction, land clearing, blasting, ground excavation, and cut and fill operations. Fugitive dust emission levels vary depending on the specific work in progress and the prevailing weather. Based on work by Cowherd (1974) and EPA reports (AP-42, 1985, p. 11.2.4-1), a fugitive emission factor of 1.2 tons/acre of construction per month of activity was proposed. This emission factor relates to test data from a location with a semi-arid climate and a precipitation-evaporation (PE) index of 50. The PE index (based on Hilo Airport data) for the Puna area with its higher rainfall is 202.

Applying the correction ($f = 1/(202/50)^2$) and allowing for 12 acres of disturbed area and 5 acres of temporary construction area, the corrected fugitive emissions for heavy construction amount to about 2,500 lb/month (1.135 metric tons/month).

Table 5-7

DIESEL EMISSIONS DURING CLEARING AND GRUBBING[a]

Equipment	Pollutant Emissions (grams/hour) CO	HC	NOx	SO_2	TSP
Bulldozer	335	106	2,290	158	75
Front-End Loader	251	85	1,090	83	78
Cranes[b]	376	143	2,060	129	126
Excavator	660	284	2,820	210	184
Total (grams/hour)	1,622.00	618.00	8,260.00	580.00	463.00
Total (kilograms/day)[c]	12.98	4.94	66.08	4.64	3.70
Total (metric Tons/year)[d]	1.43	0.54	7.27	0.51	0.41

(a) Based on EPA document AP-42, September 1985, pp. 3.2.7-2, 3.

(b) Based on two cranes.

(c) Based on an 8-hour day.

(d) Based on a 5-month (110 day) period.

Table 5-8

DIESEL EMISSIONS DURING POWER PLANT CONSTRUCTION [a]

Equipment	Pollutant Emissions (grams/hour) CO	HC	NOx	SO_2	TSP
Bulldozer	335	106	2,290	158	75
Front-End Loader	251	85	1,090	83	78
Cranes[b]	376	143	2,060	129	126
Excavator	660	284	2,820	210	184
Trucks[c]	1,220	396	6,920	412	232
Total (grams/hour)	2,842.00	1,014.00	15,180.00	992.00	695.00
Total (kilograms/day)[d]	22.74	8.11	121.44	7.94	5.56
Total (metric Tons/year)[e]	5.91	2.11	31.57	2.06	1.45

(a) Based on EPA document AP-42, September 1985, pp. 3.2.7-2, 3.

(b) Based on two cranes

(c) Based on two trucks: one transit concrete mix truck and one water truck.

(d) Based on an 8-hour day.

(e) Based on 5-day weeks, 52 weeks/year (260 days/year).

Cox (1981) reported mercury (Hg) concentrations in the soil ranging from 0.015 to 1.25 ppm(w). The corresponding mercury concentration would be less than 1.88×10^{-4} ug/m^3, assuming an upper limit of 150 ug/m^3 for fugitive dust concentrations. This value is well below the ambient level goal of 0.01 ug/m^3 given by Cleland and Kingsbury (1977).

The region's average rainfall is greater than 120 inches per year with at least 75 percent of the days at Hilo experiencing over 0.01 inch of rain. The ground can still be damp and dust-free even on clear days. The climatic conditions favor the control of fugitive dust during construction activities.

Pipeline cleanout is a one-time activity required prior to pipeline use. Emissions from this activity cannot be controlled. TSP emission rates are estimated to be 43.1 lb/hr and H_2S emission rates are estimated to be 292.5 lb/hr. The process normally lasts 1 hour per pipeline and removes foreign debris from the pipeline. The wellfield will contain six pipeline headers and will require six cleanouts totalling approximately 6 hours. Pipeline cleanouts occur prior to completion of the well distribution system and are exempted from meeting the proposed State H_2S emission limits.

IMPACTS OF THE POWER PLANT OPERATION ON AIR QUALITY

Small quantities of pollutants may be emitted from the cooling tower during normal power plant operation and from the rock muffler during steam stacking. Pollutants will also be emitted in the unlikely event of steam release through the rupture disk system. The air quality impacts of the pollutant emissions are analyzed below.

Noncondensable gas emissions from the power plant during normal operations originate from the cooling tower and include CO_2 and H_2S. No measurable quantities of boron, arsenic, or mercury have been detected in the steam condensate by recent source tests of four wells in the area (KS-1, KS-1A, KS-2, and HGP-A). TSP are also emitted. The analysis for the proposed project focused on the ambient concentrations of H_2S and TSP since these two pollutants are the object of existing or proposed regulations. The analysis considered

emissions of these pollutants from the cooling tower and from the steam release facility (rock muffler) during steam stacking. Emissions of these pollutants were also considered for abnormal occurrences including rupture disk event and injection system failure.

ISCST was used to model rock muffler emissions during steam stacking, fugitive emissions during plant operation, and surge pond emissions during injection system failures. Aerodynamic downwash from plant structures was included in modeling rock muffler emissions. The fugitive emissions and pond emissions were modeled as area sources. MPTER and COMPLEX I were used to model the cooling tower and rupture disk emissions.

There are no federal AAQS for H_2S. The Hawaii Department of Health has proposed a 1-hour maximum ambient concentration of 139 ug/m^3 (0.1 ppmv). The State has also proposed a 1-hour H_2S incremental concentration limit of 7 35 ug/m^3 (0.025 ppmv). Table 5-9 presents results of the most recent model calculations of H_2S ground-level concentrations during normal operation and steam stacking. Even assuming worst case background H_2S concentrations, the ambient and incremental H_2S concentrations for normal operation and steam stacking will be less than the proposed State H_2S 1-hour ambient and 1-hour incremental concentration limits. Current modeling results indicate that the highest H_2S GLC was located approximately 0.2 km north of the PGV site for normal operation.

However, the second-highest H_2S GLC for normal operation (8.5 ug/m^3) was located approximately 2.7 km south-southwest of the site. Maximum H_2S GLC locations for steam stacking were located approximately 0.7 km south of the site.

Upset occurrences are events which are expected to occur infrequently during the life of the project. A malfunction or error may result in steam pressure buildup in a pipeline and subsequent release of steam through the rupture disk system. The estimated H_2S emission rate is 292.5 lb/hr for a rupture disk event. Two hours per event is deemed sufficient time for an operator to isolate and/or correct the problem. No H_2S abatement would be in place during these 2 hours.

Table 5-9

H_2S EMISSIONS AND MAXIMUM GROUND-LEVEL CONCENTRATIONS FOR NORMAL PLANT OPERATION AND STEAM STACKING

Operation	Emissions lb/hr	Emissions g/s	Incremental Maximum 1-Hour GLC ug/m^3	Incremental Maximum 1-Hour GLC (ppmv)	Proposed State 1-Hour Incremental Limitations ug/m^3	Proposed State 1-Hour Incremental Limitations (ppmv)	Proposed State 1-Hour Maximum AAQS ug/m^3	Proposed State 1-Hour Maximum AAQS (ppmv)
Production	4.0	0.50	10.9	0.008	35	(0.025)	139	(0.10)
Steam Stacking [a]	21.3	2.66	18.2	0.013	NA		NA	

(a) Based on a maximum total steam flow rate of 540,000 lb/hr, 1,950 ppm(w) maximum H_2S content, and an assumed value of 98 percent of H_2S control by the rock muffler system.

The failure of a brine injection well or both brine injection pumps would result in the brine being routed to a surge pond. The pond is capable of handling approximately 48 hours of produced brine. The estimated H_2S emission rate is 1.0 lb/hr from the pond during an injection system failure. The production wells will be shut in if the injection system is expected to be unavailable for a longer period.

Emissions of H_2S during rupture disk events and injection system failures are exempted from the proposed State H_2S limitations.

TSP emissions and 24-hour maximum GLCs are shown in Table 5-10. This table also shows the State of Hawaii's 24-hour TSP AAQS value of 150 ug/m^3. Based on current modeling results, the maximum TSP GLC locations were approximately 1.7 km southwest of the PGV site for normal operations, 0.7 km south of the site for steam stacking, 1 km southwest of the site for a rupture disk event, and 1 km south-southwest of the site for an injection failure. The plant meets the strict Hawaii AAQS in all cases for TSP since background TSP concentrations are about 20 to 40 ug/m^3 and modeling results indicate the maximum ambient TSP concentration that could occur for steam stacking would be less than 88 ug/m^3.

The impact of the cooling tower drift on ambient concentrations of trace elements was estimated based on the trace element content of the steam condensate. Results are presented in Table 5-11 for trace elements for which an ambient level goal was reported by Cleland and Kingsbury (1977). The predicted maximum concentrations of arsenic, boron, magnesium, and mercury at the cooling tower are significantly less than the corresponding ambient level goals of Cleland and Kingsbury (1977). No significant air quality impacts are expected to occur due to trace element emissions from the cooling tower drift.

Table 5-10

TSP EMISSIONS AND MAXIMUM GROUND-LEVEL CONCENTRATIONS
FOR NORMAL AND UPSET OPERATING CONDITIONS

Item	Emissions lb/hr	Emissions g/s	Incremental Maximum 24-hour GLC ug/m^3	24-hour Hawaii AAQS ug/m^3
Production[a]	0.010	$1.3x10^{-3}$	0.02	150
Steam stacking[b]	156	20	48.0	150
Well rupture[b][c] disk event	43	5.4	0.6	150
Injection failure[d]	5.4	0.68	1.5	150

(a) Based on a drift loss rate of 0.005%, 1,200 ppm(w) of solid particles in steam and 5 cycles of concentration in the cooling tower.

(b) The emission rate of particulate matter (Y) was estimated from the steam flow rate (X) according to the following equation: $Y = 0.00029 X - 0.42$, where X and Y are in lb/hr (Dames & Moore, 1984).

(c) Based on maximum steam flow rate for one well of 150,000 lb/hr.

(d) TSP will remain in brine if brine injection system fails. Brine is routed to a surge pond.

Table 5-11

ESTIMATED MAXIMUM CONCENTRATIONS OF TRACE ELEMENTS IN THE COOLING TOWER DRIFT

Element	Maximum Concentration in Cooling Tower Drift[a] ug/m^3	Ambient Level Goal[b] ug/m^3
Arsenic	0.0039	0.005
Boron	0.1930	7.400
Magnesium	0.0386	12.000
Manganese	0.0010	12.000
Mercury	< 0.0001	0.010

(a) Based on a drift loss rate of 0.005% of cooling water circulation rate, 5 cycles of concentration in the cooling tower, and cooling tower water concentrations of 0.05 mg/liter arsenic, 2.52 mg/liter boron, 0.50 mg/liter magnesium, 0.01 mg/liter manganese, and 0.00008 mg/liter mercury.

(b) Source: Cleland and Kingsbury, 1977.

Air quality impacts of radon-222 were also assessed. The measured concentrations of radon-222 in the geothermal steam ranged from 749 to 3010 pCi/liter of condensate. Based upon the maximum concentration (3010 pCi/l of condensate), a total cooling tower air flow of approximately 11,300,000 pounds per hour, and 540,000 pounds of steam per hour (for 30 MW) the radon concentration in the cooling tower plume is 0.17 pCi/liter of air. When the radon is dispersed in the air the ground-level concentration will be even less. The maximum radon-222 ground-level concentration for steam stacking is approximately 0.003 pCi/liter of air. Residential exposures to less than 4 picocuries per liter of air (pCi/l) are not significant according to EPA guidelines. No activities or operations associated with PGV project would result in radon ground-level concentrations approaching 4 pCi/l of air.

IMPACTS OF FACILITY DECOMMISSIONING ON AIR QUALITY

The work required for decommissioning and restoration of the site is similar to that needed for the site development and plant construction phases. The extent of the work will be limited to a shorter period of time and air quality impacts will be equal to or less than those impacts described in the subsection on clearing and construction activities.

5.3 PROPOSED MITIGATION MEASURES

CONSTRUCTION IMPACTS

Well drilling operations will be designed and managed to control leakage of the geothermal fluid. H_2S emissions will be negligible during drilling operations since a mud drilling technique will be used. H_2S emissions during flow testing will be abated by chemical injection. Planned well venting and pipeline cleanout operations will be scheduled for daylight hours and the public will be notified. Atmospheric conditions will be considered in scheduling these operations. Well venting will occur once per well and pipeline cleanout will occur once per wellpad.

Rotary drilling rig engine exhaust will be controlled by regular maintenance to prevent undue discharges. Air contaminants during clearing and construction will be emitted from the diesel engine exhaust of the construction equipment. Regular maintenance of the engines will prevent undue exhaust discharges. Fugitive emissions in the form of dust from heavy equipment construction activities will vary daily depending on the equipment activity and the weather. Fugitive dust emissions do not occur during rains, or when the earth is damp. The region is quite rainy with over 0.01 inch of rain per day on at least 75 percent of the days at Hilo. The exposed soil in working areas will be sprinkled during dry periods to control dust. Open-bodied trucks transporting dry materials will be covered. The temporary occurrences of fugitive dust during construction will be insignificant.

POWER PLANT OPERATION IMPACTS

The principal atmosphere contaminants emitted during normal plant operation are H_2S released at the cooling tower and trace elements present in the cooling tower drift. H_2S is also emitted from the rock muffler during steam stacking.

Emissions of H_2S will be controlled by the plant process equipment. Geothermal steam from the wells will be sent to a separator for brine removal and piped to the turbine generator. Turbine exhausts will flow to the condenser where the steam will be condensed.

The power plant design will incorporate multiple safeguards to protect public health, safety, and the environment against unexpected impacts. Non-condensable gases will be separated, dissolved in the blowdown and reinjected into the reservoir as a liquid during normal plant operation. A backup primary H_2S abatement system will be installed to control H_2S emissions when the process fluids injection system is unavailable. The backup system will be a burner/scrubber which incinerates H_2S to form SO_2. The SO_2 will be contacted in a scrubber with caustic to form sodium sulfite and bisulfite. The H_2S emissions from the backup system will be no higher than emissions during injection abatement. The liquid effluent from the scrubber is routed to the process fluids injection well.

Cooling tower drift will be controlled by demisters with a 0.005 percent release efficiency based on the circulating water flow rate. The drift water droplets, which contain dissolved solids and noncondensable gases in the same low concentrations as the circulating water, will be released from the two cooling towers. This small amount of drift will have no adverse environmental effects.

All normal discharges will meet the concentration limits prescribed by OSHA standards to protect employees as well as State and Federal AAQS to protect the public.

The H_2S abatement systems apply to normal operating conditions and procedures. Uncontrolled release of geothermal fluids containing up to 1,950 ppm(w) of H_2S may occur during a rupture disk event. Steam flow will be diverted into a rock muffler and H_2S control equipment activated. It is estimated to take two hours to isolate a rupture disk event.

FACILITY DECOMMISSIONING IMPACTS

Emissions from intermittent engine exhaust of heavy equipment will be controlled by efficient engine tune-up and maintenance procedures. Particulate matter from fugitive dust sources will be controlled by sprinkling surfaces as necessary. Some of this dust will be controlled naturally since the site is in an area of high rainfall. The decommissioning activities will last only a few months and are not expected to have lasting impacts on the physical environment.

METEOROLOGICAL AND AIR QUALITY MONITORING

The meteorological and air quality monitoring system will be kept in continuous operation to ensure that all design and environmental criteria are met. Meteorological monitoring will be conducted at two sites, H_2S monitoring will be conducted at four sites, and Radon-222 monitoring will be conducted at one site as shown on Figure 5-1. Monitoring will be continuous and measurements will be reported as 1-hour average values.

Meteorological monitoring will be conducted at the Woods Site and at the proposed plant site. Meteorological monitoring at the Woods Site includes wind speed, wind direction, wind direction fluctuation (sigma theta), temperature, relative humidity, rainfall, and solar radiation. Meteorological monitoring at the proposed plant site includes wind speed, wind direction, temperature, relative humidity, and rainfall.

Continuous ambient measurements of H_2S will be conducted at four sites: Woods, Schroeder, Gilman, and the HGP-A fenceline site. Continuous ambient measurements of Radon-222 will be conducted at the Schroeder Site.

In addition, periodic sampling and analysis of water catchment systems will be conducted.

Section 6

NOISE

Existing ambient noise levels in and around the Puna Geothermal Venture (PGV) project site are discussed in this section. Predicted noise levels for project construction, operation and decommissioning phases are presented. Noise will be controlled by the use of effective mufflers and silencers, acoustic insulation on selected piping and valves, quiet fans, motors, and baffles for the cooling tower, enclosures for the turbine generator sets, plant layouts designed to shield residents from significant noise sources, and schedules that restrict loud construction or maintenance operations to daylight hours.

6.1 ENVIRONMENTAL SETTING

EXISTING SITE CONDITIONS

The area around the Puna Geothermal Venture (PGV) project site is a mixture of light to dense vegetation, consisting of papaya orchards, woodlands, other natural vegetation, and barren lava. Included in the PGV site are two volcanic puu (hills), Puu Honuaula and an unnamed puu, which rise about 150 feet above the surrounding land. Each Puu will have the effect of muffling the noise associated with the PGV facility. The site is exposed to the normal northwest trade winds, which blow nine months out of the year and frequently exceed 12 mph (Burgess, 1980) with gusts up to 20 mph. Several residential subdivisions abut the PGV facility. These residential subdivisions include Lanipuna Gardens (89 lots) to the southwest and Pohoiki-Bay Estates (14 lots), Kapoho Estates (10 lots), and Leilani Estates (2,266 lots) to the southeast. Residences in Lanipuna Gardens, Pohoiki-Bay Estates and Kapoho Estates will be most affected by the various noises at the site since they are closest to the plant site.

NOISE ORDINANCE

Currently, no known noise ordinance with numerical limits is applicable to the site. The County of Hawaii Planning Department has developed Geothermal Noise Level Guidelines from a study of noise in the Puna District (Darby-Ebisu and Associates, Inc., 1981). The study was based on the U.S. Environmental Protection Agency noise criteria and may be applied to this project as the basis for use permit conditions. These guidelines consider 55 dBA during daytime (7:00 a.m. to 7:00 p.m.) and 45 dBA during nighttime (7:00 p.m. to 7:00 a.m.) as satisfactory sound levels for residential areas.

The allowable noise limit for impact noise (noise of short duration, typically less than 1 second, and caused by impacts of pipes, tools, etc.) is 10 dBA higher than the overall daytime and nighttime limits. The allowable noise levels may not be exceeded more than 10 percent of the time in any 20-minute period.

Typical noise level measurements are conducted with sound level meters which measure sound pressure levels (Lp) in eight octave bands ranging in frequency from 63 Hz to 8000 Hz. The definition of Lp is 20 times the logarithm to the base 10 of the ratio of the pressure of the sound (in micropascal) to the reference pressure (20 micropascal). The units of Lp are decibels (dB). The A-weighting scale was developed for noise considerations to represent the human response to sound encompassing a range of frequencies. The human ear does not respond uniformly to sounds in all frequencies, being more sensitive to sounds in the middle or speech frequencies (1000 Hz to 4000 Hz) than to sounds in the low or high frequencies (E. T. Chanlett, 1973). The low and high frequency components of a sound are negatively weighted with respect to the middle frequency components to obtain a single value representing the human response to sound containing a wide range of frequencies. The resultant Lp is "A-weighted" and has the units of dBA. The A-weighted Lp is also called the noise level.

EXISTING SITE NOISE LEVELS

An environmental noise survey was conducted at the PGV site to determine current ambient (background) noise levels during weekday periods. Two battery-powered noise monitoring systems were used to measure the ambient noise levels for 24-hour periods at four locations. The survey was conducted during early September 1986.

Monitoring Locations

Four noise monitoring locations, chosen in conjunction with Bill Burkhard of Alpha Micro Systems, were used in this survey and are shown on Figure 6-1. Two of the locations were on residential properties located south and southwest at approximately 0.5 and 1 mile, respectively, from the PGV proposed power plant site. These residence locations are:

- Brees Station, lot 54, Lanipuna Gardens, Lauone
- Gilman Station, residence, Kaupili Street

The two remaining monitoring locations were on the PGV site, one at Wellpad A and the other at Wellpad B.

Noise Descriptors

The noise descriptors (L_{90} and L_{eq}) used for the purpose of the survey are defined below:

- L_{90} is the A-weighted sound pressure level that is exceeded 90 percent of the time. The specified time period is 1 hour. The L_{90} is commonly used as an indicator of the ambient (background) noise level.
- L_{eq} is the equivalent sound level, which is the energy average of the A-weighted sound pressure level. The specified time period is 1 hour. The energy average is the constant noise level for an hour that has the same average energy as the actual fluctuating level during the hour.

Summary of Results

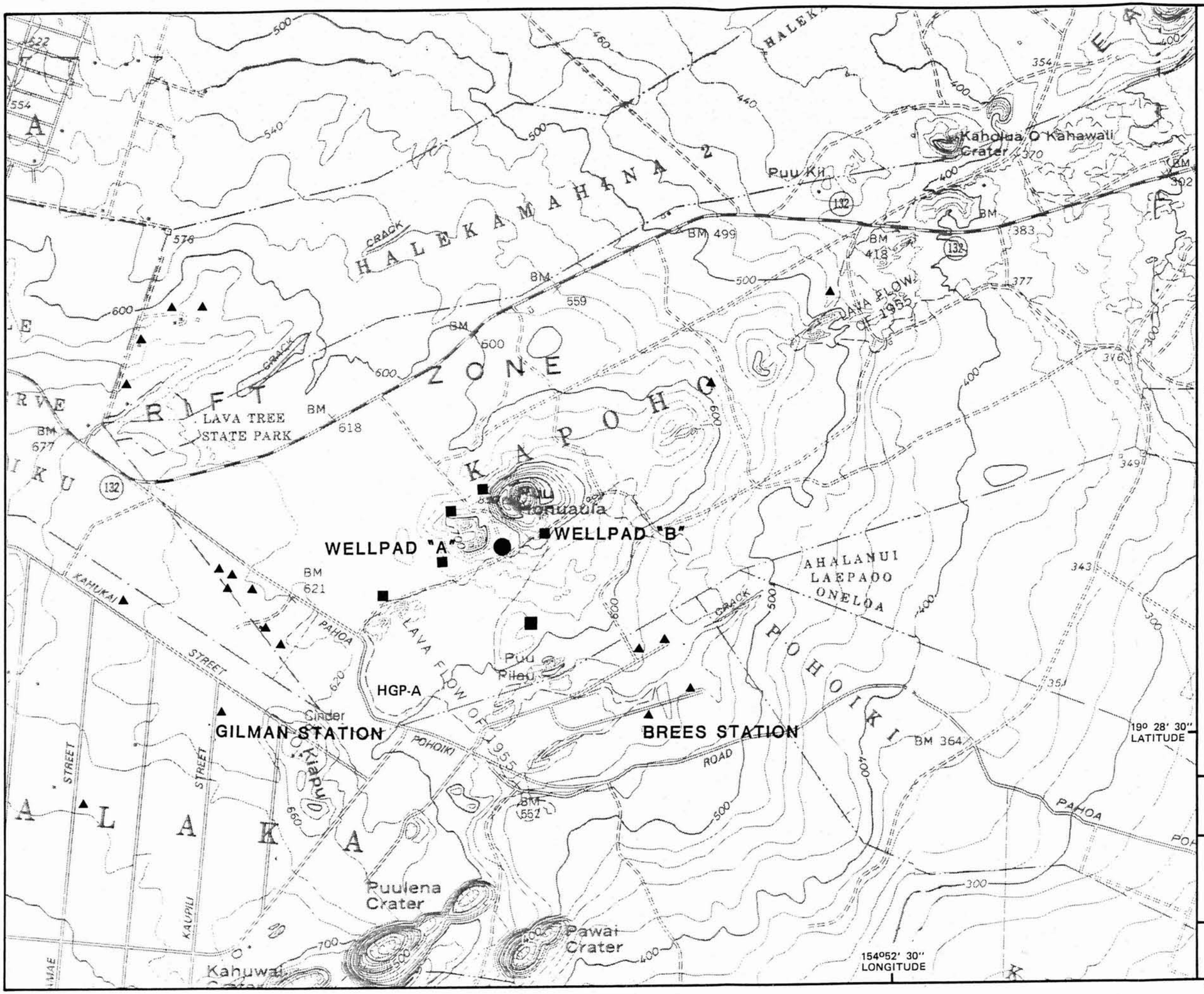
The background hourly L_{90} and L_{eq} A-weighted sound pressure levels measured during a nominal 24-hour period at each monitoring location are tabulated in Table 6-1. Background noise levels during the survey period on and around the PGV site range from L_{eq} values of 34.2 dBA (7 p.m. at Brees Station) to 53.2 dBA (5 a.m. at Gilman Station), which exceeds the County noise guidelines of 45 dBA. The relatively high background noise was due to moderate wind (6 mph or greater) and moderate to heavy rain conditions (winds at Hilo average 7.2 mph year-round and annual rainfall is approximately 120 inches). Early morning rains were observed each day during this survey period and localized rain showers of short duration were observed during daytime hours. The range of hourly L_{90} and average L_{eq} sound levels measured at off-site residence locations and on-site locations during day and nighttime periods are presented in Table 6-2.

The prevalent noise during daytime hours is from distant and local traffic, wind, birds, and insects. Noise from operation of the HGP-A Facility, located on Pahoa-Pohoiki Road, just south of the PGV site, was barely audible at the PGV on-site monitoring locations (Wellpads A and B) and inaudible at the two off-site resident monitoring stations.

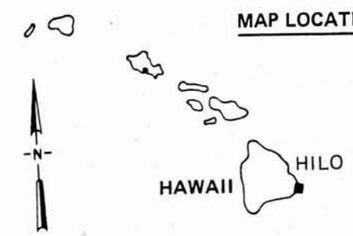
6.2 ENVIRONMENTAL IMPACTS OF THE PROPOSED ACTION

Development of the geothermal facility will occur in stages. Characteristic noise sources for each stage can be identified, the duration of which will vary from one activity to another. Expected noise sources are listed below and described in the subsections that follow:

- Construction noise, which is associated with earthmoving and construction equipment used during road-building, wellpad construction, pipeline laying, and building erection. This noise will occur primarily during the initial stages of the project.



MAP LOCATION



LEGEND:

- POWER PLANT
- PRODUCTION WELLPAD
- HOMES NEAR PROJECT SITE

SCALE
CONTOUR INTERVAL 20 FEET

0 — ½ MILE
0 — 1000 — 2000 FEET
0 — 1 KM

SOURCE: U.S.G.S., 1980, 1981a, 1981b

PUNA
GEOTHERMAL VENTURE PROJECT
HONOLULU, HAWAII

Figure 6-1
NOISE MONITORING LOCATIONS

FLUOR DANIEL	JOB. NO.	DRAWING NO.	REV.

Table 6-1

TWENTY-FOUR-HOUR NOISE MONITORING DATA

Monitoring Locations	On-Site Wellpad A		Off-Site Resident Brees Station		On-Site Wellpad B		Off-Site Resident Gilman Station	
Time Period	23 Hours		24 Hours		24 Hours		24 Hours	
Hour Ending	L90 (dBA)	Leq (dBA)	L90 (dBA)	Leq (dBA)	L90 (dBA)	Leq (dBA)	L90 (dBA)	Leq (dBA)
12:00	-	-	-	-	-	-	-	-
13:00	-	-	36	51.0	-	-	-	-
14:00	36	38.1	35	43.9	-	-	36	50.3
15:00	36	37.7	35	43.3	33	54.4	34	43.7
16:00	36	37.5	34	42.7	34	36.8	32	46.7
17:00	37	45.5	35	44.6	34	42.8	32	50.2
18:00	38	50.0	33	43.2	36	40.2	35	39.1
19:00	36	40.5	32	34.2	38	40.8	40	47.7
20:00	36	39.8	35	36.7	41	43.5	50	53.1
21:00	36	38.7	34	36.6	36	39.8	39	42.8
22:00	37	37.8	34	35.8	35	38.6	39	41.2
23:00	36	41.1	34	36.0	38	41.6	38	41.8
0:00	36	41.9	35	36.8	38	41.0	41	44.5
1:00	37	40.1	35	37.0	39	41.9	42	44.3
2:00	37	40.6	35	37.2	37	39.7	44	49.4
3:00	37	40.8	35	37.0	39	40.8	48	50.1
4:00	36	41.8	35	37.1	39	41.2	49	51.9
5:00	38	40.8	34	36.6	41	42.6	51	53.2
6:00	39	42.7	34	36.4	38	41.7	50	52.2
7:00	37	44.2	35	46.4	36	46.8	43	47.3
8:00	35	39.0	34	43.9	39	42.5	35	43.8
9:00	35	63.4	34	46.8	37	44.3	36	43.3
10:00	36	41.1	34	48.4	33	42.8	35	42.9
11:00	36	64.0	37	43.6	32	35.0	34	43.8
12:00	36	36.7	40	46.3	33	40.0	33	43.0
13:00	-	-	-	-	33	37.2	34	51.2
14:00	-	-	-	-	34	39.3	-	-

Table 6-2

RANGE OF HOURLY L_{90} AND AVERAGE L_{eq} SOUND LEVELS

	On-Site Locations		Off-Site Locations	
	Wellpad A (dBA)	Wellpad B (dBA)	Brees Station (dBA)	Gilman Station (dBA)
	Hourly L_{90} Sound Levels			
Daytime	35 to 38	32 to 39	32 to 40	32 to 40
Nighttime	36 to 39	35 to 41	34 to 35	38 to 51
	Hourly Average L_{eq} [a] Sound Levels			
Daytime	37 to 64	35 to 54	34 to 51	39 to 51
Nighttime	38 to 44	39 to 47	36 to 46	41 to 53

(a) Rounded to the nearest dB level.

- Traffic noise, which is generated by trucks and automobiles travelling to and from the project. Traffic noise will occur throughout the life of the project.

- Drilling operations, flow testing and well venting noise, which occurs primarily at the beginning of the project, but also sporadically throughout the life of the project.

- Plant operation noise, which is generated by the turbine/generators, cooling tower, water pumps, steam piping, and steam vents located in the power plant facility. Plant operation noise will occur throughout the life of the project.

CONSTRUCTION NOISE

Power equipment used during the initial stages of the project to construct roads, wellpads, the power plant, and pipelines will generate noise. Construction will normally be restricted to weekday (Monday through Friday) daylight hours. The primary noise is expected to be caused by large diesel-powered equipment.

Backup alarms, which are standard safety features of construction equipment, produce a loud beeping sound that, by law, must be clearly audible above the construction noise. The distinctive beeping noise will often be audible with noise levels ranging up to 100 dBA at 50 feet. The use of these alarms will be intermittent.

Power plant construction noise will be caused by heavy equipment, such as bulldozers, excavators, cranes, loaders, compressors and portable generators. Neither pile driving nor blasting is planned. The octave band noise levels and equipment usage factors used in predicting construction equipment noise (in dBAs) are shown in Table 6-3. Construction noise will range from 89 dBA (light construction) to 94 dBA (heavy construction; all equipment in use) at 50 feet. Noise from impacts of pipes and other miscellaneous short-duration noise sources will produce higher short-term noise levels.

Table 6-3

EQUIPMENT NOISE LEVELS USED TO PREDICT
PLANT CONSTRUCTION NOISE

(Sound Pressure Levels in dB at 50 feet)

Equipment	No.	Equip. Usage Factor	Octave Band Center Frequency (Hz) 63	125	250	500	1000	2000	4000	8000	dBA
Bulldozer	1	0.27	103	97	88	83	84	79	74	69	89
Front-End Loader	1	0.10	100	94	85	80	81	76	71	66	86
Excavator	1	0.10	99	93	84	79	80	75	70	65	85
Mid-Size Crane	1	0.16	92	86	77	72	73	68	63	58	78
Small Crane	1	0.16	89	83	74	69	70	65	60	55	75
Air Compressor	1	0.85	100	94	85	80	81	76	71	66	86
Portable Generator	1	0.85	99	93	84	79	80	75	70	65	85
Motor Vehicles	4	0.10	91	85	76	71	72	67	62	57	77
Welding Machines	6	0.70	90	84	75	70	71	66	61	56	76

Sources: F. M. Kessler, et al., 1978; J. D. Barnes, L. N. Miller and E. W. Wood, 1977; U.S. EPA, 1971.

Figure 6-2 graphically plots the predicted noise levels due to construction of the project. Homes that are near the project site are identified on the figure. Concentric circles are used to identify noise levels at 5 dBA intervals to 55 dBA (the daytime noise guideline limit). All noise predictions include the effects of atmospheric attenuation only; other attenuations, such as foliage, barriers, and terrain effects are not considered. Foliage and terrain attenuation during favorable atmospheric conditions can cause significantly lower noise than is predicted in this section. Figure 6-2 shows the location of areas (shaded) where noise levels are most likely to be lower due to terrain barrier effects. Power plant construction noise is predicted to be 55 dBA approximately 2100 feet (0.4 mile) from the power plant. This distance corresponds with the closest resident locations, which are in the Lanipuna Gardens subdivision.

Wellpad and road construction will require heavy equipment similar to that used for power plant construction. Noise levels will usually be less than those during construction of the power plant, since fewer pieces of heavy equipment will be required. This noise will occur throughout the project area. Preparation of drill sites may require several weeks of work, typically not continuous, so that the total elapsed time may be several months. Wellpads A and B are already completed. Up to four additional wellpads (C, D, E and F) are currently anticipated over the life of the project.

Traffic Noise

Seventy vehicle round trips per day (California Energy Commission, 1981) are expected for a typical (110 MW) geothermal steam field and power plant development project during construction and well drilling based on the transportation study for the Geysers Geothermal Resource Area. The PGV facility is approximately one-fourth the size of the Geysers facility. The traffic associated with construction of the PGV plant will probably be 35 vehicle round trips per day.

Noise levels for the access road traffic were estimated using the federal highway noise prediction model (U.S. Federal Highway Administration, 1977). It was assumed that the average speed of the traffic was 30 to 40 mph and that the vehicles were traveling up a grade. The hourly average traffic noise (L_{eq}) was calculated to be between 30 and 40 dBA at a distance of 200 feet from the roadway, using worst case assumptions.

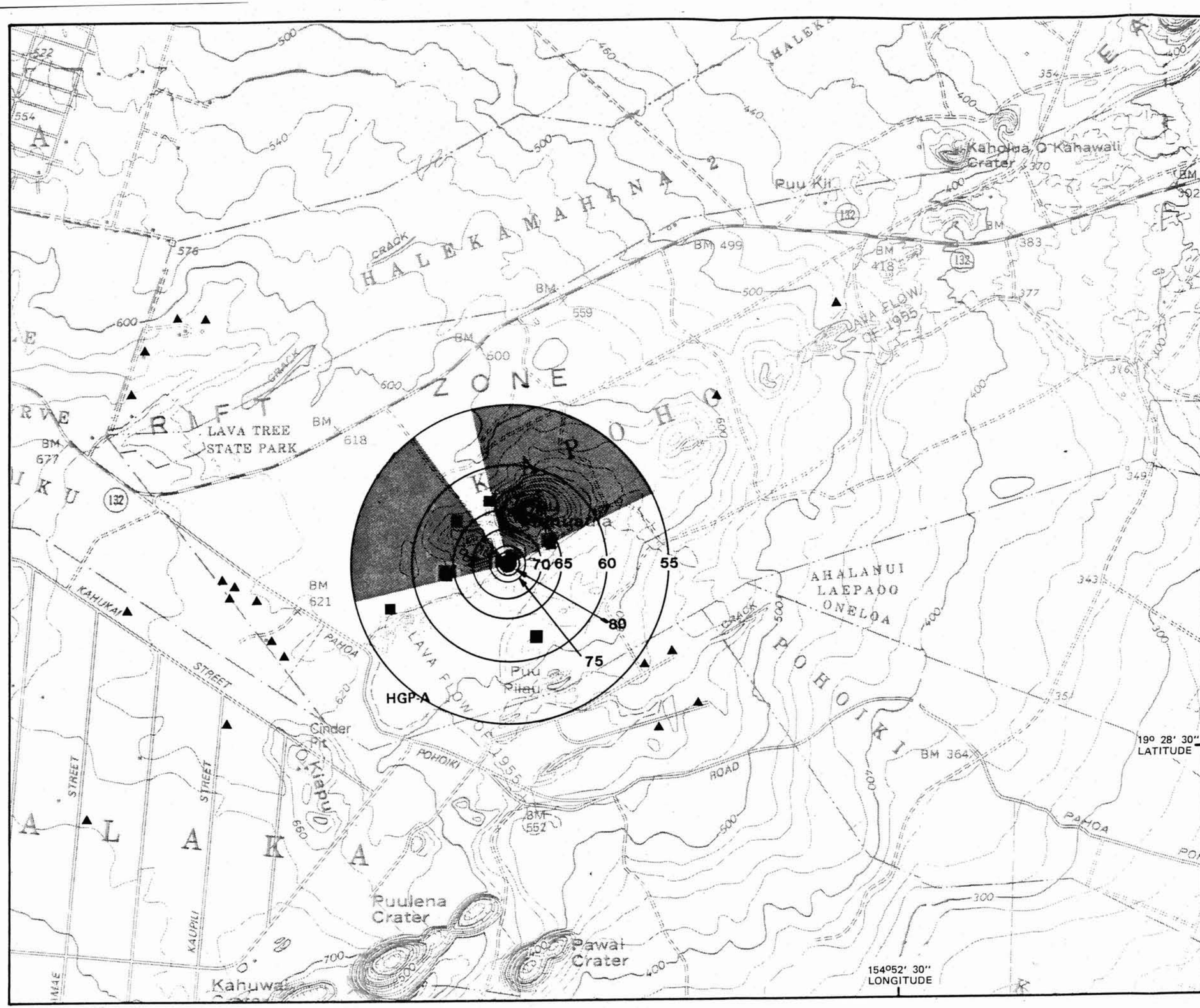
Well Drilling and Well Workover Operation Noise

Noise generated during well drilling will be minimal. The primary noise sources will be the mud circulation equipment, generators and engines, all of which are located on the drilling rig and are acoustically insulated. The initial drilling phase may last up to two months for each well.

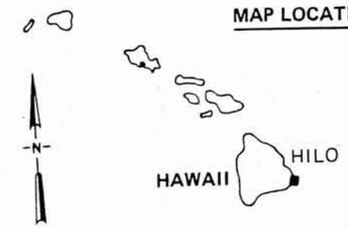
Drilling noise predictions were based on noise measurements made near a specially quieted Barnwell drill rig at Puna, Hawaii, and on pipe impact noise measured at the Geysers Geothermal Resource area in California. The octave band noise levels used to predict well drilling noise are listed in Table 6-4. Well drilling noise levels range from 64 to 75 dBA at 50 feet. Maximum pipe impact noise is 93 dBA at 50 feet. Such noise would be of very short duration.

Figures 6-3 through 6-8 show the predicted continuous noise level contours for well drilling at Wellpads A, B, C, D, E, and F, respectively. The contours were developed assuming that pipe impact noise occurs 10 percent of the time.

Predicted well drilling noise levels range from 46 to 50 dBA at Kapoho and Pohoiki-Bay Estate residences due to drilling at Wellpad E. Well drilling noise levels from the other wellpads should not exceed 45 dBA at these resident locations. Predicted levels at Lanipuna Gardens range from 46 to 51 dBA due to drilling at the Wellpad F and from 45 to 48 dBA due to drilling at Wellpad B. Well drilling noise levels from other wellpads should not exceed 45 dBA at Lanipuna Gardens. Noise levels due



MAP LOCATION



LEGEND:

- ● POWER PLANT
- ■ PRODUCTION WELLPAD
- ▲ HOMES NEAR PROJECT SITE

NOISE LEVELS ARE IN dBA

SHADED AREA IS WHERE NOISE LEVELS COULD BE LOWER DUE TO TERRAIN BARRIER EFFECTS

SCALE
CONTOUR INTERVAL 20 FEET

0 — ½ MILE
0 — 1000 — 2000 FEET
0 — 1KM

SOURCE: U.S.G.S., 1980, 1981a, 1981b

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Figure 6-2
PREDICTED NOISE LEVEL CONTOURS FOR PLANT CONSTRUCTION AND DECOMMISSIONING

FLUOR DANIEL	JOB. NO.	DRAWING NO.	REV.

Table 6-4

NOISE LEVELS USED TO PREDICT
WELL DRILLING NOISE
(Sound Pressure Levels in dB at 50 Feet)

	Octave Band Center Frequency (Hz)								
Item	63	125	250	500	1,000	2,000	4,000	8,000	dBA
Steady noise of specially quieted Barnwell drill rig, no steam venting noise [a]	76	76	77	73	70	63	60	52	75
Maximum pipe impact noise [c][d]	-[b]	-[b]	79	88	90	88	76	-[b]	93
Steady noise from one diesel generator[a]	56	52	57	58	60	59	53	46	64

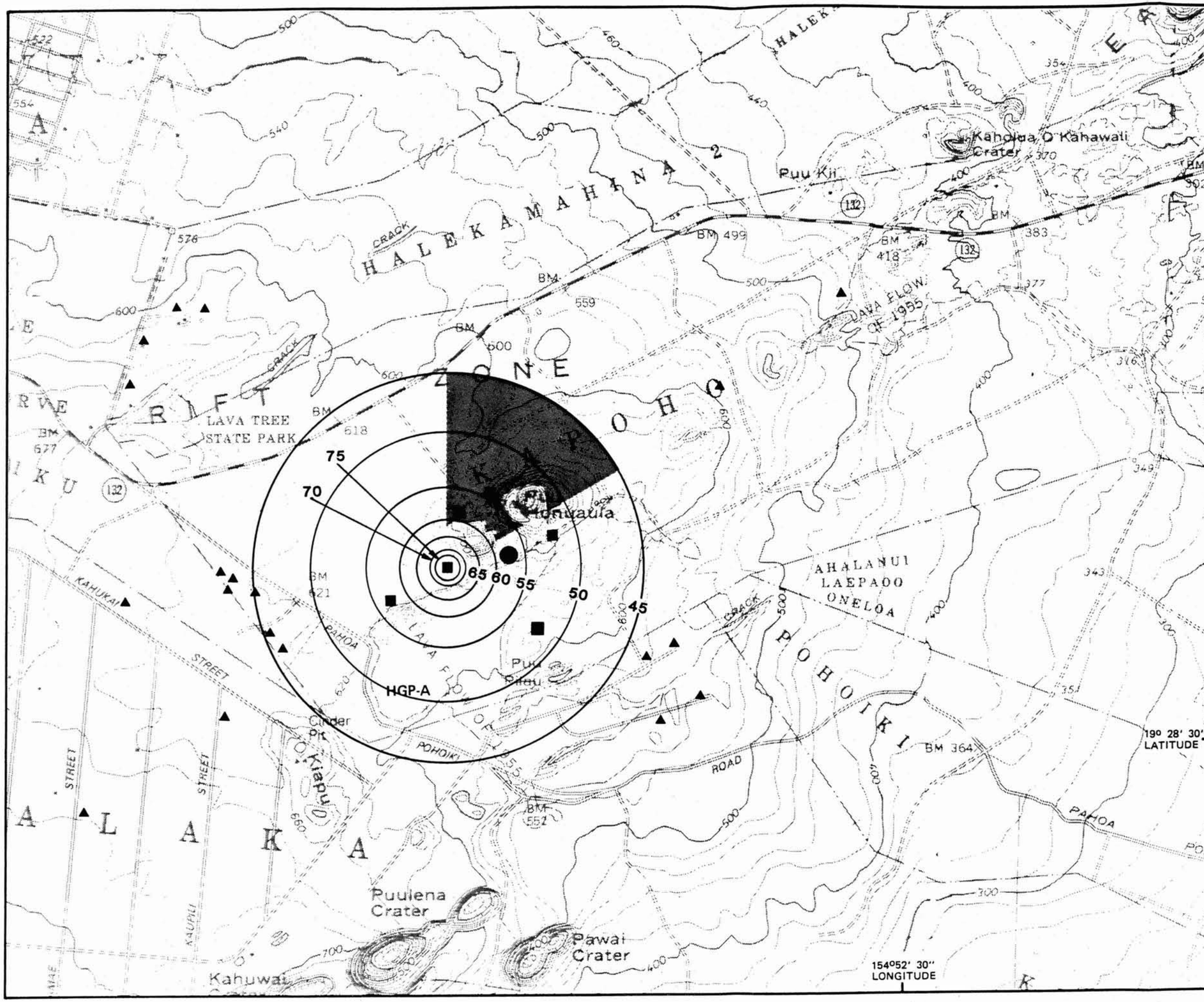
(a) Darby-Ebisu, 1982.
(b) Noise levels at this frequency would not contribute significantly.
(c) Consultants in Engineering Acoustics, 1981.
(d) Maximum pipe impact noise is assumed to occur during 10% of total drilling time (i.e., the equipment usage factor for pipe impacts is 0.10).

to drilling at any of the wellpads should not exceed 45 dBA at Leilani Estate resident locations, the largest subdivision in the immediate vicinity of the project. Noise levels at Lava Tree State Park will not exceed 45 dBA during drilling at any of the wellpads.

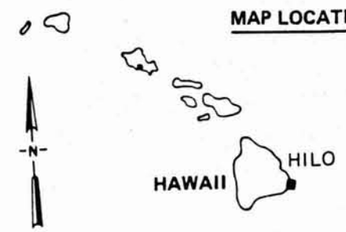
Remedial well workover, which may occur approximately 5 years after the initial well drilling, will use air as the circulating medium instead of mud. The noise from drilling with air is expected to be higher due to the air compressors and the discharge of air and rock cuttings. The noise of escaping steam is added to the air compressor noise when steam is encountered during air drilling. A muffling system will be utilized to reduce steam venting noise to a level 10 dBA above that of the air compressors. It may be possible to further reduce routine steam venting noise levels to that of the air compressors and attempts will be made to do so wherever feasible. Well workovers may last up to 5 days.

Well workover noise predictions were based on noise measurements made near a specially quieted Barnwell drill rig at Puna, Hawaii, and on pipe impact and air compressor noise measured at the Geysers Geothermal Resource area in California. The octave band noise levels used to predict well workover noise are listed in Table 6-5. Well workover noise levels range from 75 to 85 dBA at 50 feet, assuming that at least one air compressor operates continuously during well workover activities.

Figures 6-9 through 6-14 show the predicted steady noise levels for well workover at Wellpads A, B, C, D, E, and F, respectively. Air drilling, used only for well workover, is usually needed in five year intervals and lasts up to five days. The contours were developed assuming that pipe impact noise occurs 10 percent of the time.



MAP LOCATION



LEGEND:

- ● POWER PLANT
- ■ PRODUCTION WELLPAD
- ▲ HOMES NEAR PROJECT SITE

NOISE LEVELS ARE IN dBA

SHADED AREA IS WHERE NOISE LEVELS COULD BE LOWER DUE TO TERRAIN BARRIER EFFECTS

SCALE
CONTOUR INTERVAL 20 FEET

0 — ½ MILE
0 — 1000 — 2000 FEET
0 — 1 KM

SOURCE: U.S.G.S., 1980, 1981a, 1981b

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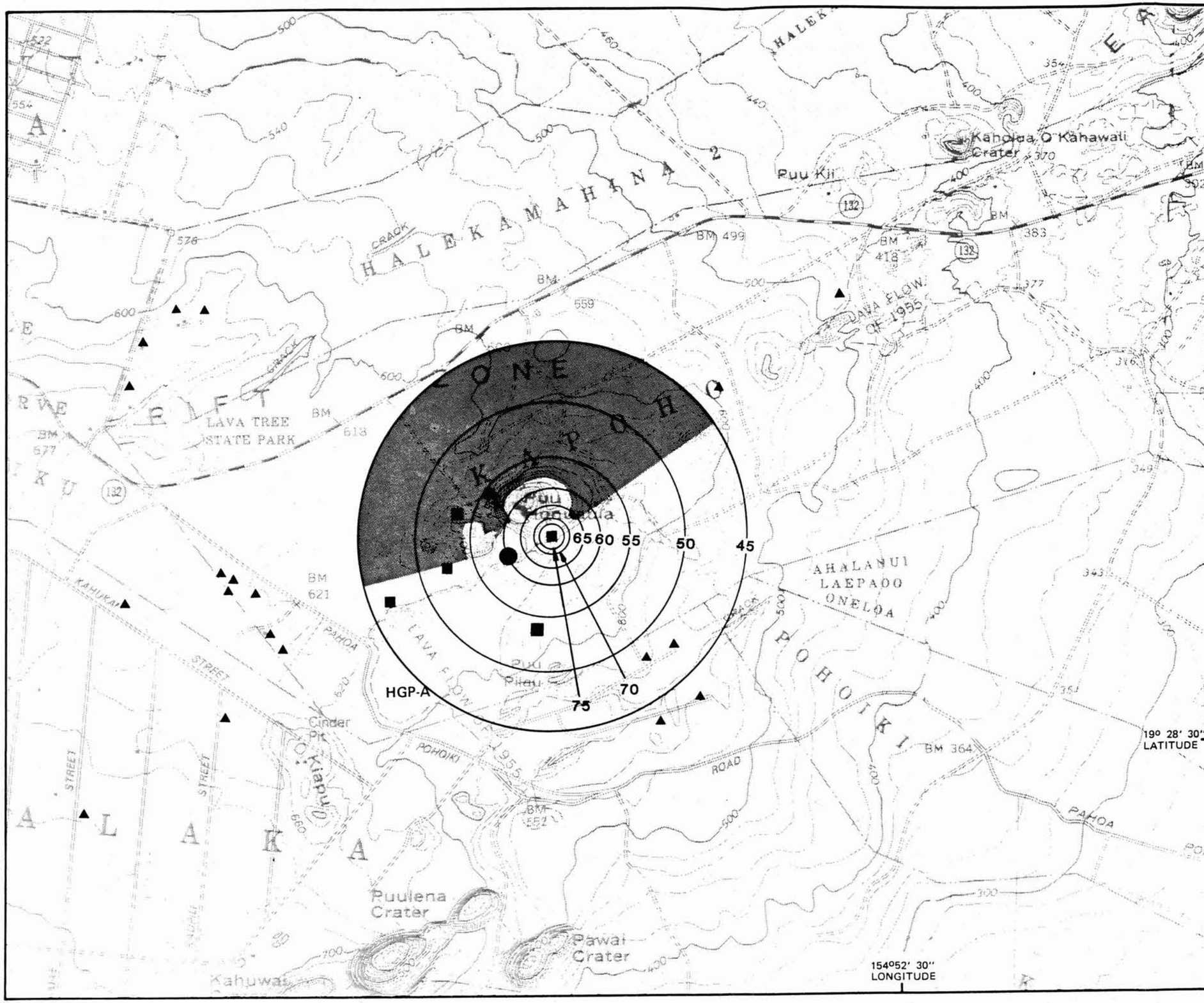
Figure 6-3
PREDICTED CONTOURS OF WELL DRILLING NOISE AT WELLPAD "A"

FLUOR DANIEL	JOB. NO.	DRAWING NO.	REV.



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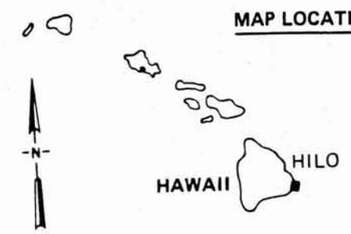

LEGEND:

- ● POWER PLANT
- ■ PRODUCTION WELLPAD
- ▲ HOMES NEAR PROJECT SITE

NOISE LEVELS ARE IN dBA

SHADED AREA IS WHERE NOISE LEVELS COULD BE LOWER DUE TO TERRAIN BARRIER EFFECTS

SCALE
CONTOUR INTERVAL 20 FEET

0 — ½ MILE
0 — 1000 — 2000 FEET
0 — 1KM

SOURCE: U.S.G.S., 1980, 1981a, 1981b

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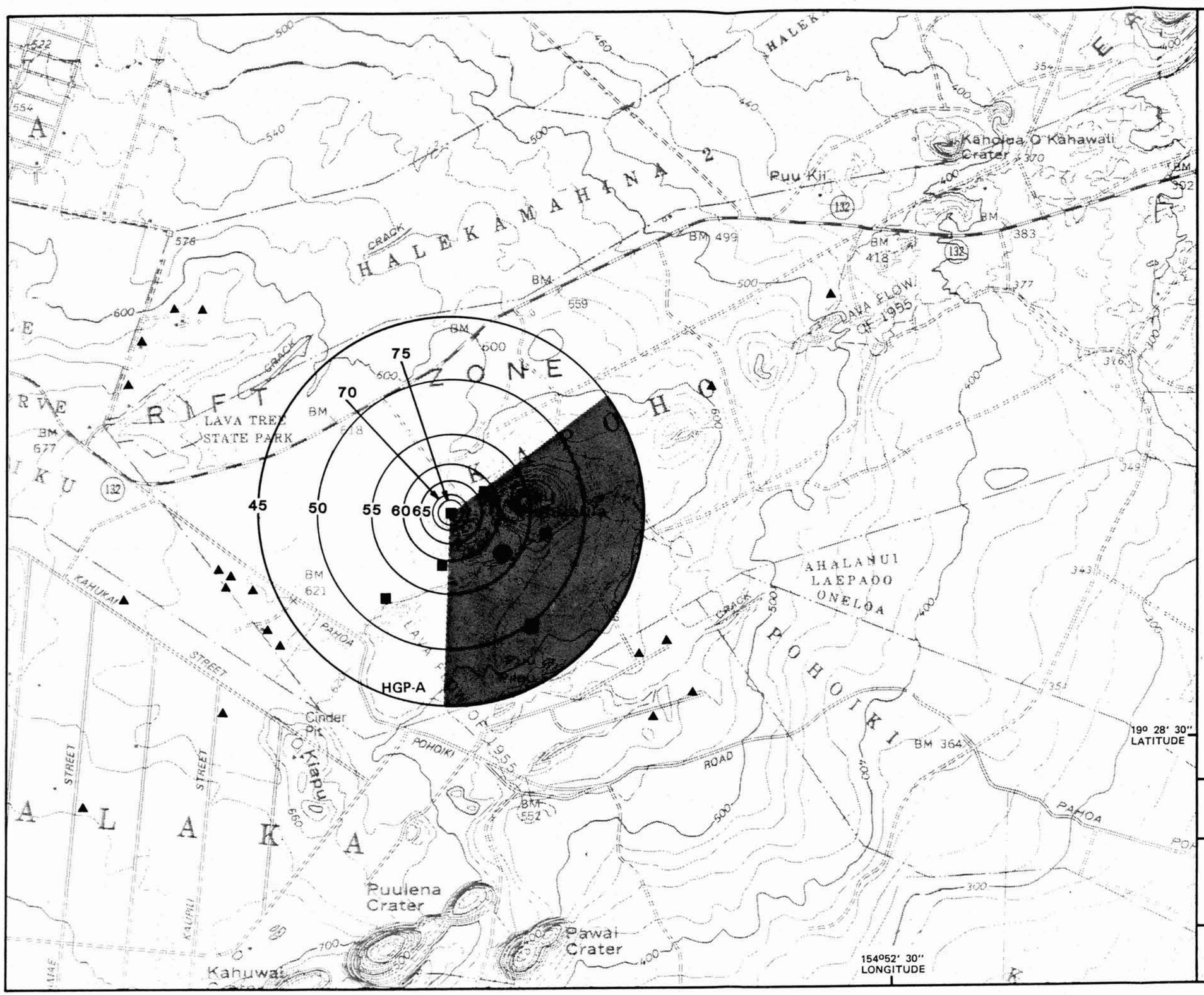
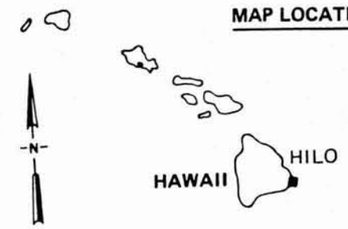
Figure 6-4
PREDICTED CONTOURS OF WELL DRILLING NOISE AT WELLPAD "B"

FLUOR DANIEL	JOB. NO.	DRAWING NO.	REV.



MAP LOCATION



LEGEND:

- ● POWER PLANT
- ■ PRODUCTION WELLPAD
- ▲ HOMES NEAR PROJECT SITE

NOISE LEVELS ARE IN dBA

SHADED AREA IS WHERE NOISE LEVELS COULD BE LOWER DUE TO TERRAIN BARRIER EFFECTS

SCALE
CONTOUR INTERVAL 20 FEET

0 — ½ MILE
0 — 1000 — 2000 FEET
0 — 1KM

SOURCE: U.S.G.S., 1980, 1981a, 1981b

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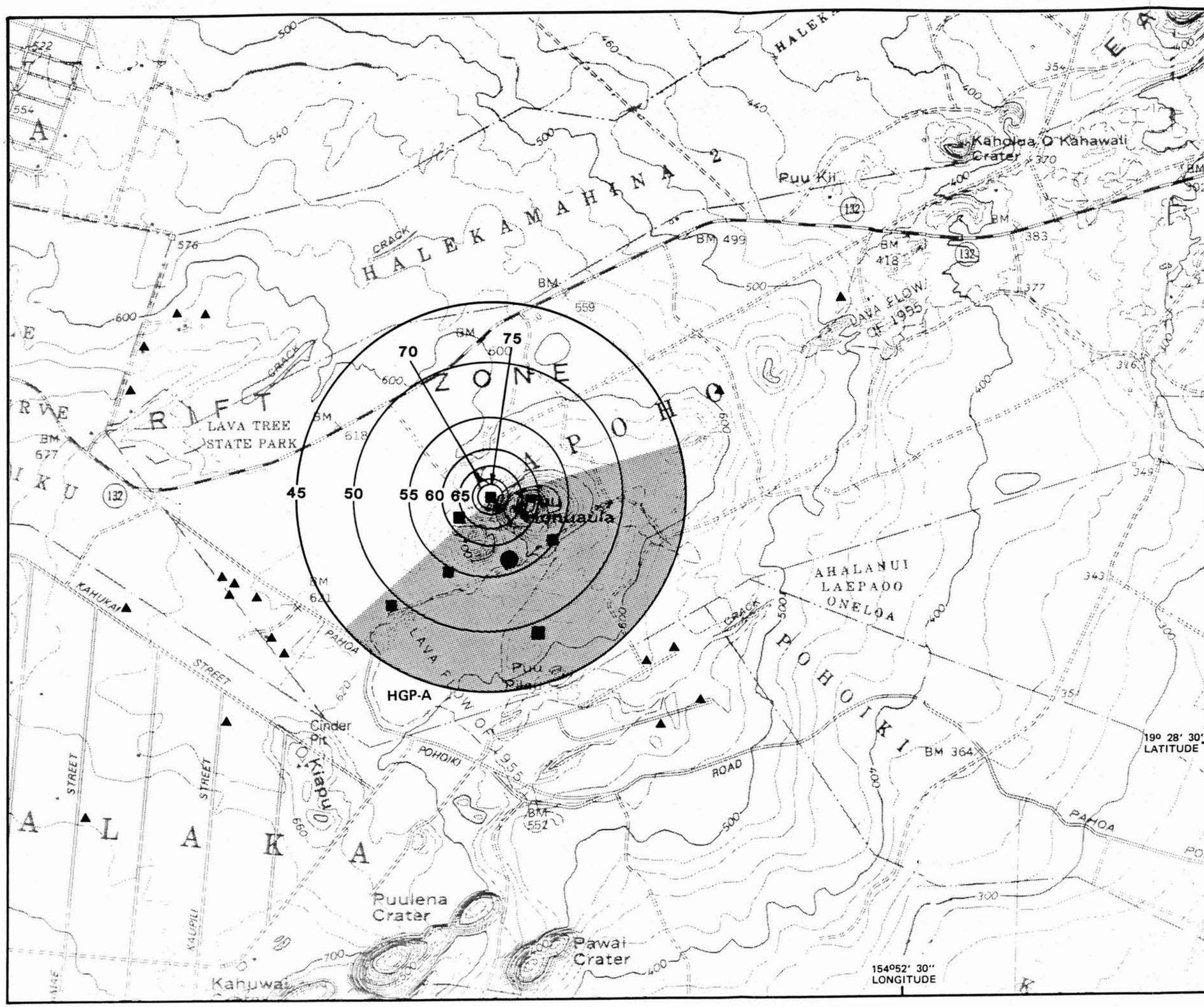
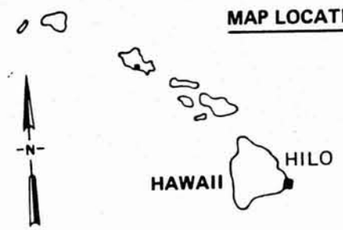
Figure 6-5
PREDICTED CONTOURS OF WELL DRILLING NOISE AT WELLPAD "C"

FLUOR DANIEL	JOB. NO.	DRAWING NO.	REV.



MAP LOCATION



LEGEND:

- POWER PLANT
- PRODUCTION WELLPAD
- HOMES NEAR PROJECT SITE

NOISE LEVELS ARE IN dBA

SHADED AREA IS WHERE NOISE LEVELS COULD BE LOWER DUE TO TERRAIN BARRIER EFFECTS

SCALE
CONTOUR INTERVAL 20 FEET

0 — ½ MILE
0 — 1000 — 2000 FEET
0 — 1KM

SOURCE: U.S.G.S., 1980, 1981a, 1981b

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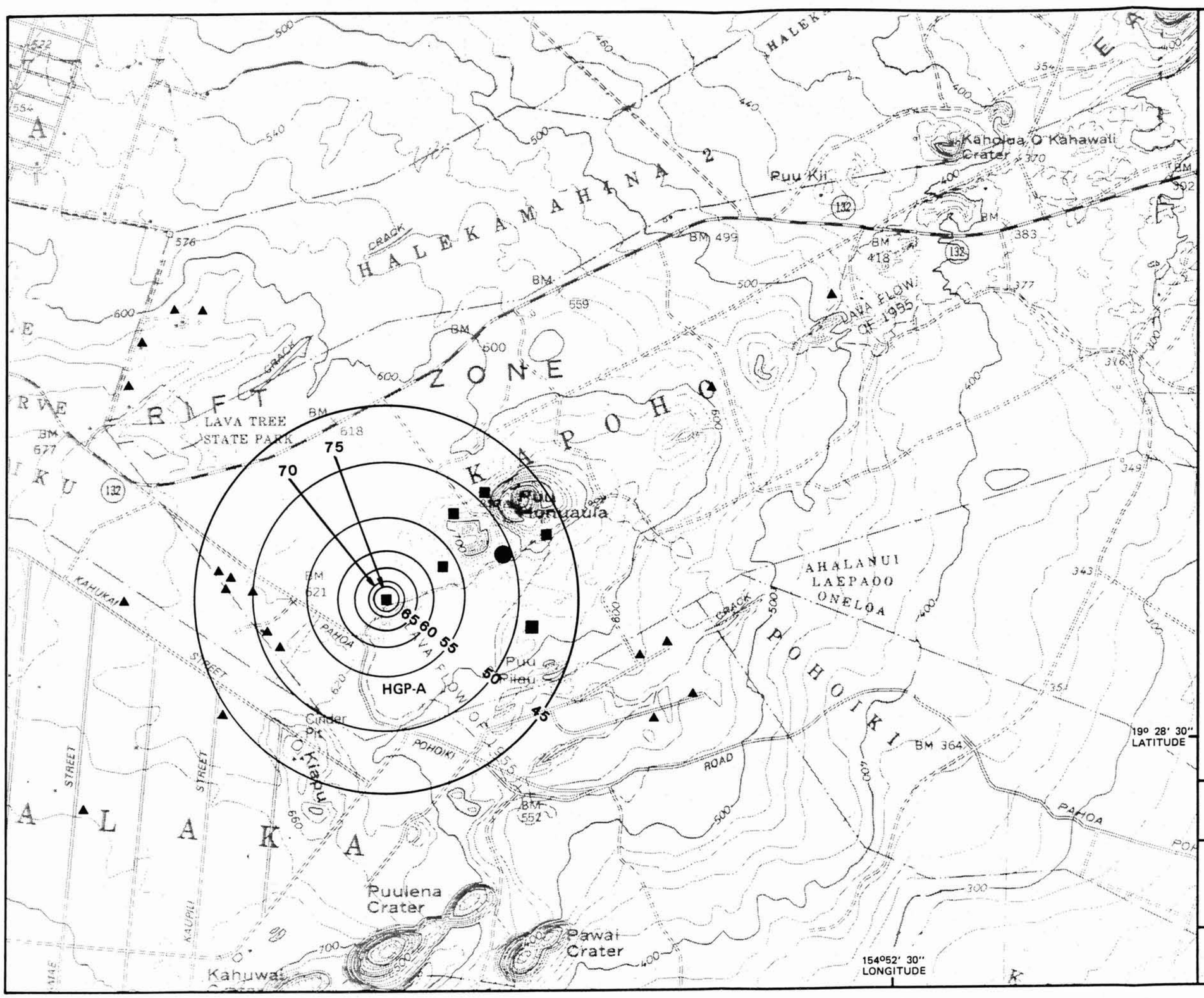
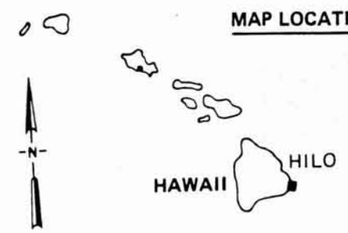
Figure 6-6
PREDICTED CONTOURS OF WELL DRILLING NOISE AT WELLPAD "D"

FLUOR DANIEL	JOB. NO.	DRAWING NO.	REV.



MAP LOCATION



LEGEND:

- POWER PLANT
- PRODUCTION WELLPAD
- HOMES NEAR PROJECT SITE

NOISE LEVELS ARE IN dBA

SCALE
CONTOUR INTERVAL 20 FEET

0 — ½ MILE
0 — 1000 — 2000 FEET
0 — 1KM

SOURCE: U.S.G.S., 1980, 1981a, 1981b

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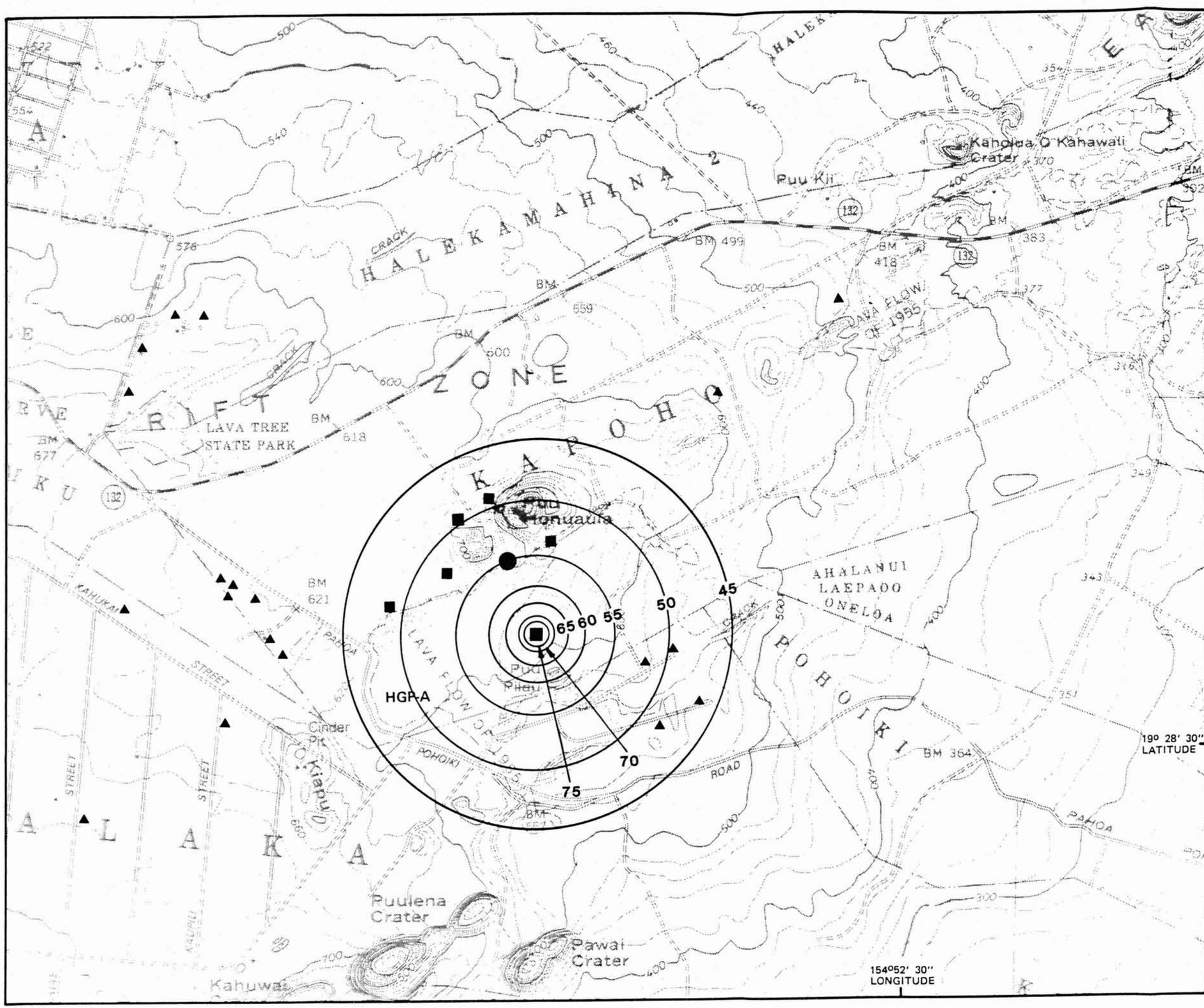
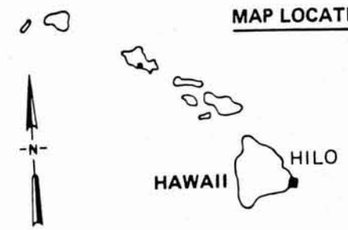
Figure 6-7
PREDICTED CONTOURS OF WELL DRILLING NOISE AT WELLPAD "E"

FLUOR DANIEL	JOB. NO.	DRAWING NO.	REV.



MAP LOCATION



LEGEND:

- ● POWER PLANT
- ■ PRODUCTION WELLPAD
- ▲ HOMES NEAR PROJECT SITE

NOISE LEVELS ARE IN dBA

SCALE
CONTOUR INTERVAL 20 FEET

0 — ½ MILE
0 — 1000 — 2000 FEET
0 — 1 KM

SOURCE: U.S.G.S., 1980, 1981a, 1981b

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HONOLULU, HAWAII

Figure 6-8
PREDICTED CONTOURS OF
WELL DRILLING NOISE
AT WELLPAD "F"

FLUOR DANIEL	JOB. NO.	DRAWING NO.	REV.

Table 6-5

NOISE LEVELS USED TO PREDICT
WELL WORKOVER NOISE
(Sound Pressure Levels in dB at 50 feet)

	Octave Band Center Frequency (Hz)								
Item	63	125	250	500	1,000	2,000	4,000	8,000	dBA
Steady noise of specially quieted Barnwell drill rig, no steam venting noise[a]	76	76	77	73	70	63	60	52	75
Steady noise of thoroughly muffled steam during drilling	86	86	87	83	80	73	70	62	85
Maximum noise of pipe impact[c][e]	-[b]	-[b]	79	88	90	88	76	-[b]	93
Steady noise from two air compressors[d] with enclosures	83	83	80	73	65	62	60	58	75
Steady noise from one diesel generator[a]	56	52	57	58	60	59	53	46	64

(a) Darby-Ebisu, 1982.
(b) Noise levels at this frequency would not contribute significantly.
(c) Consultants in Engineering Acoustics, 1981.
(d) Ibid.
(e) Maximum pipe impact noise is assumed to occur during 10% of total drilling time (i.e., the equipment usage factor for pipe impacts is 0.10).

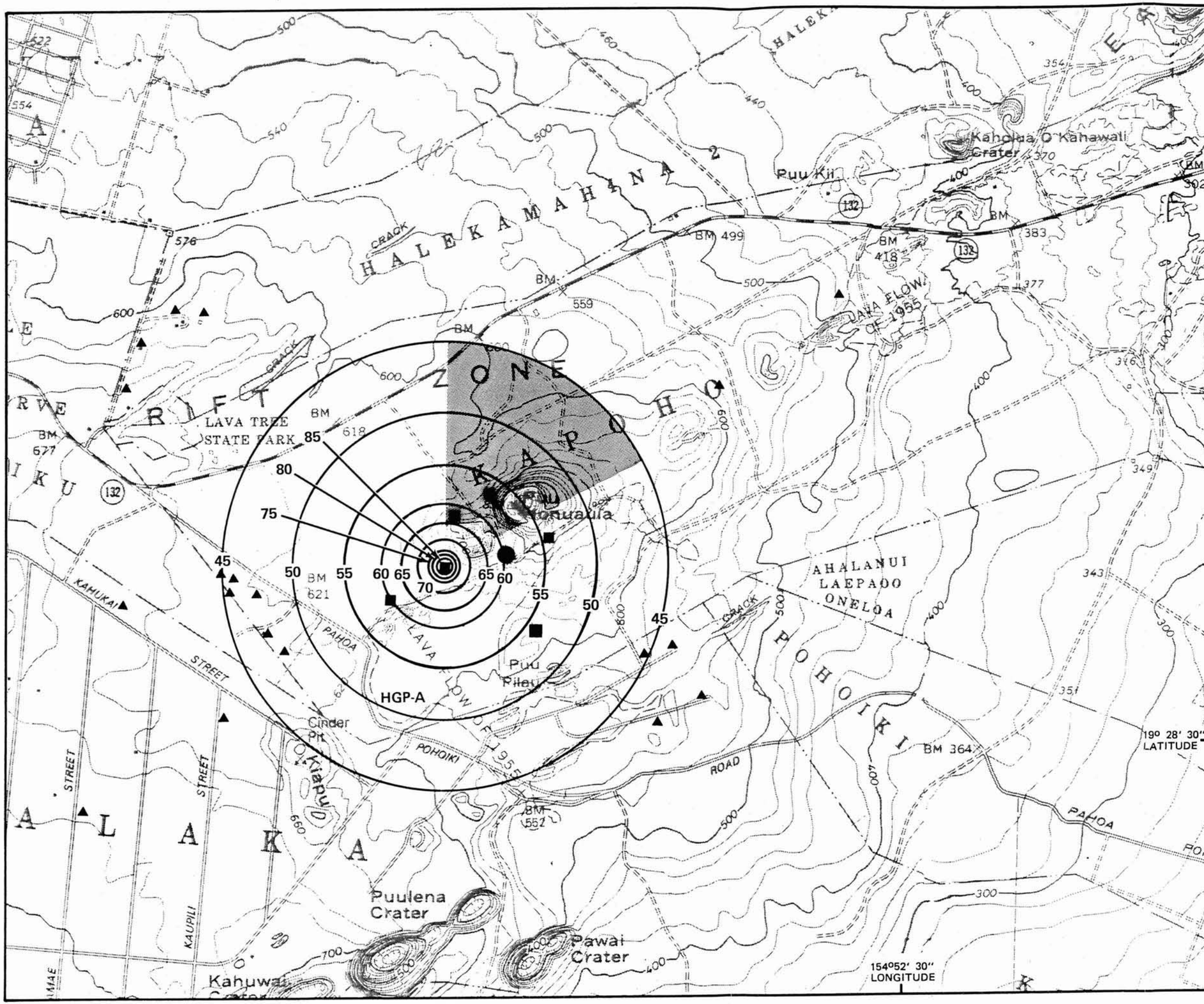
Predicted well workover noise levels from Wellpad A would increase to 48 dBA for some residences of Kapoho and Pohoiki-Bay Estates. Some homes in Lanipuna Gardens would incur dBA levels of 46 dBA. Leilani Estate residences would not hear workover noises above 45 dBA. Noise levels would not exceed 45 dBA in Lava Tree State Park.

Well workover noise levels from Wellpad B could reach 50 dBA in some parts of Lanipuna Gardens. Noise levels at Kapoho Estates and Pohoiki-Bay Estates will be below 45 dBA. Noise levels at Leilani Estates will be significantly lower. Noise levels at Lava Tree State Park will not exceed 45 dBA during well workover.

Noise levels at Lanipuna Gardens will not exceed 45 dBA from well workover at Wellpad C or D. Noise levels at Kapoho and Pohoiki-Bay Estates will marginally exceed 45 dBA from workover at Wellpad C, and will be below 45 dBA from Wellpad D workover. Noise levels at Lava State Tree Park will not exceed 45 dBA from workover at either wellpad.

Residents of Kapoho and Pohoiki-Bay Estates will be most affected by well workover at Wellpad E since it is the closest to the subdivisions. Noise levels could increase to 54 dBA in portions of the subdivisions. Noise levels in a small portion of Leilani Estates would increase to 47 dBA during workover activities. Lanipuna Gardens would not incur noise levels above 45 dBA. Levels at Lava Tree State Park will not exceed 45 dBA from workover at Wellpad E.

Residents of Lanipuna Gardens will be most affected by well workover at Wellpad F, since it is the closest to the subdivision. Noise levels were predicted to increase up to 54 dB in some parts of the subdivision. Noise levels at other residential subdivisions and Lava State Tree Park should not exceed 45 dBA due to workover at Wellpad F.



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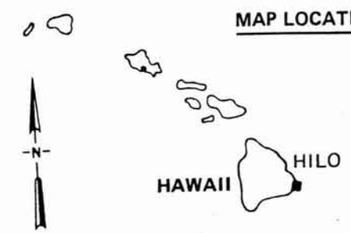

LEGEND:

- ● POWER PLANT
- ■ PRODUCTION WELLPAD
- ▲ HOMES NEAR PROJECT SITE

NOISE LEVELS ARE IN dBA

SHADED AREA IS WHERE NOISE LEVELS COULD BE LOWER DUE TO TERRAIN BARRIER EFFECTS

SCALE
CONTOUR INTERVAL 20 FEET

0 — ½ MILE
0 — 1000 — 2000 FEET
0 — 1 KM

SOURCE: U.S.G.S., 1980, 1981a, 1981b

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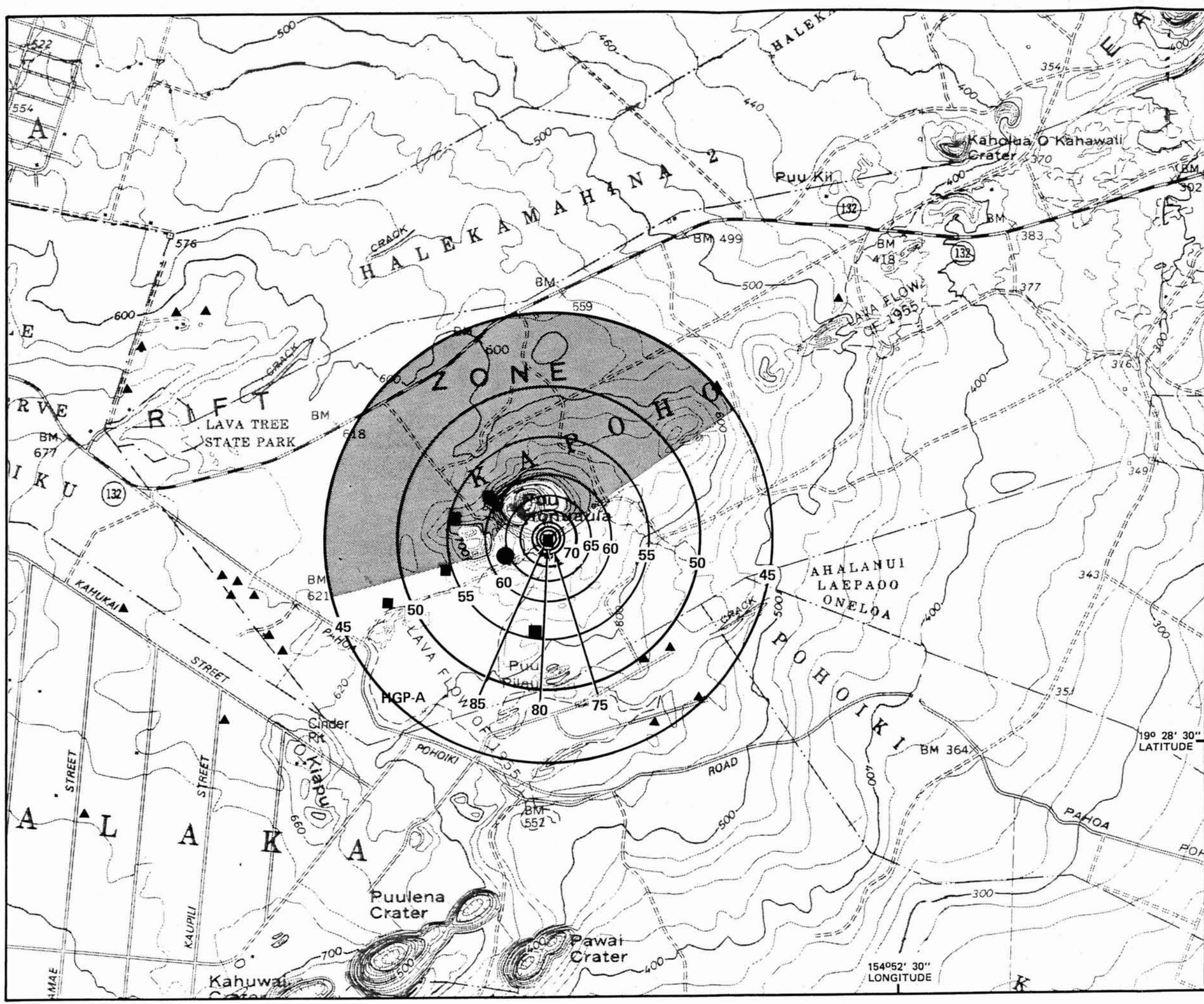
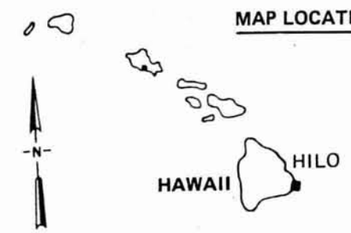
Figure 6-9
PREDICTED CONTOURS OF WELL WORKOVER NOISE AT WELLPAD "A"

FLUOR DANIEL	JOB. NO.	DRAWING NO.	REV.



MAP LOCATION



LEGEND:

- ● POWER PLANT
- ■ PRODUCTION WELLPAD
- ▲ HOMES NEAR PROJECT SITE

NOISE LEVELS ARE IN dBA

SHADED AREA IS WHERE NOISE LEVELS COULD BE LOWER DUE TO TERRAIN BARRIER EFFECTS

SCALE
CONTOUR INTERVAL 20 FEET

0 — ½ MILE
0 — 1000 — 2000 FEET
0 — 1 KM

SOURCE: U.S.G.S., 1980, 1981a, 1981b

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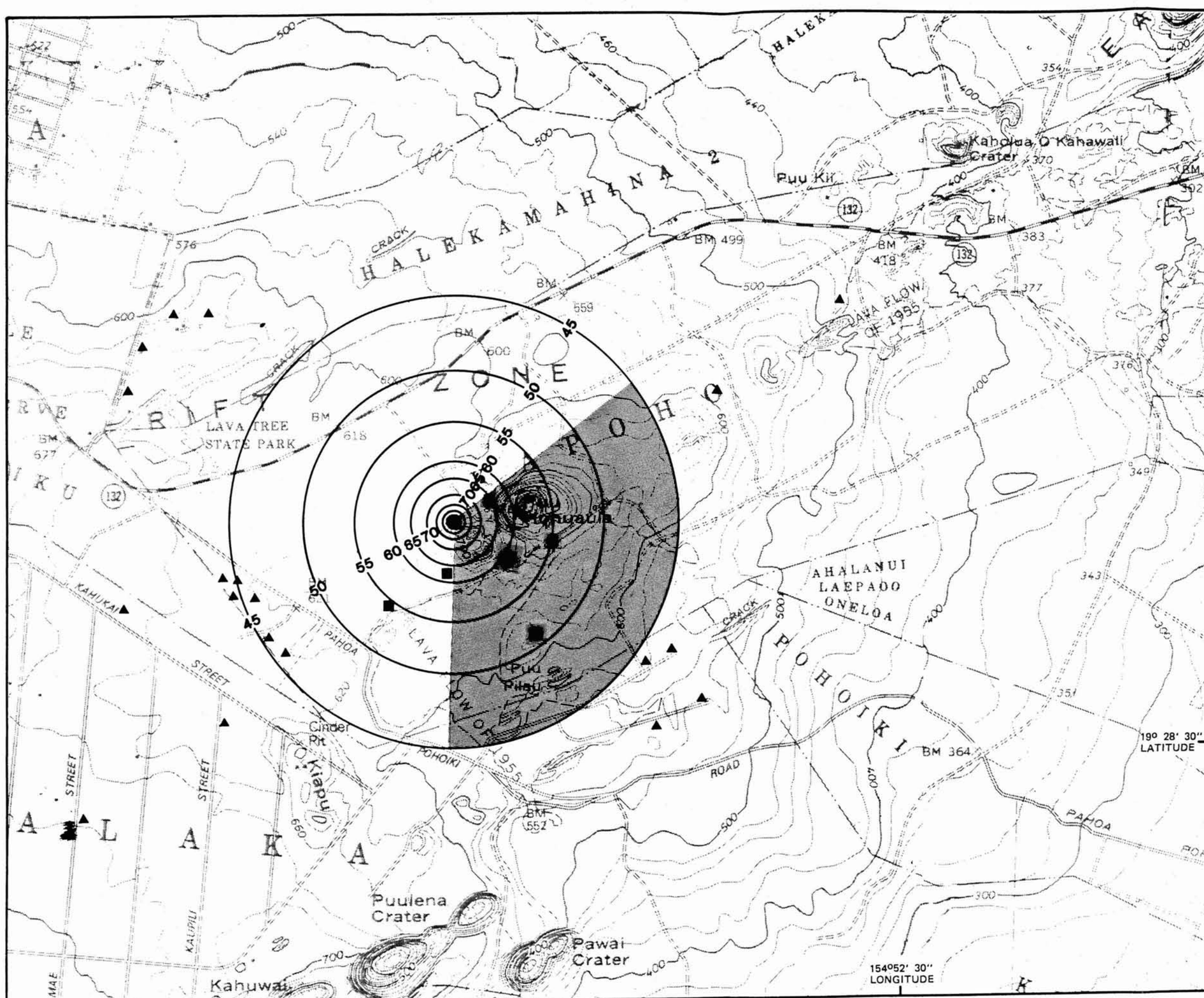
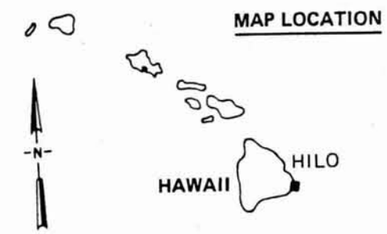
Figure 6-10
PREDICTED CONTOURS OF WELL WORKOVER NOISE AT WELLPAD "B"

FLUOR DANIEL	JOB. NO.	DRAWING NO.	REV.





LEGEND:

- ● POWER PLANT
- ■ PRODUCTION WELLPAD
- ▲ HOMES NEAR PROJECT SITE

NOISE LEVELS ARE IN dBA

SHADED AREA IS WHERE NOISE LEVELS COULD BE LOWER DUE TO TERRAIN BARRIER EFFECTS

SCALE
CONTOUR INTERVAL 20 FEET

0 — ½ MILE
0 — 1000 — 2000 FEET
0 — 1 KM

SOURCE: U.S.G.S., 1980, 1981a, 1981b

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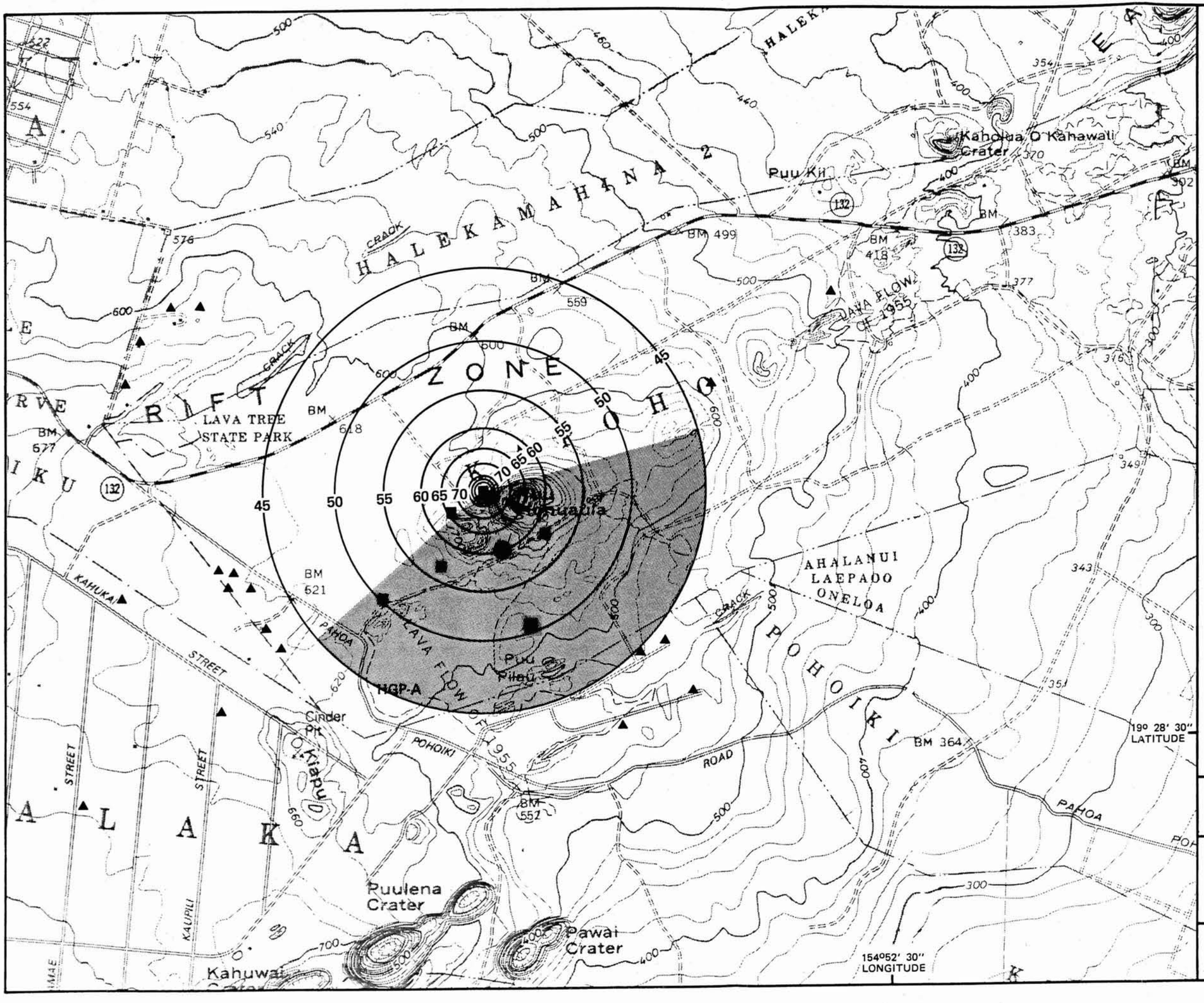
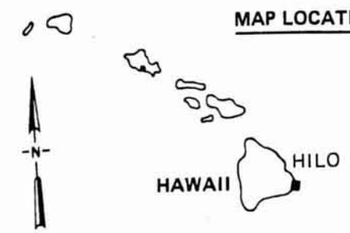
HONOLULU, HAWAII

Figure 6-11
PREDICTED CONTOURS OF WELL WORKOVER NOISE AT WELLPAD "C"

FLUOR DANIEL	JOB. NO.	DRAWING NO.	REV.



MAP LOCATION



LEGEND:

- ● POWER PLANT
- ■ PRODUCTION WELLPAD
- ▲ HOMES NEAR PROJECT SITE

NOISE LEVELS ARE IN dBA

SHADED AREA IS WHERE NOISE LEVELS COULD BE LOWER DUE TO TERRAIN BARRIER EFFECTS

SCALE
CONTOUR INTERVAL 20 FEET

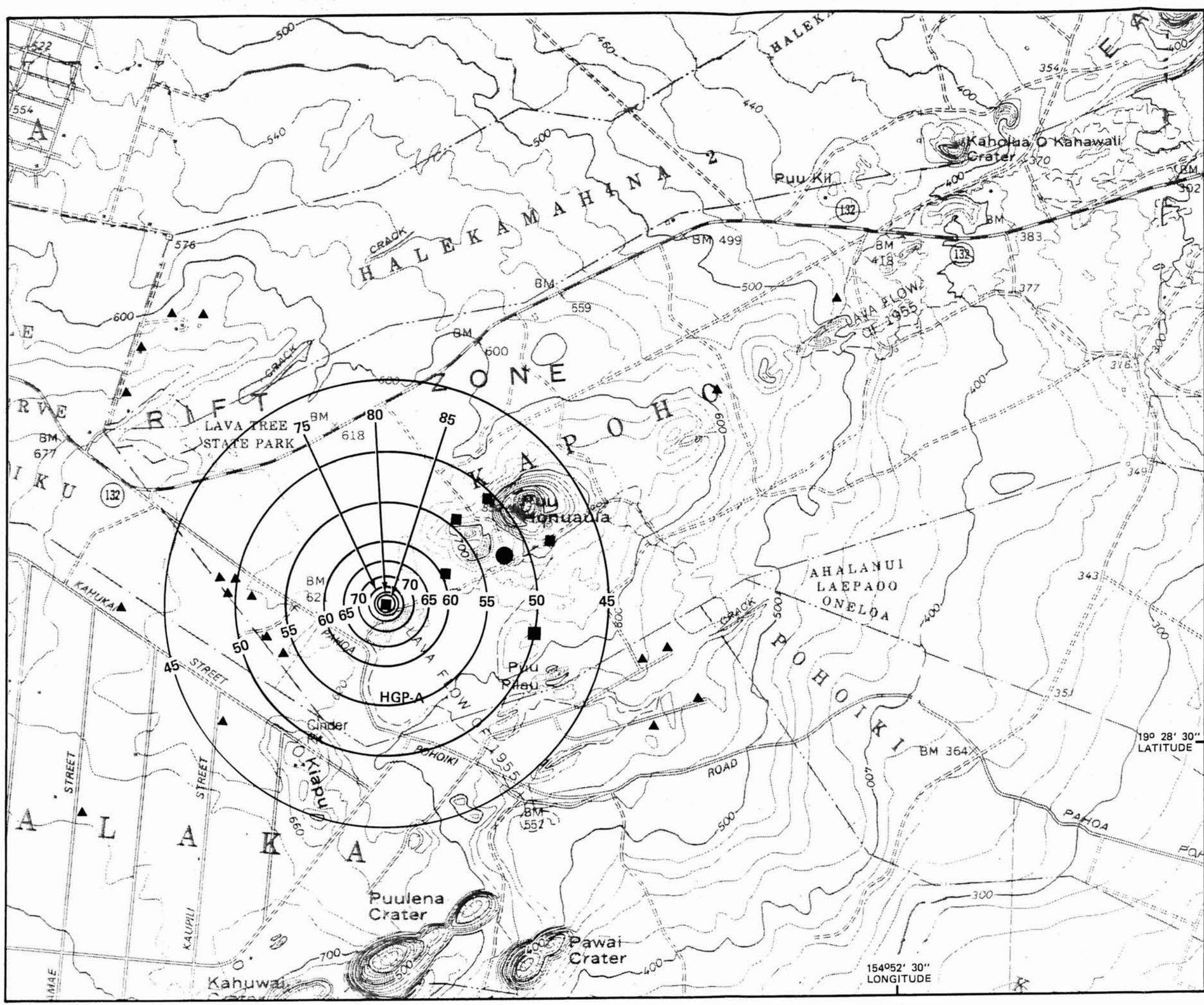
0 — ½ MILE
0 — 1000 — 2000 FEET
0 — 1KM

SOURCE: U.S.G.S., 1980, 1981a, 1981b

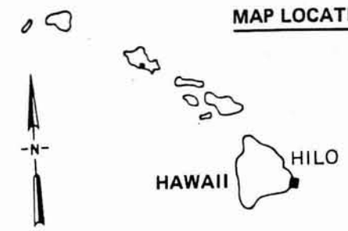
PUNA
GEOTHERMAL VENTURE PROJECT
HONOLULU, HAWAII

Figure 6-12
PREDICTED CONTOURS OF WELL WORKOVER NOISE AT WELLPAD "D"

FLUOR DANIEL	JOB. NO.	DRAWING NO.	REV.



MAP LOCATION



LEGEND:

- ● POWER PLANT
- ■ PRODUCTION WELLPAD
- ▲ HOMES NEAR PROJECT SITE

NOISE LEVELS ARE IN dBA

SCALE
CONTOUR INTERVAL 20 FEET

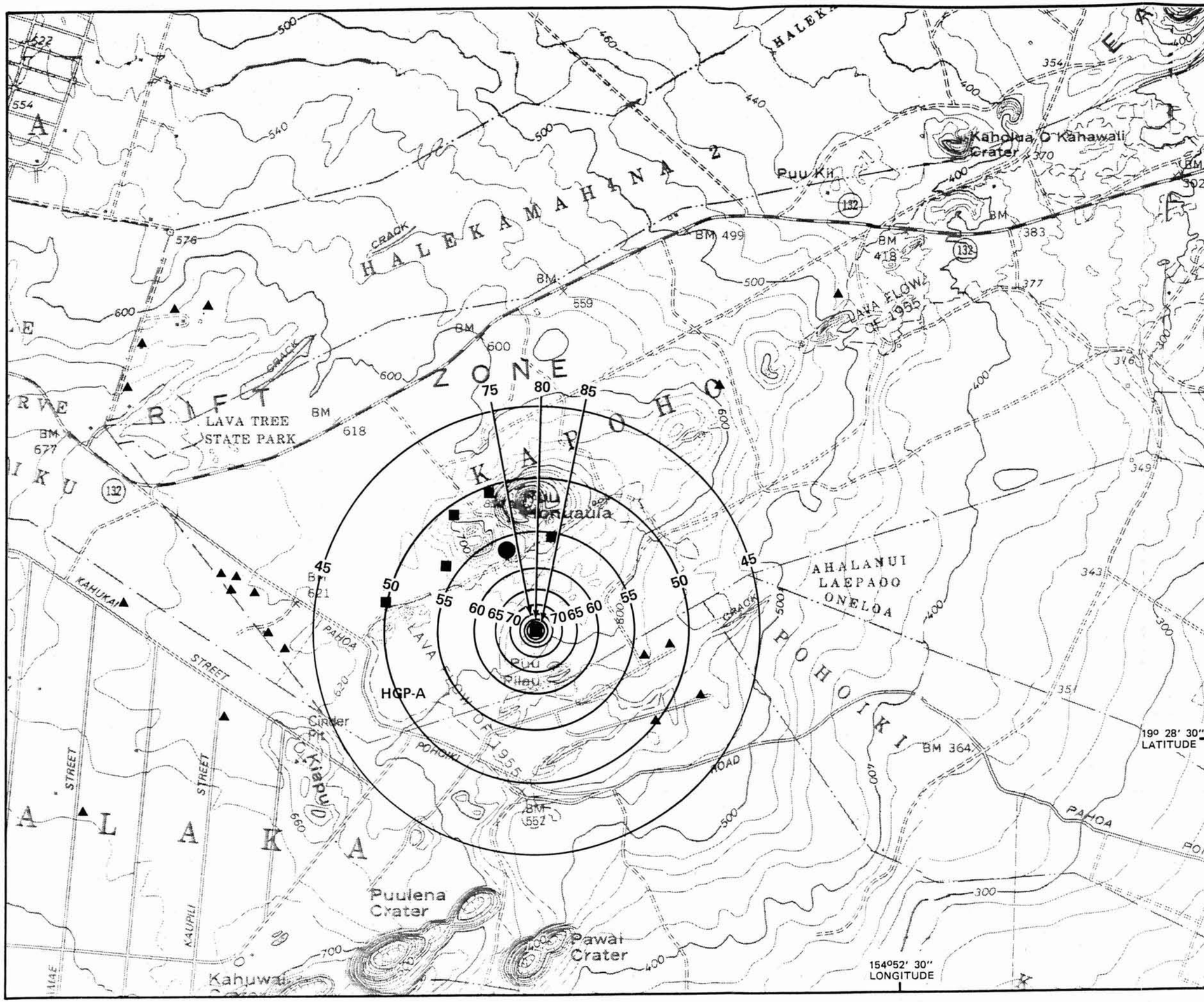
0 — ½ MILE
0 — 1000 — 2000 FEET
0 — 1 KM

SOURCE: U.S.G.S., 1980, 1981a, 1981b

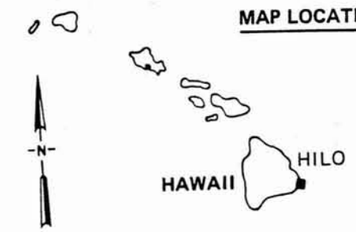
PUNA
GEOTHERMAL VENTURE PROJECT
HONOLULU, HAWAII

Figure 6-13
PREDICTED CONTOURS OF WELL WORKOVER NOISE AT WELLPAD "E"

FLUOR DANIEL	JOB. NO.	DRAWING NO.	REV.



MAP LOCATION



LEGEND:

- ● POWER PLANT
- ■ PRODUCTION WELLPAD
- ▲ HOMES NEAR PROJECT SITE

NOISE LEVELS ARE IN dBA

SCALE
CONTOUR INTERVAL 20 FEET

0 — ½ MILE
0 — 1000 — 2000 FEET
0 — 1 KM

SOURCE: U.S.G.S., 1980, 1981a, 1981b

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GEOTHERMAL VENTURE PROJECT
HONOLULU, HAWAII

Figure 6–14
PREDICTED CONTOURS OF
WELL WORKOVER NOISE
AT WELLPAD "F"

FLUOR DANIEL	JOB. NO.	DRAWING NO.	REV.

Noise from grading or other drill site construction activities is not included. All predicted noise levels include the effects of atmospheric attenuation only. Other attenuations such as foliage and terrain effects are not estimated, which results in a worst case analysis. The sound shadow zones on each figure show where the noise levels will often be lower due to barrier effects of the terrain. The noise model assumes that drilling will occur at one well at a time, and that the drill rig is thoroughly silenced to the noise levels shown in Table 6-5 by use of high-quality mufflers, effective noise shielding, and enclosures.

Certain well casing placement operations are a source of short-term noise. Cementing the wellbore is another short-term noise. Cementing noise is estimated to be 10 dB above steady drilling noise and is highly dependent on the noise controls used on the cementing truck. Well casing placement and cementing operation noise levels are not included on Figures 6-3 through 6-14.

Well Venting, Flow Testing and Pipeline Cleanout Noise

A well is vented directly to the atmosphere after completion to clean the well of dirt and debris prior to flow testing. Two periods of up to 4 hours each (8 hours total per well) are usually required for well venting. Well venting is a one-time activity that typically occurs when the well is first drilled. Noise levels during well venting could reach 125 dBA at 50 feet and 50 to 83 dBA at 1 mile (Burgess, 1980).

The well will be tested to determine its capacity and other characteristics after it is drilled and vented. Testing may initially require up to 10 days; however, it is the objective of the project to reduce this time to 24 to 48 hours of flow as more experience is gained on the wellfield. Testing may be performed continuously or intermittently for the required period. The PGV plant will utilize an effective rock muffler during flow testing to quiet the steam discharge to 55 dBA or less at the lease boundary.

Well pipelines need to be cleaned and pressure-tested prior to production. This process is referred to as pipeline cleanout and consists of intermittently venting steam from the well at high velocity to an opening in the pipeline where it is released, unmuffled, directly to the atmosphere. PGV will notify nearby communities of pipeline cleanout events. Cleanout normally occurs once for each section of pipeline and normally lasts about one hour. Noise levels due to pipeline cleanout may be as low as those for steady drilling (75 dBA at 50 feet) or as high as those for unmuffled well venting which can reach 125 dBA at 50 feet, and between 50 to 83 dBA at 1 mile.

PLANT OPERATION NOISE

Noise during operation will be generated by the following sources:

- Turbine-generators
- Cooling towers
- Circulating water pumps and motors
- H_2S abatement systems
- Noncondensable gas (NCG) removal system
- Steam stacking (controlled venting through rock mufflers)
- Steam gathering system (including valves)

The octave band noise levels and the resulting dBA values for the sources used in predicting operational noise are shown in Table 6-6. Noise levels range from 66 to 81 dBA at 50 feet. Figure 6-15 shows the maximum noise level contours during normal plant operation. Noise levels of 45 dBA will not be exceeded at any of the surrounding subdivisions or at Lava Tree State Park.

Table 6-6

NOISE LEVELS USED TO PREDICT
NOISE FROM PLANT OPERATION
(Sound Pressure Levels in dBA at 50 Feet)

	Frequency (Hz)								
Item	63	125	250	500	1,000	2,000	4,000	8,000	dBA
Turbine[a]	69	69	65	63	60	58	53	45	66
Cooling tower, per cell[a]	78	78	75	72	68	65	62	54	74
H_2S abatement system (compressor)	75	69	65	79	77	66	56	45	80
NCG removal system (1-inch insulation)[c]	--[b]	74	73	73	73	75	76	69	81
Flow noise in steam pipes[d]	51	52	50	51	48	46	43	33	53

(a) Edison Electric Institute, 1978.
(b) Noise level for this frequency was not obtainable or significant.
(c) Consultants in Engineering Acoustics file data, 1985.
(d) Includes acoustic insulation on steam piping.

The estimate of source noise assumes that effective noise controls will be applied to the turbines, some piping, the H_2S abatement system, the NCG removal system, and possibly other equipment. It also assumes effective suppression of noise from the steam release facility and the use of efficient rock mufflers in the steam release facility. Noise levels during stacking episodes will not be higher at existing residences than during normal plant operation because a highly efficient rock muffler will be used when it is necessary to release steam to the atmosphere. The piping and valves will also require special attention during design and may require thermal/acoustical lagging in places.

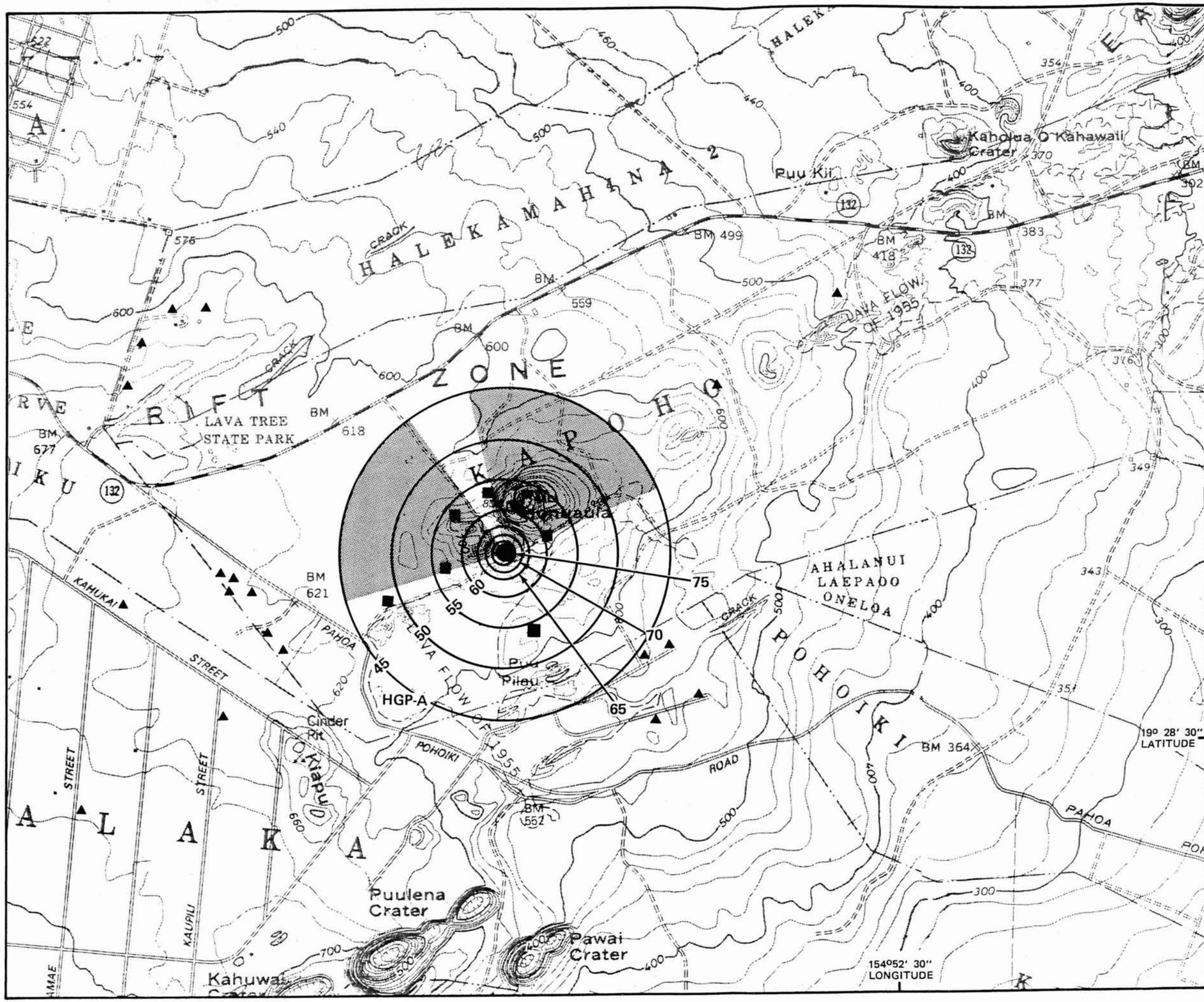
Occasional noise sources include separator drains, condensate drippings, and maintenance activities. Unplanned rupture disk events and injection system failures also generate noise.

An unplanned rupture disk event may last up to two hours before being controlled. Noise levels may reach 125 dBA at 50 feet and 50 to 83 dBA at one mile. Failure of injection systems will result in process fluids being routed through the facility rock muffler. Noise levels generated by an injection system failure will not exceed normal operating noise levels.

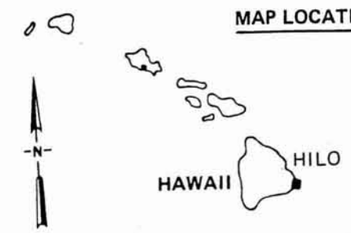
The design pressure drop across the control valve at the wellhead will be 16 pounds per square inch (psi) and will not cause significant noise. The noise from the control valves could be 40 to 45 dBA at 0.5 mile, depending on valve type and size, piping configuration, and insulation if this pressure drop becomes sizeable (between 75 psi and 150 psi), (Consultants in Engineering Acoustics, 1981). Noise from water droplet impingement at pipeline bends is expected to be minor (Burgess, 1980).

DECOMMISSIONING NOISE

The major noise sources during plant decommissioning and abandonment will be the same heavy construction equipment used for plant construction. The octave band noise levels used to predict construction noise also reflect decommissioning noise, since the equipment and the noise sources are substantially the same. Momentary noise from collapsing structures during



MAP LOCATION



LEGEND:

- ● POWER PLANT
- ■ PRODUCTION WELLPAD
- ▲ HOMES NEAR PROJECT SITE

SCALE
CONTOUR INTERVAL 20 FEET

0 — ½ MILE
0 — 1000 — 2000 FEET
0 — 1 KM

SOURCE: U.S.G.S., 1980, 1981a, 1981b

PUNA
GEOTHERMAL VENTURE PROJECT
HONOLULU, HAWAII

Figure 6-15
PREDICTED CONTOURS OF NOISE FROM NORMAL POWER PLANT OPERATION

FLUOR DANIEL	JOB. NO.	DRAWING NO.	REV.

demolition may be plainly audible above the general noise of construction equipment. The noise levels may be lower as a result of terrain barrier effect "sound shadows." No blasting is planned during plant shutdown and abandonment.

6.3 PROPOSED MITIGATION MEASURES

The following discussion covers proposed mitigation measures for drilling rig noise, construction noise, operation noise, and plant decommissioning noise. These noise mitigation measures and operating precautions will result in no significant noise impact on nearby residents, recreational areas, or biological resources.

DRILLING RIG NOISE

Continuous drill rig noise will be reduced by:

- Using residential-grade exhaust mufflers
- Placing or constructing an acoustic enclosure around the drill rig engines and other noisy mechanisms
- Silencing engine radiator air inlets and outlets

These methods have been successfully used during drilling of Wellpads A and B on the site. Operations that may cause higher noise or impacts of pipes, such as pulling the drill bit out of the hole for replacement (roundtripping), will be scheduled for the daylight hours as much as possible.

Silencers and/or acoustic enclosures will continue to be used on all auxiliary equipment, such as diesel engines, generators, and pumps. Effective rock mufflers will be employed to mitigate noise during flow testing and well workover activities. The public will be notified when planned, short-term well venting and pipeline cleanout activities will occur. These activities will be scheduled for daylight hours only. Other measures to reduce noise include orienting drilling equipment to direct maximum noise away from residences.

CONSTRUCTION NOISE

Construction equipment, including auxiliary equipment such as portable generators and air compressors, will have highly effective exhaust mufflers which do not compromise engine operation. Construction activities will also be limited to daytime hours. Backup alarms will be limited to the minimum legal limits.

OPERATION NOISE

Controls that will be used to reduce wellfield and plant operating noise are listed below:

- Insulate selected pipes and valves with acoustically effective material
- Install silencers or rock mufflers on pressurized steam outlets, where possible
- Acoustically insulate steam ejectors
- Arrange plant layout to shield residents from cooling tower noise
- Use quiet fans, motors, and baffles for the cooling towers
- Use acoustical insulation and/or enclosures for the turbine generator
- Baffle or muffle ventilation openings to control noise emissions from the turbine hall building
- Schedule loud maintenance during daylight hours

PLANT DECOMMISSIONING NOISE

Noise mitigation measures for plant decommissioning and abandonment will be generally the same as those for construction. Residential mufflers will be used on all equipment exhausts, and enclosures will be provided for all portable equipment, such as air compressors, generators, and pumps. Plant and wellfield dismantling will be done during daytime hours.

Section 7

BIOLOGICAL RESOURCES

7.1 ENVIRONMENTAL SETTING

This section describes the flora and fauna that is located in the vicinity of the project. Several biological studies have been undertaken in connection with the PGV project. One study (Char & Stemmermann, 1984) surveyed the vegetation types, plant species, bird species and mammal species within a 1-mile radius (approximately 2,010 acres) of the power plant location. This section draws heavily from that study.

BOTANICAL RESOURCES

Char and Stemmermann (1984) conducted a botanical survey of the project site vicinity. The objectives of the botanical survey were to:

- Identify and map the major vegetation types present within the study area.
- Determine the occurrence of federal and state designated, proposed or candidate threatened and endangered species within the study area.
- Provide data sufficient for inclusion in a future EIS to be prepared by others.

Prior to undertaking the survey, a search of the pertinent literature was made to familiarize the investigators with previous studies conducted in the area.

Literature Survey

One source that Char and Stemmermann (1984) examined prior to conducting their own survey was the final EIS for the HGP-A project (Kamins 1978). It contained results of a botanical survey within a 1-mile radius of the HGP-A drill site. The survey (lead by Barbara A. Siegel and Sanford M. Siegal) was cursory and did not involve detailed botanical reconnaissance, transects, and a species checklist. Short descriptions of the dominant vegetation types present were made. The most commonly occurring vegetation type in the area was the ohia (Metrosideros) forest. For the well site itself, a short list of the plant species present was provided. No threatened and endangered plants were believed to be present within the well site.

Also examined as part of the literature search was a series of publications dealing with geothermal development in the State of Hawaii (Siegel 1979-1980) that focused briefly on the flora near the HGP-A well.

A number of botanical surveys were commissioned by the PGV project in portions of the project site. (Ecotrophics 1981a, 1981b, 1982). These studies assessed if any changes occurred in the toxic materials uptake by plants or soils following the operation of the HGP-A facility. The botanical survey by Lamoureux and Williams (in Ecotrophics 1982) provides good descriptions of the vegetation types as well as a comprehensive checklist of the species present in or near the study area. One proposed threatened plant species, Tetraplasandra hawaiiensis, was found during their survey.

In a survey of the Halepuaa Forest Reserve (located 3 miles north of the study area) by Clarke et. al. (1979), nine major and four minor vegetation types were described and data were collected on rare, threatened and endangered species. Pockets of a new Cyrtandra species, as yet undescribed, were found in the cracks and gullies throughout the native vegetation. Large trees of Tetraplasandra hawaiiensis were also infrequently found.

After volcanic activities associated with the 1955 eruption subsided, a study was made of plant succession on the lava flow. Plots were established primarily at the Kamaili and Kii sites. Studies by Doty (1967, 1972) and Doty

and Mueller-Dombois (1966) showed that on new lava flows there is a succession of blue-green algae, lichens, mosses, ferns and flowering plants. The pioneer communities ameliorate and stabilize conditions by holding water at the surface where it leads to evaporational cooling, and by producing shade. In time, a herbaceous ground cover and an admixture of tree and shrub species begin to appear on the older, weathered lava.

Project Survey Results

The PGV project's botanical survey (Char and Stemmermann, 1984) was conducted by a team of three botanists conducted the field survey during the five-day period from 26 January to 30 January 1984. A total of 15 man-days were required to gather the technical data contained in this report.

Tentative vegetation types delineated from recent aerial photographs were ground checked and correlated with the photographs. Criteria such as the dominant life form, the associated plant species, and the canopy cover were used as differential characters in identifying each vegetation type. Each vegetation type was described by structure and floristics. Three strata were identified -- the tree layer, shrub layer, and herb layer. A visual estimate of abundance was made for each species within each of the different vegetation types.

Areas which were less disturbed were intensively surveyed since rare species are most likely to occur in such situations. Well pads A & B, the areas designated for the proposed geothermal facilities, and the immediate areas with native plants, such as Puu Honuaula and several scattered Metrosideros forests near cracks, were intensively surveyed since these areas would be impacted directly or indirectly by the proposed geothermal operations.

Species identification was made in the field. Plants which could not be positively identified were collected for later determination in the herbarium and laboratory. Whenever rare, threatened or endangered species were encountered, their location was mapped as accurately as possible and notes were made

on their distribution, physiological condition, and habitat. Voucher specimens were also prepared. These vouchers were to be deposited in the herbaria at the Bishop Museum and the Botany Department, University of Hawaii.

A total of 240 plant species were found during the course of the botanical field survey. A complete list of species, listing taxa, common name, status, vegetation type in which it is located, and frequency of observation is included in Appendix C. Of these species, 163 (68 percent) are introduced species, 65 (27 percent) are native species, and 12 (5 percent) are of Polynesian introduction. Of the 65 native species recorded, 33 are endemic; i.e., they occur naturally only in the Hawaiian Islands. Table 7-1 lists the endemic plant species found in the study area, since endemic species are of particular importance.

One candidate endangered plant species was found during the survey -- Tetraplasandra hawaiiensis. A single plant of the Bobea species was also found. The identity of the species was inconclusive, but could have been Bobea timonioides because the Bobea species lacked flowers or fruit. Bobea timonioides is considered a candidate endangered species by the U. S. Fish and Wildlife Service. Three rare species of Cyrtandra were located in the study area: Cyrtandra paludosa var. integrifolia, Cyrtandra paludosa var. irrostrata, and Cyrtandra sp., (as yet undescribed). None of these species occurred on the well or power plant sites. According to Char and Stemmermann (1984) those native species which did occur on the well and power plant sites were not considered rare, threatened or endangered.

Nine vegetation types were found within the 1-mile study area:

- Cultivated Areas
- Fallow Fields
- Closed Metrosideros Forest
- Open Metrosideros Forest
- Open Metrosideros-Lichen Forest
- Open Metrosideros/Diospyros Forest
- Open Metrosideros-Psidium Forest

Table 7-1

ENDEMIC SPECIES FOUND
DURING FIELD SURVEY[a]

TAXA	COMMON NAME
FERNS AND FERN ALLIES	
Athyrium sandwichianum	Hoio
Sadleria cyatheoides	Amauma
Cibotium chamissoi	Hapuuii
Cibotium glaucum	Hapuu
Elaphoglossum crassifolium	Ekaha
Dicranopteris emarginata	Uluhe, false staghorn fern
Adenophorus tamariscinus	Wahine-noho-mauna
Mecodium recurvum	Ohiaku
Vandenboschia cyrtotheca	Kilau
Polypodium pellucidum var. *volcanicum*	Ae
Selaginalla arbuscula	Lepelepaamoa
Christella cyatheoides	Kikawaio
MONOCOTYLEDONS	
Seleria testacea	--
Freycinetia arborea	Ieie

(a) - For more details see Appendix C, which lists genus, author citation of each species, biogeographic status of each species, vegetation type(s) in which the species was observed, and frequency of observation.

Table 7-1

ENDEMIC SPECIES FOUND
DURING FIELD SURVEY[a]
(continued)

TAXA	COMMON NAME
DICOTYLEDONS	
Alyxia olivaeformis	Maile
Ilex anomala	Kawau, kaawau
Tetraplasandra hawaiiensis	Ohe
Perrottetia sandwicensis	Olomea, puaa olomea
Diospyros ferrea subsp. *sandwicensis*	Lama
Antidesma platyphyllum	Hame
Cyrtandra paludosa var. *integrifolia*	--
Cyrtandra paludosa var. *irrostrata*	--
Cyrtandra sp.	--
Hibiscus youngianus	Hauhele, akiohala
Cocculus ferrandianus	Huehue, hueie
Myrsine lessertiana	Kolealaunui
Metrosideros polymorpha	Ohia, ohialehua
Pisonia umbellifera	Papalakepau
Bobea sp.	Ahakea
Psychotria hawaiiensis	Kopiko
Wikstroemia sandwicensis	Akia
Pipturus hawaiensis	Mamaki
Touchardia latifolia	Olona

(a) - For more details see Appendix C, which lists genus, author citation of each species, biogeographic status of each species, vegetation type(s) in which the species was observed, and frequency of observation.

- Mixed Forest
- Scrub

Much of the study area is modified by previous human activities, and during the study period, consisted of cultivated and fallow fields. The cultivated fields have since been abandoned. About one-third of the study area is covered by the 1955 lava flow. Of the native vegetation types, the open Metrosideros forests occupy the most area. The wellpad and power plant locations are situated on scrub vegetation and fallow fields. The dominant vegetation are introduced (non-native) weedy species and abandoned papaya plants.

Within each of the vegetation type the relative abundance of each species (or absence) was identified in a list of plant species. The complete list is included in Appendix C. The abundance ratings are based entirely upon a comparison of the frequency with which a species occurred, as compared to all other species, within the study area. It does not necessarily denote the abundance of that particular species in the Hawaiian Islands.

The rating of "rare" means that the species was observed 1 to 10 times within a given vegetation type. Again, it is important to understand that a species that is found to be "rare" in the study area is not necessarily rare in Hawaii or rare in the U.S. Conversely, a species found more than 10 times in a given vegetation type in the study area, may be uncommon in Hawaii or uncommon in the U.S. For example, the endemic Tetraplasandra hawaiiensis is not "rare" in the study area, but is a candidate for the Federal endangered species list. Similarly, a species may be rare in one vegetation type but abundant in one or more other vegetation types.

Vegetation Types

Discussed below are the nine vegetation types that were identified during the 1984 survey within a 1-mile radius study area. The location of each vegetation type is graphically depicted on Figure 7-1. A summary of the plant species that were found in each vegetation type is included in the vegetation type descriptions.

Cultivated Areas -- Designated as "c" on the vegetation map

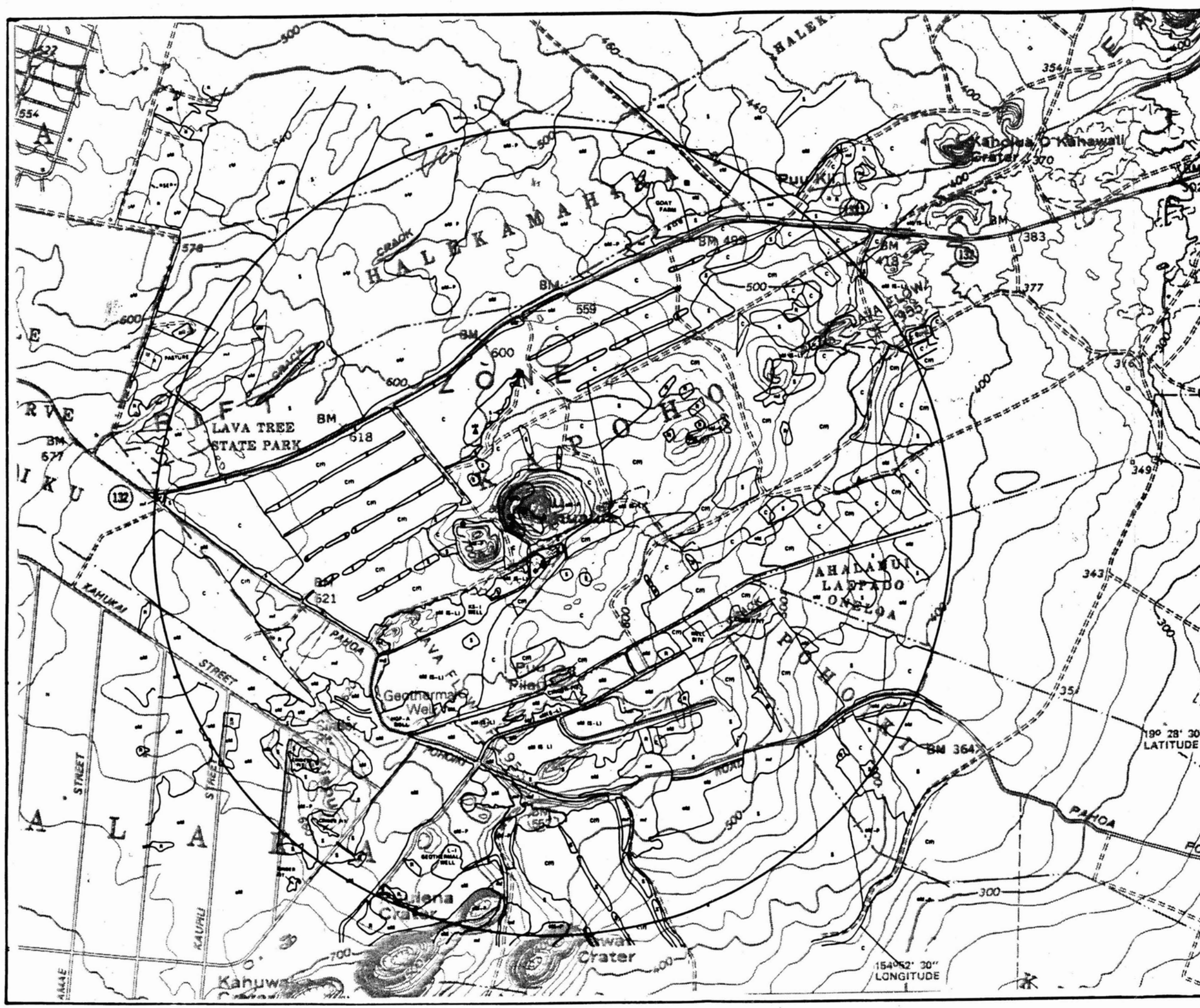
The cultivated areas presented a mosaic of different crops, stages of cultivation, and various human activities. A network of paved and unpaved roads crisscrossed the fields. Papaya (*Carica papaya*) was the main crop grown in the cultivated areas during the study period. A few banana (*Musa* X *nana*) fields, one field of vanda orchids (*Vanda teres* X *V. hookeriana*) and one weedy plot of macadamia nut trees (*Macadamia ternifolia* var. *integrifolia*) were also observed.

The papaya fields were in various stages of cultivation. Younger fields had plants a meter high while older fields had plants 7-8 feet high. Weedy growth was found primarily along the unpaved roadsides and consists of exotics commonly associated with cultivated areas. The most commonly encountered weedy species were a number of *Euphorbia* species, *Lindernia crustacea*, *Ageratum conyzoides*, *Borreria* sp., *Polygala paniculata*, *Hyptis pectinata*, and *Cyperus brevifolius*. Some of the papaya fields were frequently herbicided.

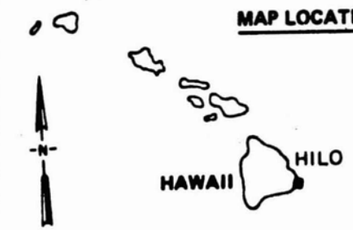
Fallow Fields -- Designated as "c(f)" on the vegetation map

Certain portions in the cultivated areas have remained fallow for a long time and can be characterized as open, grassy areas with scattered shrubs. Many of these fallow fields are abandoned sugar cane fields, and plants of sugar cane (*Saccharum officinarum*) were frequently encountered during the survey. Molassesgrass (*Melinis minutiflora*) and Californiagrass (*Brachiaria mutica*) formed the dominant cover.

Often these two grasses were found intermixed with *Desmodium* sp., *Desmodium cajanifolium*, and sensitive plant (*Mimosa pudica*). Scattered shrubs of pluchea (*Pluchea odorata*) and guava (*Psidium guajava*) were common. Smaller shrubs such as Jamaica vervain (*Stachytarpheta jamaicensis*), comb hyptis (*Hyptis pectinata*), and *Buddleja asiatica* were also frequently found.



MAP LOCATION



LEGEND

C	Cultivated areas
C(f)	Fallow fields
cM	Closed *Metrosideros* forest
oM	Open *Metrosideros* forest
oM(S-L)	Open *Metrosideros-Lichen* forest
oMD	Open *Metrosideros/Diospyros* forest
oM–P	Open *Metrosideros-Psidium* forest
mf	Mixed forest
s	Scrub
R	Residence
●	*Bobea* sp.
▲	*Cyrtandra* spp.
■	*Tetraplasandra hawaiiensis*
○	Study Area Boundary

SCALE

CONTOUR INTERVAL 20 FEET

0 — ½ MILE

0 — 1000 — 2000 FEET

0 — 1KM

SOURCE: U.S.G.S., 1980, 1981a, 1981b

PUNA
GEOTHERMAL VENTURE PROJECT
HONOLULU, HAWAII

Figure 7-1
VEGETATION MAP

(Char and Stemmermann, 1984)

FLUOR DANIEL	JOB. NO.	DRAWING NO.	REV.

Closed Metrosideros Forest -- Designated as "cM" on the vegetation map

Closed Metrosideros forests was found on Puu Honuaula, around the large cracks scattered throughout the cultivated areas, in a few parts of the Leilani Estates, and near Puu Pilau. These forests are usually found on very old aa lava and are structurally well developed.

The closed Metrosideros forest consists of tall-stature Metrosideros polymorpha (ohia), 66 to 98 feet tall, with canopy cover greater than 60 percent. The shrub layer, which is 7 to 16 feet tall, usually consists of a mixture of native and exotic species, although in some closed forests, the native elements such as Psychotria hawaiiensis (kopiko) may be dominant. The most abundant native species in this layer are the tree ferns, Cibotium glaucum and Cibotium chamissoi. Other native shrubs include lama (Diospyros ferrea), kopiko (Psychotria hawaiiensis), kolealauniu (Myrsine lessertiana), and hame (Antidesma platyphyllum). The most frequently occurring exotic shrubs are strawberry guava (Psidium cattleianum), guava (Psidium guajava), and Malabar melastome (Melastoma malabathricum). Usually these exotic shrubs are thicker near the edges of the forest. Ground cover is roughly 70 percent and consists of a mixture of grasses such as Sacciolepis indica, Paspalum conjugatum, Oplismenus hirtellus, and ferns such as Nephrolepis exaltata and Christella dentata.

The ephiphytic community is well-developed in this forest type. Vines of ieie (Freycinetia arborea) and piia (Dioscorea pentaphylla) are frequently found climbing up the trunks of ohia trees. Ferns and fern allies such as bird's-nest fern (Asplenium nidus), Vittaria elongata, ekaha (Elaphoglossum crassifolium), Lycopodium phyllanthum, and moa (Psilotum nudum) are occasionally encountered.

The ground under the closed Metrosideros forest is damp and the rough aa lava blocks are covered with the moss Rhizogonium spiniforme.

The greatest number of native species occurred in this vegetation type. Three rare species of Cyrtandra spp., and the proposed federal endangered

species of Tetraplasandra hawaiiensis were observed in this vegetation type during the survey. The uncommon filmy ferns, Mecodium recurvum and Gonocormus minutus, were observed in the damp cracks and crevices of the closed forest.

Open Metrosideros Forest -- Designated as "oM" on the vegetation map

The open Metrosideros forest occurs on relatively young, not deeply weathered lava flows. This vegetation type occupied large areas within the study area, such as the northern section above the Pahoa-Kapoho Road (Halekamahina), the Leilani Estates, and the southern section along the Pahoa-Pohoiki Road.

The open Metrosideros forest is composed of medium-stature, 16 to 52 feet tall, widely spaced trees. Canopy cover varies from 20 to 30 percent. An almost impenetrable mat of uluhe (Dicranopteris emarginata), 3 to 8 feet tall, covers the ground. Shrubs of Myrsine lessertiana, Pluchea odorata, Psidium guajava, and Melastoma malabathricum are also widely scattered throughout the uluhe tangle. In places where the uluhe is thin, plants of Andropogon virginicus, Styphelia tameiameiae, Arundina bambusifolia, and Macharina mariscoides are frequently found.

Open Metrosideros-Lichen Forest -- Designated as "oM(s-L)" on the vegetation map

Part of the 1955 lava flow is included in the study area. The vegetation on the lava flow was characterized by an open (5 to 20 percent cover), low-stature (3 to 13 feet) Metrosideros forest or woodland with a ground cover composed of the whitish-gray-colored lichen, Stereocaulon volcani, and the moss, Campylopus exasperatus. The hairy swordfern, Nephrolepis multiflora, was abundant in the many cracks and crevices that occur in the pahoehoe lava. Scattered shrubs of pukiawe (Styphelia tameiameiae), pluchea (Pluchea odorata), and Buddleja asiatica as well as grasses such as broomsedge (Andropogon virginicus) and bush beardgrass (Andropogon glomeratus) were found on the more weathered parts of the lava flow. Young plants of Metrosideros, 5-11 inches tall, are also common to fairly abundant on the lava flow.

The lava fields near Hinalo Road have been bull-dozed and the vegetation cover was slightly denser and consists of a greater number of weedy species. The Metrosideros trees were shorter (2-7 feet tall) and were more widely scattered than on the undisturbed pahoehoe and aa lavas.

Open Metrosideros/Diospyros Forest -- Designated as "oMD" on the vegetation map

This vegetation type was observed during the survey only on the west slopes of Puu Honuaula. Lama (Diospyros ferrea) is co-dominant with Metrosideros, although in some parts of this forest, lama forms almost pure stands with only a few scattered Metrosideros trees. Canopy cover was less than 60 percent. Several large Myrsine lessertiana trees that are 26 to 33 feet tall with basal diameters of 12 to 14 inches, were found in this vegetation type. Scattered trees of Pandanus odoratissimus are also occasionally found in this forest.

Many species found in the open Metrosideros-Psidium forest are also present in this vegetation type. The shrub layer is a mixture of exotic species such as Psidium guajava, Psidium cattleianum, Melastoma malabathricum, and native species such as Psychotria hawaiiensis and Myrsine. The ground cover is a mixture of grasses such as Sacciolepis indica and Oplismenus hirtellus, seedlings of the shrub and tree species mentioned above, and smaller shrubs such as Stachytarpheta jamaicensis and Rubus rosaefolius.

Two rare endemic species of Cyrtandra were found: Cyrtandra paludosa var. integrifolia and Cyrtandra paludosa var. irrostrata. In addition, three large trees of the endemic Tetraplasandra hawaiiensis, which is a candidate endangered species, were found in this vegetation type during the field survey.

Open Metrosideros-Psidium Forest -- Designated as "oM-P" on the vegetation map

This vegetation type was found in some areas north of the Pahoa-Kapoho Road, on Puu Honuaula and its smaller adjacent Puu (spatter cone), and in some areas near Puulena Crater.

The open Metrosideros-Psidium forest is composed of medium to tall stature Metrosideros (ohia) trees, 25 to 66 feet tall, with canopy cover varying from 20 to 50 percent. Scattered trees of Diospyros ferrea (lama), Aleurites moluccana (kukui), Cecropia obtusifolia (guarama), and Melochia umbellata (melochia) are occasionally found. Psidium guajava (guava) and tall Psidium cattleianum (strawberry guava) form a distinct subcanopy layer.

The two species of Cibotium (tree ferns), Sadleria cyatheoides (amaumau), Myrsine lessertiana (kolealauniu), and Melastoma malabathricum (Malabar melastome) are common components of the shrub layer. The ground cover is a mosaic of plant associates. In areas where the canopy is more open patches of uluhe (Dicranopteris emarginata) or broomsedge (Andropogon virginicus) can be found. In areas where the canopy is denser the ground cover may consist either of a mixture of shade-tolerant grasses such as basketgrass (Oplismenus hirtellus) and Hilograss (Paspalum conjugatum), smaller shrubs such as thimbleberry (Rubus rosaefolius), and seedlings of the tree and shrub species or the ground cover may be dominated by ferns such as Christella dentata (oak fern) and Nephrolepis exaltata (okupukupu).

The ephiphytic community in this vegetation type is also well-developed. Plants of Pleopeltis thunbergiana, Asplenium nidus, Ophioglossum pendulum, and Elaphoglossum crassifolium are often found on the ohia trees.

All three Cyrtandra species, the Tetraplasandra hawaiiensis, and the Bobea sp. were found in this vegetation type.

Mixed Forest -- Designated as "mf" on the vegetation map

This vegetation type is a mixture of Metrosideros and exotic trees: Albizia falcataria, Cecropia obtusifolia, Melochia umbellata, Eugenia jambos (rose apple) and Mangifera indica mango. A few kukui trees (Aleurites moluccana are also frequently found in these forests. Mixed forest was often found bordering the roadsides in the study area. Almost pure stands of Albizia, up to 98 feet tall, can be found along the Pahoa-Pohoiki Road.

The mixed forest is a medium to tall stature forest (33-98 feet tall), and canopy cover is usually greater than 60 percent. The shrub layer may consist of scattered shrubs if the canopy cover is thick or fairly dense shrubs if the canopy cover is thinner. The shrub layer is composed most commonly of the two Psidium species, Leucaena leucocephala (koahaole), Pluchea odorata (pluchea), Melastoma malabathricum (Malabar melastome) and the native shrubs Psychotria hawaiiensis (kopiko) and Pipturus hawaiensis (mamaki). Young saplings of the tree layer species are also numerous. Ground cover is a mixture of grasses such as Melinis minutiflora (molassesgrass), Brachiaria mutica (Californiagrass), and Pennisetum purpureum (Napiergrass), smaller shrubs such as Coleus blumei (coleus), Rubus rosaefolius (thimbleberry), and Stachytarpheta jamaicensis (Jamaica vervain), herbs such as Borreria sp., Begonia sp., and Mimosa pudica (sensitive plant), and ferns such as Christella dentata (oak fern) and Nephrolepis multiflora (hairy swordfern).

Scrub or Ruderal Community -- Designated as "s" on the vegetation map

The scrub or ruderal community is found in areas that are frequently disturbed or have been cleared, such as those areas along roads and trails, near the power lines east of Lava Tree State Park, and along forest borders. These sites were usually dominated by a number of weedy shrubs and grasses.

This vegetation type may vary from open, grassy areas with scattered shrubs (5 to 10 percent cover) to more or less dense shrub cover (60 to 70 percent), 5 to 20 feet tall. Andropogon virginicus (broomsedge), Melinis minutiflora (molassesgrass), and Brachiaria mutica (Californiagrass) form the dominant grass cover. The most commonly occurring shrubs are the two Psidium species, Pluchea odorata, and Melastoma malabathricum. Several plants of Clidemia hirta, a noxious weed, were found across the road from the Kapoho Electric Substation near pole number 313.

A number of scrub thickets found in the cultivated and fallow fields are lumped under this vegetation type. These thickets apparently were left undisturbed by the farmers to serve as windbreaks. They appear as long, narrow bands across some of the fields. These thickets may be up to 20 feet tall, are

very dense, and are composed primarily of shrubs such as Pipturus hawaiensis, Pluchea odorata, Buddleja asiatica, and small trees of Trema orientalis and Melochia umbellata.

The area east of the powerlines near the Lava Tree State Park appeared to have been disturbed at one time. The vegetation was open and consisted of 3-20 feet tall, scattered ohia with 5-10 percent cover, patches of Andropogon (30 to 40 percent cover), and Melastoma-Dicranopteris thickets (20-30 percent cover).

BIRD AND MAMMAL RESOURCES

Because of the extent of agricultural disturbance at the project site, the primary animal species of concern are native birds and mammals. A bird and animal survey was performed (Char and Stemmermann, 1984) in the same study area as the plant study area. It covered a 1-mile radius around Puu Honuaula. Two and one half days of field work was performed between January 24 and February 12, 1984.

Birds

Eleven species of nine avian families were observed in the study area. Only two of these species (the Hawaiian hawk and the lesser golden plover) are native; the remaining species are introduced from outside the islands.

Table 7-2 lists the species present in the study area and their approximate densities, expressed as relative abundances. Table 7-3 presents distributions of bird species by habitats within the study area. Birds observed in the study are briefly described below.

Table 7-2

BIRD SPECIES OCCURRING IN THE PUU HONUAULA REGION[a]

Common Name	Species; Family	Status[b]	Density in Study Area[c]
Hawaiian hawk, Io	*Buteo solitarius*; Accipitridae	Re,E	U
Lesser golden plover, Kolea	*Pluvialis dominica*; Charadriidae	Vr	U
Spotted dove	*Streptopelia chinensis*; Columbidae	Fl	R
Barred dove	*Geopelia striata*; Columbidae	Fl	R
Barn owl	*Tyto alba*; Tytonidae	Fr	Occ.
Melodius laughing-thrush	*Garrulax canorus*; Timaliidae	Fl	U
Japanese white-eye	*Zosterops japonicus*; Zosteropidae	Fl	A
Common myna	*Acridotheres tristis*; Sturnidae	Fl	A
House sparrow	*Passer domesticus*; Ploceidae	Fl	R
Northern cardinal	*Cardinalis cardinalis*; Fringillidae	Fl	C
House finch	*Carpodacus mexicanus*; Fringillidae	Fl	A

(a) The nomenclature and phylogenetic order follows the American Ornithologist's Union *Checklist of North American Birds*, 6th Edition (1983), and Pyle's Preliminary Checklist of the Birds of Hawaii (1977).

(b) Status (Symbols after Pyle's Preliminary Checklist of the Birds of Hawaii (1977), Elepaio 37(10):112-121):
- Re = Resident species; native, endemic at the species level
- Fl = Foreign introduced species; long established and breeding in Hawaii (for more than 25 years)
- Fr = Foreign introduced species; recently established and breeding in Hawaii (for less than 25 years)
- Vr = Visitor species; breeds elsewhere, regular migrant to Hawaii
- E = Currently on the Federal List of Endangered Species

(c) Density (expressed as relative abundance):
- Occ.= Occasional
- R = Rare
- U = Uncommon
- C = Common
- A = Abundant

Table 7-3

INCIDENCE OF BIRD SPECIES OBSERVED IN VARIOUS STUDY AREA HABITATS[a]

Common Name	Habitats[b] A	B	C	D	E	K1	K2	K3	K4	F	Total
Hawaiian hawk, Io				5				1	2		8
Lesser golden plover, Kolea			4	1	3						8
Spotted dove	1		1							1	3
Barred dove					1						1
Barn owl		1									1
Melodius laughing thrush	2	1	2	4		1	2	1		3	16
Japanese white-eye	5	11	26	33	3	3	1	12	5	8	107
Common myna	5	6	7	14	20			9	3		64
House sparrow			3								3
Northern cardinal	2	1	8	13	1	2	5	2	4		38
House finch	11	7	21	41	9	1	2	6	9	1	108
Total	26	27	72	111	37	7	10	31	23	13	357

(a) The nomenclature and phylogenetic order follows the American Ornithologist's Union Checklist of North American Birds, 6th Edition (1983), and Pyle's Preliminary Checklist of the Birds of Hawaii (1977).

(b) Habitats:
- A = Large-stature exotic forest near Lava Tree State Park and along Pahoa-Pohoiki Rd.
- B = Ohia forest north of Pahoa-Kapoho Rd.
- C = Ohia forest, Leilani Estates
- D = Puu Honuaula and smaller Puu to its immediate southwest
- E = Papaya fields (active and inactive) and other agricultural areas in study site
- K1 = Small Kipuka (crack) 1/3 mile northeast of Puu Honuaula
- K2 = Small Kipuka (crack) 1/2 mile east/southeast of Puu Honuaula
- K3 = Large Kipuka (crack) 1 mile east of Puu Honuaula
- K4 = Large Kipuka (crack) 1/4 mile west/northwest of Puu Honuaula
- F = Puulena Crater

Hawaiian Hawk (Io)

The Hawaiian hawk, which is endemic to the Island of Hawaii, is the only remaining species in a once diverse endemic raptor fauna (Olson and James, 1982). This species is on the Federal List of Endangered Species. Its breeding range encompasses most of the Island of Hawaii including the Puna District, which is an especially dense breeding area. The success of the Hawaiian hawk breeding in Puna is due primarily to the prime agricultural lands extending south and east of the town of Pahoa, which includes the study area.

Four field studies of the Hawaiian hawk in the project area have been conducted in connection with the PGV project. The studies were conducted between January 1, 1984, and July 15, 1986 (Char and Stemmermann, 1984; Stemmermann, 1985; Jeffries, 1985; Jeffries, 1986). The studies have shown that the project area around the Puu Honuaula is heavily used by hawks hunting for prey species because of the open nature of this agricultural area and its potential for attracting prey species to discarded fruit and weed seeds.

Five to seven adult and juvenile Hawaiian hawks are estimated to utilize the area within a 1-mile radius of Puu Honuaula. Figure 7-2 shows locations in where Hawaiian hawks were sighted during the four field studies. No hawks were sighted during Stemmermann's survey between June 14, 1984 and June 24, 1984. Table 7-4 presents the total number of hawk sightings, estimated total individuals, total number of nests, and number of active nests that were reported in each of the four studies. Hawks were most frequently found perching in the small enclaves of native forest adjacent to papaya fields. These areas include Puu Honuaula, the adjacent Puu to the southwest, and two of the long, narrow Kipukas within the study site. Hawks were also seen in flight over both forested and cultivated areas.

During three of the study periods, four nesting sites were located within a 1-mile radius of the project site. Only one of these nests has been active each year. Nest no. 2 is located about 1 mile east of the project site and was active all 3 years. A single nestling was raised in 1985, and another nestling was raised in 1986. No hawk nests have been found on Puu Honuaula. Prey that was fed to the young hawks included rodents and small birds (Jeffries, 1985, 1986).

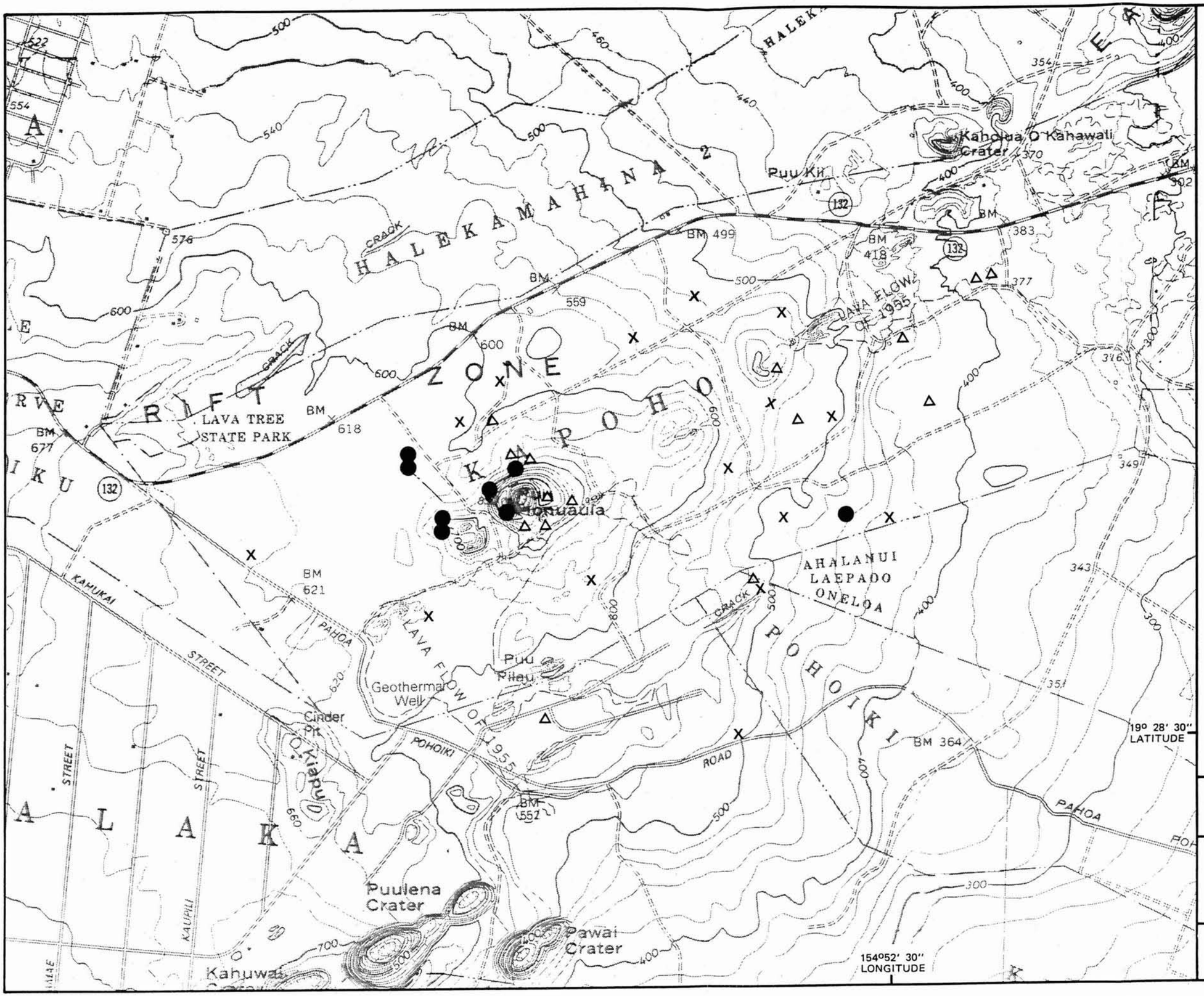
In June 1984, Stemmermann (1985) noted adult hawks adding nesting material to nest no. 2 but never observed eggs or young. Hawaiian hawks apparently do not breed every year but will maintain a nest and often an alternative nest within their territory. This second nest could be used if the first nest proved inadequate. No activity has been seen at a second nest site 330 feet west of the active nest (nest no. 2); however, this well-kept nest is most likely an alternative nest maintained by the active breeding pair.

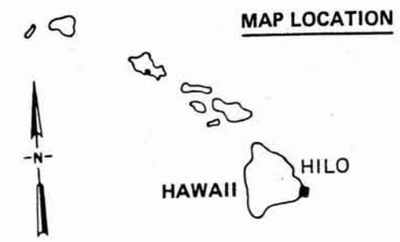
The frequency of hawk sightings suggests that hawks are nesting in nearby areas and foraging for food over the study area. Land clearing for agricultural purposes, although detrimental to nesting sites, has allowed for an increase in food availability for hawks and, thus, an increase in the number of hawks utilizing the area from adjacent territories.

Indirect human disturbance is noted to have only a minor affect on nestlings; however, prolonged loud noise or close human activity could be detrimental to reproductive success. During the study periods, the active nest found in the study area was less than 330 feet from a producing papaya field. It was constantly exposed to human disturbance; bulldozers, field workers, and tractors were continually in the area and in the view of the young and adults. The hawks became agitated only when the noise was excessive (the sound of a bulldozer operating nearby or a helicopter flying low and overhead). Because of continued human activity, they apparently had become, to some extent, habituated to this disturbance. The papaya field is now abandoned.

Lesser Golden Plover

Wintering populations of the lesser golden plover, or Kolea, a shorebird that breeds in Siberia and Arctic North America, arrive in the Hawaiian Islands in late August and leave in March and April. On their wintering grounds, individual birds are often territorial and site-tenacious, returning to the same location year after year (Brunner, personal communication, 1984). The Kolea were widely distributed in fairly small numbers throughout the study area. They are most commonly found in agricultural fields and open areas and, in smaller numbers, on subdivision roads.





● SIGHTINGS (1984 SURVEY)

X SIGHTINGS (1985 SURVEY)

△ SIGHTINGS (1986 SURVEY)

SCALE
CONTOUR INTERVAL 20 FEET

0 — ½ MILE
0 — 1000 — 2000 FEET
0 — 1 KM

SOURCE: U.S.G.S., 1980, 1981a, 1981b

PUNA
GEOTHERMAL VENTURE PROJECT
HONOLULU, HAWAII

Figure 7-2
LOCATION OF HAWAIIAN HAWK SIGHTINGS, 1984, 1985 AND 1986

FLUOR DANIEL	JOB. NO.	DRAWING NO.	REV.

Table 7-4

SUMMARY OF HAWAIIAN HAWK STUDIES

Survey Dates	Total Hawk Sightings	Estimated Total Individuals	Total Nests	Active Nests	Survey Author, Year
January 1, 1984 - February 6, 1984	8	4	-	-	Char and Stemmerman, 1984
June 14, 1984 - June 29, 1984	-	7	4	1	M. Stemmerman, 1985
June 4, 1985 - July 15, 1985	23[a]	5 to 7	3	1	J. Jeffries, 1985
April 28, 1986 July 15, 1986	18[b]	5 to 7	3	1	J. Jeffries, 1986

(a) Does not include hawk sightings at nest sites.
(b) Census method changed.

Spotted Dove

The spotted dove was found in very low densities in forested portions of the study area, particularly in the Leilani Estates and adjacent areas and in the vicinity of Lava Tree State Park.

Barred Dove

The barred dove was observed only once in the study area, in papaya fields north of the Puu Honuaula well sites. This species is primarily a seed-eating bird (Schwartz and Schwartz, 1949; Berger, 1983) and requires a source of drinking water. This factor probably plays an important role in determining the low abundance of both the spotted dove and the barred dove in the study area.

Barn Owl

The barn owl is a relatively recent introduction to the Hawaiian Islands; the first birds were introduced to the Hamakua region of the island in 1958. The primary food items of this species in the Hawaiian Islands are small mammals, particularly mice and small rats (Tomich, 1971). One owl was seen soon after dusk on February 11, 1984, adjacent to the Pahoa-Kapoho Road. The barn owl probably occurs in low densities throughout the agricultural portions of the study area, although its nocturnal habits prevent accurate density estimation or determination of its distribution.

Melodious Laughing-Thrush

The melodious laughing-thrush was found in low numbers in forested portions of the study area, apparently preferring exotic vegetation to native forest. This bird was most frequently observed in exotic stands of forest on Puu Honuaula, in the Leilani Estates, and in the vicinity of Puulena Crater.

Japanese White-Eye

The Japanese white-eye was one of the most common species in the study area. It was found throughout all habitats censused. Lowest densities of this species were seen in papaya fields and other agriculturally modified habitats. Higher densities were found in closed forests (both native and exotic), with highest numbers occurring in the Leilani Estates and on Puu Honuaula. This species is an omnivore, which has provoked much speculation on its possible role in the local extinction of native forest birds through dietary competition (Banko, 1978; Banko and Banko, 1976).

Common Myna

The common myna was also particularly abundant throughout the study area. Unlike the Japanese white-eye, it showed a marked preference for open areas such as inactive papaya fields and areas under cultivation. In forested regions, mynas were invariably found in cleared areas (e.g., roads) or adjacent to forest edges. This species does not often stray from developed areas.

House Sparrow

The house sparrow was found only in Leilani Estates in very low numbers. Berger (Kamins, 1978) did not find this species in his earlier survey of the Pohoiki region, and it may be a recent addition to this environment.

Northern Cardinal

The northern cardinal was sighted in relatively low numbers throughout the study area. This species showed a distinct preference for forested areas (very common at Puu Honuaula, less common in Leilani Estates), particularly those with some exotic plant cover. It was sighted on only one occasion in cultivated fields.

House Finch

The house finch was common to abundant in all habitats within the study area and was often found in large flocks of up to 40 birds. The house finch, although primarily a seed eater, is renowned for its predilection for papaya and other soft fruits ("papaya bird" is a widespread common name for the species), which explains, to some extent, its abundance in the study site.

Potential Unobserved Bird Species in the Study Area

Several species of native forest birds are known to occur in other portions of the Puna District (especially areas at elevations below 2,000 feet) but were not seen during field observation in the project study area, despite the presence of suitable habitat. These species are listed in Table 7-5.

Table 7-5 includes data from censuses in the Kalapana Extension of Hawaii Volcanoes National Park: lowest known elevations from census counts, and approximate abundance at that elevation (Conant, 1980). Data from Hawaii Volcanoes National Park should be considered to be from a moderately undisturbed ecosystem. (Factors H, C, and D on Table 7-5 are all present to some extent but are not as severe as in the Puu Honuaula area, which has been impacted by various kinds of human activity for a number of years.)

Mammals

Signs of non-native mammals were common in the study area. Mongoose were seen and heard consistently in all agricultural habitats and were especially common in mature fields where there was a high density of shrubs and weeds for cover. One feral cat was seen in papaya fields adjacent to Puu Honuaula. Rats and mice were evident in active papaya fields due to their gnawing of ripe fallen papaya. Four species of rodents were found in these habitats (Kramer, 1971). Mus musculus, Rattus rattus, and Rattus exulans are not commonly found in fields, while Rattus norvegicus is found most frequently within 500 feet of human habitations or other structures (Eskey, 1934, cited in Kramer, 1971). There was no evidence of feral pig activity in the study area.

Table 7-5
POTENTIAL (BUT UNOBSERVED) BIRD SPECIES IN THE PGV STUDY AREA

Common Name	Species; Family	Low Elevation (NAVD) (ft)	Density	Factors Affecting Study Site Distribution[a]
Short-eared owl, Pueo	Asio flammeus sandwichensis; Strigidae	1,200	Rare	N,C
Hawaiian thrush, Oomao	Phaeornis obscurus obscurus; Turdidae	1,600	1-10 birds/40 ha	N,C,D[b]
Elepaio	Chasiempis sandwichensis sandwichensis; Musicapidae	400	11-20 birds/40 ha	N[c],C
Anakihi	Loxops virens virens; Fringillidae	50	Less than 1 bird/40 ha	N[d], S[e]
Oo	Psittirostra psittacea; Fringillidae	ca. 2,100	Rare (one individual)[f]	N,R,D,C
Apapane	Himatione sanguinea; Fringillidae	400	21-60 birds/40 ha	N,R[g]

(a) Distribution factors: N = Habitat alteration
C = Competition
D = Disease
R = Resource availability
S = Sampling technique

(b) The thrush occurs commonly well below zones of mosquito infestation, indicating the secondary importance of disease in determining this species' distribution.

(c) High densities of this species are associated with high structural diversity of habitat which is generally lacking in the Puu Honuaula area.

(d) Anakihi prefer open dry scrub and forested areas to more mesic habitats (Conant 1980, personal observation). They have been found in the Malama Ki Forest Reserve (Puna) at an elevation of 250 feet (Berger, 1983).

(e) Conant (1980) indicates greater-than-usual difficulty in detecting this species from 10:00 a.m. to 2:00 p.m. Because of limited field time available, much of the censusing for birds occurred during these hours.

(f) Only one observation at this low elevation is cited in Conant's HPS survey (1980). This species is probably found in lower Puna only as a result of the wide dispersion tendency of these birds from their distributional center, Olaa Tract at NAVD, 4,000 feet. This species requires species habitat parameters (see Berger, 1983) and undisturbed forests. It will probably not occur in habitats such as those around Puu Honuaula, which have been considerably altered.

(g) Apapane appear to require a certain minimum density of ohia or a minimum level of nectar availability (Carpenter and MacMillan, 1976; Conant, 1980, personal observation). Presence of Apapane in the Puu Honuaula area (if at all) may be sporadic due to fluctuation of resource levels. Reduction of habitat quality in the study area due to invasion of exotic plants may also be a factor affecting this species' distribution. (The latter would affect Anakihi and Elepaio in a similar manner.)

No native hoary bats were observed in the study area. This species preferentially forages along forest edges or over bodies of water (Baldwin, 1950); a suitable habitat for this species probably exists in the Puu Honuaula area. However, there are no published records of bats in the Puna District.

7.2 ENVIRONMENTAL IMPACTS OF THE PROPOSED ACTION

The discussion below addresses clearing and construction impacts, operation impacts, and impacts of facility decommissioning on the biological environment.

CONSTRUCTION IMPACTS

The well sites and proposed power plant and facilities sites are situated on fallow fields and scrub vegetation. Non-native, weedy plant species make up the dominant vegetative cover in the uncultivated areas, and abandoned papaya plants occur extensively throughout the fallow fields. Native plant species that occur on the proposed well and power plant sites are not designated as rare, threatened, or endangered on the Federal or State lists. The species are common and are found throughout the Puna District and neighboring districts. The land requirements of the PGV facility are relatively small (approximately 17 acres for the power plant, wellpads, steam lines, and access roads); therefore, no significant impacts are anticipated for the total island populations of the plant and animal species present at the sites.

OPERATION IMPACTS

Fauna resources may be affected by the noise associated with certain planned activities such as well venting and remedial air drilling. Noise levels associated with normal operations will not be loud enough to affect biological resources. High noise levels will be short-term and are not likely to have adverse affects, though the levels may temporarily disturb certain fauna.

Activities of the PGV facility are not anticipated to adversely affect the Hawaiian hawk, which is an endangered species. Predicted worst-case well workover noise levels in the vicinity of hawk sightings are much higher than normal conditions, ranging up to 85 dBA. Well venting (unmuffled), which occurs after a well is drilled and tested, could increase noise levels for a couple of hours to 125 dBA at 50 feet, and between 50 dBA and 83 dBA at 1 mile from the event. However, no hawk nesting locations have been found on-site; the nearest active nest is approximately 1 mile east of the project site. At such a distance, even the loudest possible noise from the PGV facility is unlikely to adversely affect breeding of the hawk.

Human activity at the site is not anticipated to affect the Hawaiian hawk. Human activity at the PGV facility will be low, and activities will be geographically limited to within 17 acres. The hawks are accustomed to human activity in papaya fields.

If emitted to the atmosphere, noncondensable gases (containing predominantly hydrogen sulfide (H_2S) and carbon dioxide) might potentially affect regional vegetation and wildlife. The PGV project uses a reinjection process to virtually eliminate H_2S emissions from normal operations. This process absorbs the H_2S into a process fluid and reinjects the fluid into the geothermal reservoir. During some upset conditions the amount of H_2S released may increase temporarily, but these levels are too short-term to cause adverse effects.

H_2S air emissions are not expected to adversely affect vegetation or wildlife. H_2S emissions will be nondetectable during normal operating conditions. Under worst-case assumptions, H_2S emissions during normal conditions would be less than 4 lb/hr. This level is well below injury level.

Short-term exposure to high concentrations of H_2S (5 ppm) has been shown to damage sensitive plant species (Lodgepole Blowout Inquiry Panel, 1984). A concentration of 5 ppm is higher than any potential H_2S screened-level

concentration even during worst-case upset conditions. Thus, even unlikely upset conditions would not produce high enough H_2S concentrations to damage plant species.

Another study (Thompson and Kats, 1978) showed that continuous exposure to 0.3 ppm H_2S leads to vegetation damage to H_2S-sensitive plant species. The expected ground level concentrations for normal operations are lower than 0.3 ppm. Thus, PGV's long-term effects on vegetation will not be adverse. Since natural sources of sulfide have been a feature of the environment during the evolutionary process, the aqueous environment may contain species that are tolerant to low concentrations of sulfide (Siegal, 1980). In addition, a literature review of H_2S exposure effects on wildlife (Siegel, et al., 1986; New Norway Scientific Committee, 1974), concluded that the predicted H_2S ground level concentrations are not expected to effect wildlife.

PGV has commissioned several plant monitoring studies and plant tissue analyses at the HGP-A site and adjacent areas (Ecotrophics, 1981a, 1981b, 1982). No significant increases have been detected in toxic emissions such as mercury (Hg) or arsenic (As). These findings, however, are based only on short-term observations.

IMPACTS OF FACILITY DECOMMISSIONING

During facility decommissioning, there will be minor impacts on the biological environment due to the increased use of heavy equipment and increased activity. These impacts, which will be similar to the construction impacts previously described, are expected to be minor and short-term.

7.3 PROPOSED MITIGATION MEASURES

The discussion below addresses the mitigation of construction impacts, operation impacts, and impacts of facility decommissioning on the biological environment.

Noise effects that might potentially impact fauna will be mitigated by a variety of means, including insulating certain construction equipment and using effective exhaust mufflers.

There is currently a monitoring program of the Hawaiian hawk. The Hawaiian hawk will continue to be monitored throughout the construction, operation and decommissioning phases of the project. The purpose of monitoring is to determine if the PGV project is adversely affecting the livelihood of the hawk. It will be important to account for increased use of pesticides in surrounding agricultural lands, and residential development when examining the results of the monitoring program. The local extension campus of the University of Hawaii at Hilo is being considered to execute the monitoring program. If adverse impacts are observed, PGV will minimize or halt drilling and venting activities during the hawk's nesting season.

PGV will continue its vegetation monitoring program throughout the project. It will be designed to detect any changes in the vegetation caused by power plant and well emissions. To minimize any potential adverse effects on rare native plants, the ground that will be disturbed and graded will be restricted. Of the approximately 500 acres of the project site, only 17 will be disturbed. Areas where rare native plants have been found will be avoided.

Section 8

LAND USE AND INFRASTRUCTURE

This section discusses the regional and local land use surrounding the project site. The project site is located on 500 acres occupying 17 surface acres in the lower (southern) Puna District of the Island of Hawaii. The site is within the Kapoho Section of the Kilauea Lower East Rift Geothermal Resource Subzone, which is an area zoned for geothermal development. The discussion identifies the project's impacts on land use and describes the measures that have been taken and will be taken to mitigate any impacts.

8.1 ENVIRONMENTAL SETTING

REGIONAL LAND USE

The project site is located in the Puna District, one of nine districts on the Big Island. The Puna District is the easternmost district on the Island of Hawaii. The Puna Geothermal Venture (PGV) facility will be built in the lower Puna District. The boundary between the upper and lower portions of the Puna District is the line where small-lot subdivided land in upper Puna adjoins large-scale landholdings in lower Puna.

Geothermal Resource Subzone

The project is located on approximately 500 acres of the Kapoho Section of the Kilauea Lower East Rift Geothermal Resource Subzone. In 1983, the Hawaii State Legislature passed the Geothermal Resource Subzone Act which amended Hawaii's land use laws (Chapter 205, Hawaiian Revised Statutes(HRS)). This Act mandated the designation of geothermal resource subzones, in which geothermal exploration and development could occur. The Act directs the Board of Land and Natural Resources (BLNR) to designate the subzones. The designated subzones are areas of significant geothermal potential where the positive economic and social benefits of the development outweigh the potential negative environmental and social impacts.

The project area was designated as a subzone by Hawaiian legislation. Act 151, signed into law on May 25, 1984, established three areas as geothermal resource subzones since the land owners of these areas had obtained state geothermal mining leases and developers had been issued County special use permits for geothermal development (Department of Planning and Economic Development (DPED) 1986).

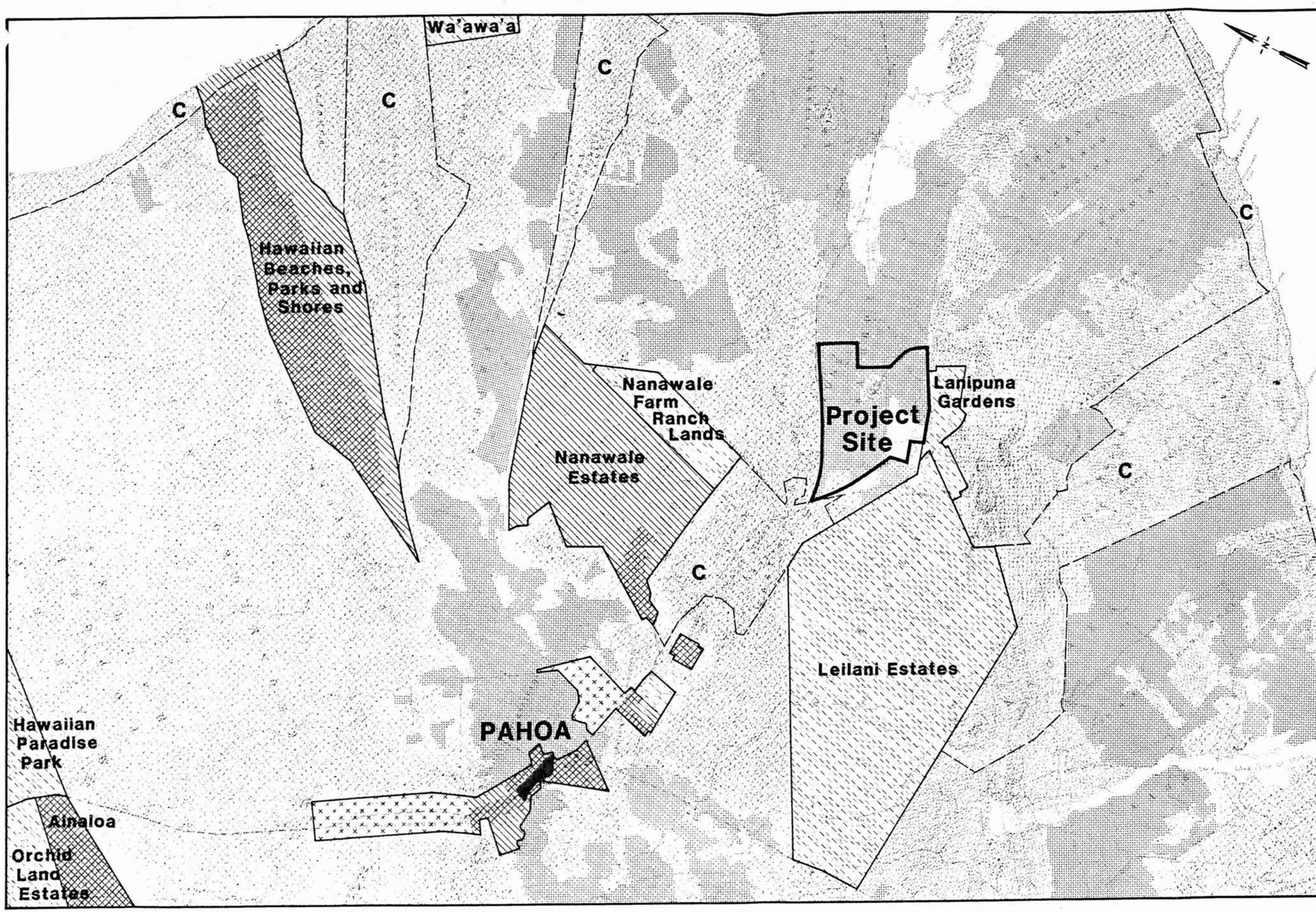
Uncultivated Vegetation

Most of the land in the lower Puna District is covered with "natural" (i.e., uncultivated) vegetation (Figure 8-1). Natural vegetation covers essentially all of the areas within the State Conservation District (the Nanawale Forest Reserve, the Malama-Ki Forest Reserve, and the coastal area between Highway 137 and the shoreline). Natural vegetation is also the predominant cover type within areas depicted on the map as "urban residential, undeveloped" and "residential agriculture, undeveloped." Small parts of these areas have been cleared for roads and a few residences.

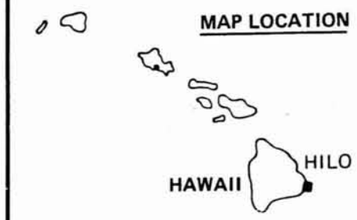
Agricultural

The second most extensive land use in the region is agricultural. Lumbering of the native ohia trees for the sawmill that operated in Pahoa between 1907 and 1918 resulted in cleared land, which was subsequently used for the cultivation of sugarcane. From the 1920s until the early 1980s, sugarcane remained the dominant crop in the region, and the Puna Sugar Company was the single largest employer. Sugar prices remained at depressed levels for several years, and in 1985 the Puna Sugar Company ceased operation.

With the closing of the Puna Sugar Company, papaya has become the principal agricultural crop. Acreage planted in papaya steadily increased over the last few years as the Puna Sugar Company phased out its sugarcane production, until the crops were found to be infested with the fruit fly. Concern over the possible spread of fruit flies has forced growers to treat the fruit before shipping. This has made it more difficult and costly for growers to market their fruit.



MAP LOCATION



LEGEND:

- Urban Residential - Undeveloped (1-5 Acres)
- Urban Residential - Developed (1-5 Acres)
- Residential Agriculture - Undeveloped (>1 Acre)
- Residential Agriculture - Developed (>1 Acre)
- Commercial
- Natural Vegetation
- Cultivated Land
- Recent Lava Flows
- C Conservation

BASED ON: State Land Use Commission District Map, Rev. Oct. 1982

SCALE

CONTOUR INTERVAL 20 FEET

.5 0 1 MI

1000 0 2000 4000 6000 FT

1 .5 0 1 KM

SOURCE: U.S.G.S., 1980, 1981a, 1981b

PUNA
GEOTHERMAL VENTURE PROJECT
HONOLULU, HAWAII

Figure 8-1

PUNA DISTRICT LAND USE

FLUOR DANIEL	JOB. NO.	DRAWING NO.	REV.

Some agricultural land in Puna is devoted to other types of produce, cattle grazing, and flower orchards, anthuriums, etc. Fallow sugarcane fields are scattered within the District.

Residential

Large portions of the Puna District, especially upper Puna, were subdivided into residential lots during the late 1950s and early 1960s. The sections of the Ainaloa, Orchid Land Estates, and Hawaiian Paradise Park subdivisions that are visible in the northwest corner of Figure 8-1 are part of the more than 40,000 acres of subdivided land in upper Puna (Planning Commission, 1974). Closer to the site, about 6,000 acres are contained in the recent subdivisions and in the older settlements of Pahoa and Kaniahiku. The distinction made on Figure 8-1 between urban residential and residential agricultural subdivisions is based on lot size. The lots classified as residential/agricultural range in size from 1 to 5 acres. Areas shown on the figure as urban residential lots include those that have been subdivided into lots of less than 1 acre (most are between 8,000 and 20,000 square feet). The determination of developed or undeveloped status was based on the density of structures shown on the three U.S. Geological Survey quadrangles (U.S. Department of the Interior, 1980, 1981) covering the area. These determinations were developed from aerial photographs taken in 1977.

Most of the subdivisions in Puna were approved in the 1950s and early 1960s, prior to the enactment of the County of Hawaii's subdivision and zoning codes. Consequently, many subdivisions do not conform to current standards for lot size and infrastructure improvements (roads, sewer, water supply, etc.). The right to develop has generally been "grandfathered," since the lots existed at the time the regulations were established.

Information on recent residential data was obtained from the County Planning Department (County Planning, 1987). In 1970, there were 1,891 housing units in the Puna District. The number of homes significantly increased during the 1970s. In 1980, the inventory of housing units had more than doubled to 4,127. The number of homes in Puna increased almost another 20 percent by 1985

to 4,925. Of the total units, 4,822 were single family dwelling units. In the vicinity of the PGV project area (Tax Map Section 4), the number of dwelling units in 1970 was 115. The number tripled to 344 by 1980. By 1985, the number of residential units had grown to 426.

Portions of the recent urban residential subdivisions have been developed and are occupied primarily by residents commuting to work in Hilo. Most of the larger lots in the residential and agricultural areas remain in their natural state. Profitable agricultural use generally is not feasible on these lots, given the lot size (1 to 5 acres) and conditions (heavily wooded and limited water supply). A smaller lot is generally adequate and cheaper for residential use.

Recreational

Puna has many natural recreational areas. These areas include the Hawaii Volcanoes National Park, Lava Tree State Park and many beach parks, such as Harry K. Brown, Isaac Hale, McKenzie and Kaimu Beach. Tour buses frequently stop at the black sand beaches of Kaimu and Kalapana but seldom stop at the other beach parks. There are five ball parks or general public parks, playgrounds at Keaau and Pahoa schools, and two gymnasiums open to the public (Canon, 1980).

Commercial

The only commercial area within 5 miles of the plant site is in Pahoa, and contains mostly restaurants and small shops. Major shopping centers are located outside the region in Keaau and Hilo.

LAND USE AT AND NEAR THE SITE

The area surrounding the PGV plant site are shown on Figure 8-2. The various land covers on and near the PGV-controlled land, as well as subdivision boundaries, are also shown on this figure. The figure is based on aerial

photographs taken by Air Survey Hawaii on March 8, 1984, and on field observations made in January 1984. Land cover categories depicted include recent lava flows, woodland vegetation, other natural vegetation, papaya orchards, other agricultural crops, and cleared land. The papaya orchards in the area have since been generally removed from production.

Residential

As shown on Figure 8-2, there are six subdivisions within 2 miles of the 500-acre parcel controlled by PGV. They are Nanawale Estates (4,289 lots), Leilani Estates (2,266 lots), Lanipuna Gardens (89 lots), Nanawale Farm Ranchlands, Kapoho Estates (10 lots), and Pohoiki Bay Estates (14 lots). All of the lots in these subdivisions are 1-acre in size except for those in Nanawale Estates, which are urban-size. Nanawale Estates is the only one of these subdivisions where substantial numbers of homes have been built, and it is the farthest from the project site.

A field survey conducted by Thermal Power in 1986 identified only 2 homes within one-half mile of the proposed power plant site, and the nearest of these was 0.4 mile from the plant site (See Figure 8-3). The same survey revealed only ten additional homes between 0.5 and 1.0 mile from the site of the proposed power plant.

Other nearby subdivisions include the Nanawale Farm Ranch Lands (also called Hawaiian Holiday Estates). The 88 lots in this subdivision are located about 1.5 miles north of the PGV sublease and range in size from 1 to 5 acres. North of the Nanawale Farm Ranch Lands is the Nanawale Estates subdivision with 4,289 urban-size lots of less than 10,000 square feet (County of Hawaii, Planning Commission, 1967).

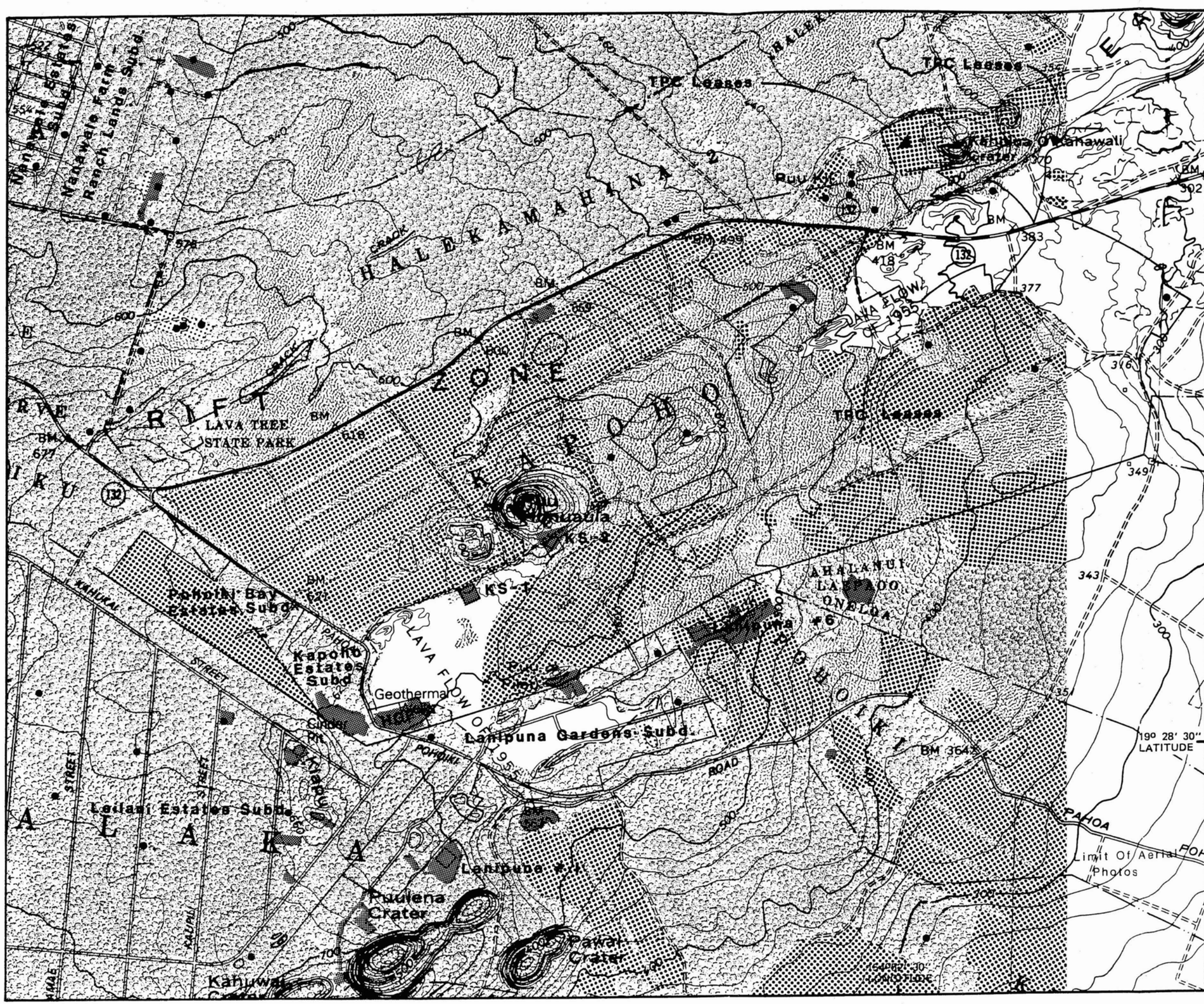
Geothermal Facilities

The PGV project is within the Kapoho Section of the Lower East Rift Geothermal Subzone. Three production wells have been drilled on the PGV plant site to date: Kapoho State 1 (KS-1), KS-1A and KS-2. There are two other geothermal projects in the immediate vicinity: HGP-A and Lanipuna. The HGP-A facility was developed from 1976 through 1981 as a research and demonstration project to generate 3 megawatts of electricity. The location of the HGP-A site is identified on Figure 8-2. It is approximately 0.5 miles southwest of the proposed plant site. The U.S. Department of Energy was the owner of the well until late 1986, when the State of Hawaii assumed ownership. The Hawaii Electric Light Company (HELCO) has been the operator of the site since the project began. Electricity produced from the HGP-A power plant is fed into HELCO's island-wide power grid. In early 1987, Thermal Power Company (TPC) signed an agreement with the State under which it will become the operations and maintenance contractor for the HGP-A power plant; TPC will not assume ownership.

The second geothermal project in the area is owned by Barnwell Geothermal, Inc. Two wells have been drilled to date: Lanipuna Well No. 1 (L-1; 0.8 miles southwest of the PGV plant site), and L-6; (0.5 miles southeast of the power plant site). State records (Tagamori, 1984) show that L-1 is drilled to 8,000 feet and L-6 is drilled to 5,000 feet. Both wells are nonproductive and drilling activity has been suspended.

Recreational

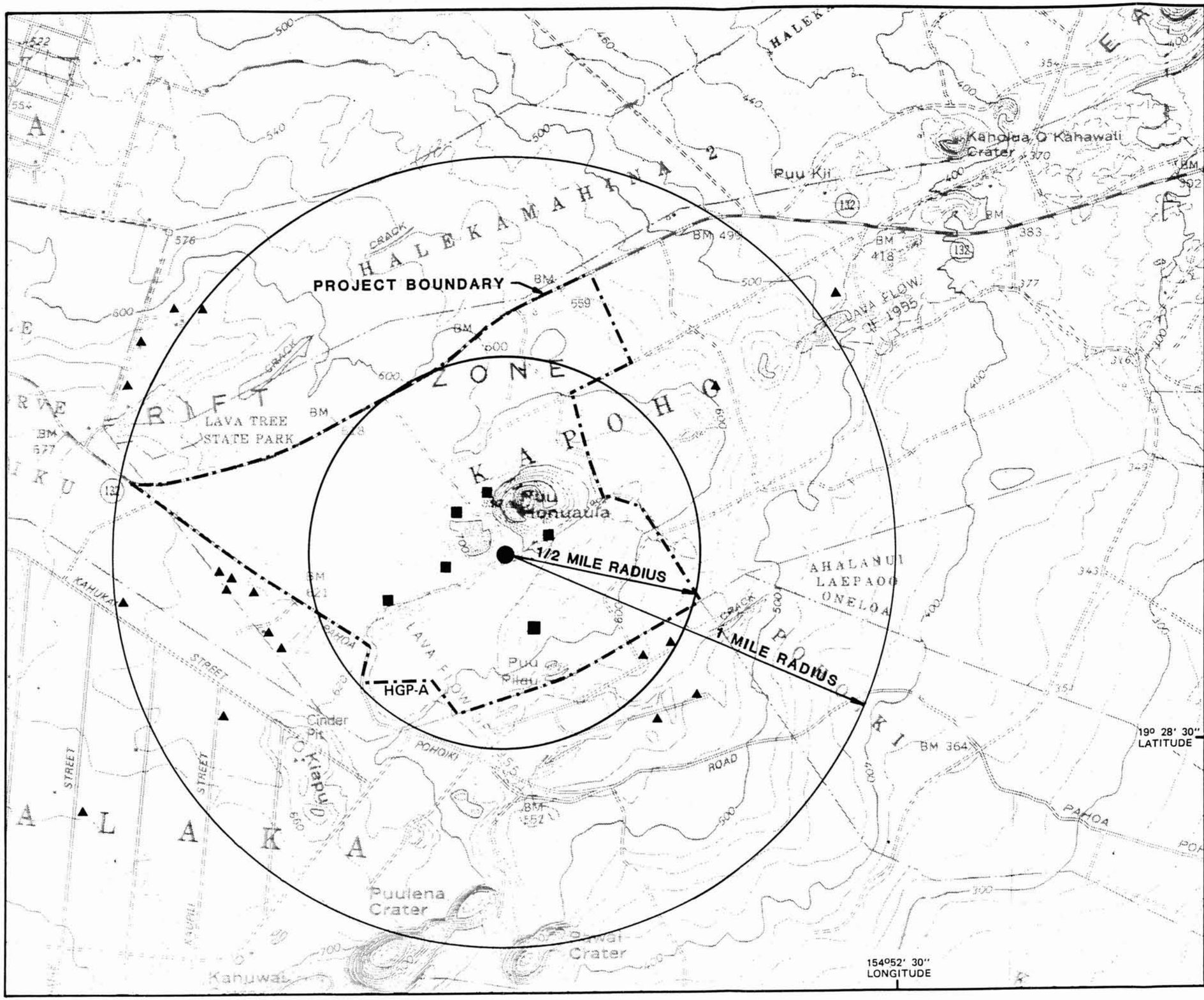
Lava Tree State Park is located approximately 1 mile northwest of the plant site. It is an aesthetic and geological resource of the area. Lava molds of trees stand among ohia trees and fern growth, forming an interesting and novel environment.



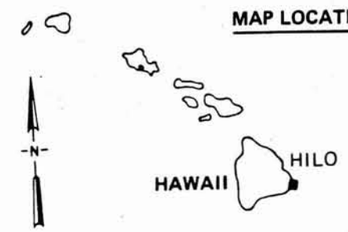
PUNA
GEOTHERMAL VENTURE PROJECT
HONOLULU, HAWAII

Figure 8-2
LAND USES IN THE PROJECT VICINITY

FLUOR DANIEL	JOB. NO.	DRAWING NO.	REV.



MAP LOCATION



LEGEND:

- ● POWER PLANT
- ■ PRODUCTION WELLPAD
- ▲ HOMES NEAR PROJECT SITE

SCALE
CONTOUR INTERVAL 20 FEET

0 — ½ MILE
0 — 1000 — 2000 FEET
0 — 1KM

SOURCE: U.S.G.S., 1980, 1981a, 1981b

PUNA
GEOTHERMAL VENTURE PROJECT
HONOLULU, HAWAII

Figure 8-3
LOCATION OF
RESIDENCES IN VICINITY
OF PROJECT SITE

FLUOR DANIEL	JOB. NO.	DRAWING NO.	REV.

Vegetation

Vegetation within 1 mile of the power plant was surveyed in 1984 (Char and Stemmermann, 1984). Much of the study area has been modified by previous human activities and consists of cultivated and fallow fields. An abandoned papaya orchard is located on the immediate project site. No actively cultivated areas exist within the 17 acres that will be utilized for the facilities. About one-third of the study area is covered by the 1955 lava flow. The remaining area consists of forest, scrub and fallow fields. Of the native vegetation types, the open Metrosideros forests occupy the most area.

INFRASTRUCTURE

Roads

State Highway 11 is the primary road from Hilo toward Kilauea Volcano. The primary routes connecting lower Puna to Keaau and Hilo are the Keaau-Pahoa Road (Highway 130), the Kapoho Road (Highway 132), the Puna Coast Road (Highway 137), and a portion of the Chain of Craters Road. State Highway 11, Chain of Craters Road, Kaimu Bypass Road, and most of the Keaau-Pahoa Road are all-weather surfaced and in good to excellent condition (DPED, 1982b). Pahoa-Pohoiki Road is the current access road to the PGV site, but will not be used as a primary access in the future because it has a blind left turn at the entrance to the site. The new access road will be Kapoho Road (Highway 132). A right-turn lane from Kapoho Road into the project area will be provided for traffic coming from the west to prevent traffic impediment caused by vehicles turning into the project area. Proper permits will be obtained from the Department of Transportation.

Keaau-Pahoa Road currently runs through the center of the town of Pahoa. The State Department of Transportation has proposed construction of the Pahoa Bypass Road, which would carry through-traffic around Pahoa's urban area. The proposed bypass road begins about 1,000 feet north of Kahakai Boulevard and rejoins the existing alignment adjacent to Pahoa High and Elementary Schools.

The new alignment is generally parallel to, and about 2,000 feet northeast of, the existing route. Plans for the Pahoa Bypass Road include two 12-foot-wide traffic lanes and 8-foot shoulders. The design has been completed and right-of-way acquisition is currently under way.

Arterial roads and highways are adequate to handle the truck traffic associated with the various current agricultural endeavors. Improvements to Pohoiki Road may be required if traffic from papaya, flowers and macadamia nut farms in the area increases. It is anticipated that "cane haul" roads will provide access to lands once used for sugarcane as agricultural development expands. Some of these roads may have to be upgraded. It is expected that roads of this type will continue to be privately owned and remain the responsibility of the landowner or the lessee.

Utilities

Telephone service is provided by the Hawaiian Telephone Company; expansion is provided as demand requires. During construction, electrical power will be provided by HELCO. A 34.5 kV overhead electrical transmission line extends along the Pahoa-Pohoiki Road to the HGP-A Site, sharing poles with the telephone system.

During operation, on-site power requirements will normally be met using power generated by the plant itself. Power from the geothermal plant will feed into HELCO's island-wide grid through a new transmission line.

A diesel generator unit will be available as an emergency backup if the system power fails. This unit is sufficient to operate one fire pump, one air compressor, the battery chargers, the HVAC system, control room systems, steam release facility H_2S abatement system and the emergency lighting. This generator will be driven by a diesel engine from fuel stored on-site to operate the emergency generating system for at least 24 hours.

Water Supply and Distribution

The public water supply and distribution system is operated and maintained by the County Department of Water Supply. There are four major public water systems in the Puna District, one of which has been extended beyond the HGP-A project site. Water requirements for the PGV facility are estimated at approximately 200 gallons per day from the public water system.

The public water supply on the island does not extend to all areas of Puna. Extensions of this water system are not required to support most of the agricultural activities predicted for the area because most crops in Puna are not irrigated. Flower and foliage products are an exception; in periods of drought, catchment may not provide sufficient water for these crops. Residents of areas without centralized water systems (including many in the Kapoho area, near the project site) rely on the roof catchment method. During periods of drought, the County assists these families in replenishing their water supply by paying two-thirds of the cost for purchase of water (Planning Department, 1979). Extensions of the County water system to current and future residents not served by the public system will be determined by the County in relation to its island-wide Capital Improvement Programs budget.

Disposal System

Municipal sewer systems are nonexistent in Puna. Sewage disposal in the district is by means of individual cesspools, septic tanks, or aerobic treatment units.

It is estimated that the proposed project would generate an average of less than 200 gallons of domestic wastewater per day. Current plans are to dispose of domestic wastewater on-site in cesspools. These cesspools are expected to perform satisfactorily due to the highly porous nature of the soils and underlying rock. Portable toilets may also be used during peak periods. No public drinking water sources would be affected by this disposal system.

8.2 ENVIRONMENTAL IMPACTS OF THE PROPOSED ACTION

LAND USE IMPACTS

Impacts of the PGV facility on agricultural, residential, and recreational land uses will be minimal. None of the areas to be disturbed (e.g., for access roads, power plant, wellpads, and steam lines) are currently or have recently been actively cultivated. Disturbed areas will be restored as near as reasonably possible to their original condition following facility decommissioning. The 1,500-foot pipelines between the power plant and Wellpad F may cause minor inconvenience (i.e., a short detour) to a few farmers if the adjacent land is actively cultivated in the future.

Housing Values

As a result of their experience with the experimental HGP-A project a number of area residents have expressed concern that continued geothermal development on the PGV property would adversely affect the value of their properties. To determine the likelihood that this would, in fact, occur, PGV hired Decision Analysts Hawaii, Inc. (1987) to study potential property value impacts, using the experience with HGP-A as a model.

In conducting its analysis, Decision Analysts Hawaii, Inc.:

- reviewed Multiple Listing Service data on Puna property sales from 1978 through mid-1987
- studied the details of all property sold in Leilani Estates during the same period
- collected and reviewed data on property tax assessments of properties of varying sizes and distances from the HGP-A well and power plant
- discussed the factors which appear to influence property values with the County tax appraiser responsible for Puna

- held in-depth interviews with the realtors responsible for most Puna property sales, focusing on the nature and cause of changes in price levels

Results of the analysis revealed that property values and sales in Puna are affected by so many factors unrelated to geothermal development (e.g., proximity to employment centers, the relative attractiveness of views, and the perceived risk of damage from lava flows) that it is impossible to use a purely statistical approach based on sales prices and/or property tax assessments to evaluate the effect of HGP-A. Because of this primary reliance was placed on information obtained during the interviews with knowledgeable realtors.

The analysis showed that the value of many, but not all, of the parcels in Puna have declined during the 1980s. Factors believed to account for this include:

- high interest rates during the early 1980s

- new tax laws passed in 1986 which reduced the speculative attraction of investment properties

- repeated national telecasts which showed homes in Puna being destroyed by molten lava (remember that a substantial part of the market for vacant parcels is among mainland residents who think they might some day retire to Puna)

- withdrawal of/increased premiums for hazard insurance on homes in many areas as a result of increased activity by Kilauea Volcano and the resulting loss of homes in some Puna subdivisions

- repeated news coverage of major police raids and arrests of marijuana growers which have contributed to the impression that Puna is a high-crime area unsafe for families

- the increased land supply and decreased incomes resulting from the closing of the Puna Sugar Company

Virtually every realtor interviewed by Data Analysts Hawaii, Inc. believed that the value of properties within approximately one-half mile of the HGP-A site were substantially lower than what they would have been if the power plant and well were not present. They were also nearly unanimous in agreeing that hydrogen sulfide (H_2S) emissions (which have a characteristic "rotten egg" smell) account for nearly all of the adverse effect. Elevated noise levels which occasionally result from well venting were considered much less of a problem, with residents having adjusted to it. The realtors felt that noise from other sources and the industrial appearance of the HGP-A facility had little effect on property values.

The consensus among the realtors interviewed was that the HGP-A well had little effect on the value of parcels more than one-half mile from the power plant and wells. Beyond a half mile from the HGP-A plant the H_2S concentration is rarely, if ever, high enough to be detectable. At that distance and less, the H_2S concentration is high enough to be odorous with some frequency. As a result, property values are only one-quarter to one-half what they would be if the odor were not present.

Following the interviews with realtors, an effort was made to determine if realtors' perceptions of reduced value could be confirmed using recent Multiple Listing Service sales data and/or property tax assessments. However, these data do not show a material difference between the value of properties within one-half mile of the HGP-A project and those farther away. Similarly, assessed property values, and the time trend of these values, appear to be about the same for properties near the project as for those for comparable properties farther away.

Finally, while the real estate sales data analyzed suggests that development of HGP-A and the ongoing geothermal prospecting and testing at other locations in the rift zone has had little adverse effect on property values, it also shows little evidence of speculative buying spurred by the presence of the resource. For most properties, the "mineral" rights to the geothermal steam

are retained by the State of Hawaii or former owners. Also absent was evidence that the value of nearby properties had been enhanced by the prospects of commercial uses associated with the possible use of excess heat or steam for industrial or agricultural purposes.

If the proposed PGV project were to have the same level of H_2S emissions and the same proximity to residential areas as the existing HGP-A facility, its effect on property values would probably be about the same as well. However, technology developments in the geothermal industry has enabled PGV engineers to design more reliable and efficient pollution control systems than HGP-A. As a result, emissions from the new facility would be substantially lower, and this means that the affected area would be substantially less than the one-half mile impact threshold associated with HGP-A. This, combined with the greater distance between the new facilities and residential receptors means that it will have little, if any, detectable effect on the value of surrounding residential properties.

INFRASTRUCTURE IMPACTS

The infrastructure impacts for the Puna District, including community services, housing, and other facility requirements, are not expected to be significant. Water supply and sewer disposal are expected to be provided by the developer.

Traffic through Pahoa will be increased during construction of the project. Approximately 35 vehicle round trips per day are expected during the well field and power plant construction. Each power generation unit and associated wells are estimated to take a total of 18 months to construct. The proposed project would add about 10 to 18 vehicle trips to existing traffic volumes during operation. These added vehicle trips amount to a less than 1 percent increase over existing volume at the intersection of Highways 130 and 132. According to data from the County Planning Department, existing traffic levels at this intersection are between 2,000 and 3,600 vehicles per day (Lyman, 1987). The increase should not cause a significant impact on traffic in the project area.

8.3 PROPOSED MITIGATION MEASURES

LAND USE

The site design was carefully prepared to limit the acreage that needs to be cleared. Only 17 acres of the 500-acre project site will be graded. Wellpads will be fenced as soon as grading is completed. All construction materials and equipment will be kept within these boundaries or on internal roads. Adequate area is available on-site to use as a staging area for the construction phase. A 5-acre temporary construction pad on-site is planned, and no offsite construction yards or bases are anticipated.

Plans for mitigation of visual impacts on residential and recreational use of the surrounding land at each well pad and the power plant will include landscaping and appropriate painting. Native vegetation is planned for landscaping. Structures will either be constructed with materials that blend into the natural vegetation, or will be painted in order to blend into the environment. See Section 12 for a detailed discussion of aesthetics.

Cleared wellpad areas or pipeline corridors that are no longer required will be promptly restored and revegetated. The project site will be restored to its original natural vegetation once the power plant and wells have reached the end of their economic life, in accordance with the rules of the DLNR. Revegetation of the portions of the pads located on the 1955 lava flow will accelerate the natural plant colonization of this generally unproductive land.

Potential adverse effects on housing and land values are mitigated by the plant design and pollution control abatement technology that is installed. This abatement technology reduces H_2S emissions to negligible amounts.

INFRASTRUCTURE

PGV plans to use Kapoho Road (Highway 132) rather than the existing access road (Pahoa-Pohoiki Road) as the primary access to the site because it has fewer curves. An entrance road will be constructed on the project site. A right-turn lane on Kapoho Road for traffic coming from Hilo or Pahoa will be constructed at the entrance to the plant site. This right-turn lane will reduce traffic congestion associated with vehicles (especially construction-related vehicles) accessing the site.

Section 9

PUBLIC HEALTH AND SAFETY

Factors associated with the PGV project which could affect the health and safety of the public and employees are discussed in this section. To present the information as clearly as possible, the normal division of environmental setting and impact analysis was not used in this section. This section is broken down to four major categories: Types and effects of risks, assessment of risks, mitigation of risks, and emergency preparedness plans.

9.1 TYPES AND EFFECTS OF RISKS

Health and safety risks associated with the PGV project can be broken down by the types of exposure and the group exposed. Most of these risks are common to any geothermal development. An assessment of the impact of these risks to both the general public and workers at the plant is contained in the following subsection.

The following list identifies the potential risks for the public and for plant operational personnel and the subsequent paragraphs provide a brief description of the effects of the risk. The risks include:

- Exposure to continuous, low levels of H_2S from well drilling, normal wellfield and power plant operations and turbine bypass operations

- Exposure to moderately higher levels of H_2S from infrequent, short duration planned and unplanned events such as well venting, well testing, steam stacking, rupture disk events, and pipeline cleanout

- Exposure to moderately higher levels of H_2S from highly unlikely but possibly longer duration uncontrolled emissions from a well blowout

- Exposure to increased noise levels resulting from construction and operation of the wellfield and power plant

- Contact with hazardous chemicals (sodium hydroxide and hydrogen peroxide) which may be used for H_2S abatement

- Exposure to trace elements which occur naturally in geothermal fluids

- Risk from high temperatures and pressures normally associated with steam and power production

- Risk from increased traffic during the construction phase of the project

- Risk of industrial accidents resulting from the use of heavy construction equipment

EFFECTS OF H_2S EXPOSURE

The exposure to H_2S appears in the first three risks identified and is a public health concern. H_2S is a colorless gas that at low concentrations has a rotten egg odor. Although it is not generally a serious health risk, it can cause respiratory poisoning at very high concentrations, acting primarily as a systemic poison (American Conference of Governmental Industrial Hygienists, (ACGIH) 1980). Some humans can detect the smell of H_2S at concentrations as low as 0.47 parts per billion (0.00047 parts per million by volume (ppmv)). Continual exposure to H_2S at 0.30 ppmv concentrations can cause nausea, insomnia, shortness of breath and headaches. Concentrations of 10 to 50 ppmv can cause eye irritation, throat agitation, fatigue, loss of appetite and insomnia after chronic (continuous) exposure. Exposure to H_2S concentrations of 200-300 ppmv can cause serious irritation to eyes and the respiratory tract. This level is the maximum concentration that can be inhaled for 1 hour without serious consequences. At concentrations of 700-1500 ppmv, death will occur within 15 to 30 minutes. Table 9-1 summarizes the health effects of H_2S exposure at various concentrations.

Table 9-1

HUMAN HEALTH EFFECTS OF HYDROGEN SULFIDE

H_2S Concentration[a] (ppmv)	Health Effects
0.00047-0.0045	Odor threshold
0.007-0.03	Slight odor
0.025	Hawaii ambient increase (proposed)
0.04-0.13	Clear definite odor
0.10	Hawaii ambient air standard (proposed)
0.12	Central nervous system effects after a 1-hour average ambient exposure to this concentration
0.30	Increased incidence of nausea, insomnia, shortness of breath, and headaches after chronic (long term) exposure.
1.0-10	Incidence of decreased corneal reflex after chronic exposure
4.6	Readily apparent, offensive odor
10	Threshold limit value for 8-hour exposure at the work place (OSHA)
10-50	Threshold for irritative action after prolonged exposure: eye irritation such as conjunctivitis and, at the higher concentrations, dry throat. Fatigue, loss of appetite, and insomnia after chronic exposure
20-30	Very strong but not intolerable odor
70-150	Eye irritation such as conjunctivitis, keratitis, and photophobia after several hours of exposure. Threshold for olfactory paralysis occurring within minutes
200-300	Serious local irritation to eyes and respiratory tract caused upon inhalation for one hour, with possible subsequent pulmonary edema. This is the maximum concentration that can be inhaled for 1 hour without serious consequences.

Table 9-1 (Cont'd)

H_2S Concentration[a] (ppmv)	Health Effects
400-700	Threshold for acute exposure with systemic reaction and possible death from prolonged exposure. Irritative effects are severe with possible pulmonary edema. Concentration is dangerous after exposure for more than 1 hour[b]
700-1,500	Death occurs within 15-30 minutes of exposure[b]
1,800 and over	Immediate respiratory paralysis[b]

(a) Most concentrations cited are approximate due to the lack of precise data, the fact that most studies of H_2S are not recent, and lack of value agreement in the literature.

(b) This information is partially based on studies of dogs, which demonstrate a sensitivity to H_2S similar to that in man.

Source: Walton & Simmons, 1978

EFFECTS OF NOISE

The County Planning Department has developed Geothermal Noise Level Guidelines from a study of noise in the Puna District (Darby-Ebisu and Associates, Inc., 1981). The guidelines consider 55 dBA during daytime (7:00 a.m. to 7:00 p.m.) and 45 dBA during nighttime (7:00 p.m. to 7:00 a.m.) as satisfactory sound levels which will not cause undue interference with activity or annoyance under normal conditions.

From a hearing conservation standpoint, a person's hearing is not impaired until noise levels exceed 70 dBA consistently over a 24-hour day. Noise levels below 70 dBA (average over 24 hours) are considered to have a negligible impact on a person's health and welfare. The Federal Occupational Safety and Health Administration (OSHA) standard for worker hearing conservation is 90 dBA for an 8 hour period, without protective hearing equipment.

EFFECTS OF HAZARDOUS CHEMICALS

The only hazardous chemicals that may be used in large quantities at the plant have been identified as liquid sodium hydroxide (NaOH) and hydrogen peroxide (H_2O_2). NaOH is a corrosive material. Skin contact with NaOH will result in burns and ulceration. Inhalation of concentrated mists containing NaOH can cause effects ranging from mild irritation to severe damage to the mucous membranes, depending upon the amount inhaled. Contact of mucous membranes or eyes with NaOH can result in burns and ulcerations. The OSHA limit for 8-hour worker exposure is 2 milligrams per cubic meter (mg/m^3)(Sax, 1986). Effects of skin or eye contact can be greatly reduced through the rapid flushing of the affected area with large amounts of water.

Hydrogen peroxide, H_2O_2, is a strong oxidizer. Contact with the skin may result in blistering. Inhalation of vapors can result in damage to mucous membranes. The eyes are particularly sensitive to irritation by H_2O_2. The OSHA limit for 8-hour workplace exposure is 1 ppm (Sax, 1979). Effects of eye or skin contact can be reduced through the prompt flushing of the affected area with large amounts of water.

EFFECTS OF TRACE ELEMENTS

Trace elements occur naturally in geothermal steam. Chemical analyses of the geothermal fluids (brine and condensate) have been performed, and no significant concentration of any trace element was found.

Trace elements can be emitted with the water vapor leaving the cooling tower stack and dispersed in the atmosphere. Preliminary data from the PG&E Geysers project suggests that there may be an exposure risk for plant maintenance workers under some maintenance conditions, such as removal of scaling from pipes, turbine blades, condensers, cooling towers, etc.

Arsenic is one of the trace elements found in Puna geothermal steam resources. Arsenic is a poison and a known carcinogen. It is used in ant poisons, insecticides, weed killers and other products. Ingestion of arsenic may cause a range of disorders such as nausea, headache, or diarrhea. Arsenic exposure is regulated by both OSHA and the Hawaii Department of Occupational Safety and Health (DOSH), which has established 10 micrograms per cubic meter (ug/m^3) as the Permissible Exposure Level (PEL). The OSHA limit for an 8-hour worker exposure to arsenic is 0.2 mg/m^3 (Dreisbach, 1983).

HEAVY EQUIPMENT EXPOSURE

Construction and maintenance workers will be exposed to the risks associated with the use of heavy construction equipment such as personal injury resulting from accidents. These risks will be no different than those normally associated with construction or industrial sites.

9.2 ASSESSMENT OF RISKS

Assessment of the risks for H_2S, well blowout, noise, trace elements, hazardous chemicals, high temperature and pressure, and traffic accident exposures are contained in the following subsection. Further discussion of the particular events relative to H_2S and noise exposures is contained in other sections of this EIS.

H_2S EXPOSURES

The ACGIH has established two H_2S exposure limits. The threshold limit value (TLV) for a worker (40-hour work week) is 10 ppmv. The short-term exposure limit (STEL) for a 15-minute exposure is 15 ppmv. For workers, the OSHA established a Maximum Permissible Exposure Limit (PEL) for H_2S of 20 ppmv. For general public exposure, the Hawaii Department of Health has proposed a maximum 1-hour ground-level concentration for H_2S of 139 ug/m^3 or 0.1 ppmv. Normal operations emit a continuous, low level concentration of H_2S. The 1-hour GLC value (0.10 ppmv) is used as the Estimated Permissible Concentration (EPC) for these operations because it applies to continuous exposure of the local residents. Short duration events do not pose the same health risk to residents. These events are more closely related to occupational exposures than to continuous residential exposures. TLV limits are the maximum concentration workers may be repeatedly exposed to (8 hours per day, 5 days per week) without adverse effect. The EPC for short-term exposure is, therefore, based on the ACGIH TLV, 10 ppmv for an 8-hour average.

The appropriate EPC values for power plant and wellfield emission events are provided in Table 9-2. Background H_2S concentrations were measured at four locations around the project site during 1981 to 1986 and are discussed in Section 5.

Anticipated Emissions

To determine the potential exposure levels resulting from the PGV project, anticipated emissions were calculated for the project. (See Table 9-3). During plant operation, more than 99 percent of the H_2S contained in the geothermal fluids will be separated from the condensed steam, absorbed in the cooling tower blowdown and reinjected back into the reservoir. This essentially closed loop disposal method will greatly reduce the potential for exposure to H_2S at or near the facility. H_2S emissions from all sources will be 4 lb/hr or less, primarily from the cooling tower. This H_2S emission rate will be less than one-half of the maximum allowable emissions proposed by the Hawaii Department of Health.

Air quality impacts were assessed by dispersion modeling techniques using the EPA approved models. The models calculate the highest ground-level concentrations at receptors for averaging times ranging from 1 to 24 hours and for the entire period of meteorological data. Table 9-2 provides a comparison of the EPC and maximum ground-level concentrations for the various events. Maximum ground-level concentrations were calculated from the appropriate incremental emission and the maximum background concentration (0.048 ppmv).

Information generated for the Pacific Gas and Electric Company's (PG&E's) Geysers facilities in Northern California (during a 3-year study) concluded that occupational health risks from exposure to H_2S under normal conditions were minimal. Workers were exposed to levels of H_2S typically at concentrations of 1 ppm or less. Comprehensive physical examinations and laboratory studies were conducted at the end of each of the 3 years. No chronic ill effects were observed from exposure to the H_2S or other components of geothermal emissions.

WELL BLOWOUTS

Well blowouts refer to the uncontrolled venting of fluids due to a failure of the casing or wellhead equipment. The potential for this occurrence is extremely small.

Potential causes of this failure may be corrosion, erosion, mechanical failure and geologic events. The precautions taken to prevent these causes from creating a blowout are discussed later in this section under "Mitigation of Identified Risks."

In terms of risks, a well blowout is equivalent to several other wellfield events. The H_2S emission levels and noise levels are similar to those of well venting or rupture disk events as shown in Table 9-3.

Table 9-2

ESTIMATED PERMISSIBLE CONCENTRATION (EPC) VALUES FOR H_2S

Operation	Estimated Permissible Concentration	Maximum Ground-Level Concentration[a]
Normal Operation	0.10 ppmv/1 hr	0.054 ppmv/1 hr
Turbine Bypass	0.10 ppmv/1 hr	0.054 ppmv/1 hr
Steam Stacking	0.10 ppmv/1 hr	0.072 ppmv/1 hr
Injection Failure	10.0 ppmv/8 hr	0.049 ppmv/8 hr
Well Venting	10.0 ppmv/8 hr	0.415 ppmv/8 hr
Well Flow Testing	10.0 ppmv/8 hr	0.072 ppmv/8 hr
Well Workover	10.0 ppmv/8 hr	0.061 ppmv/8 hr
Pipeline Cleanout	10.0 ppmv/8 hr	0.248 ppmv/8 hr
Rupture Disk Event	10.0 ppmv/8 hr	0.215 ppmv/8 hr
Well Blowout	10.0 ppmv/8 hr	0.415 ppmv/8 hr

(a) Conservative estimate of maximum GLC based upon highest recorded ambient concentration (0.048 ppmv) and worst case incremental increase from modeling of operation.

TABLE 9-3

H2S AND NOISE EMISSION SUMMARY

EVENT	MAXIMUM ANTICIPATED H2S EMISSIONS (lb/hr)	EMISSION BASIS	ESTIMATED DURATION OF EMISSION	ESTIMATED WORST YEAR FREQUENCY (a)	ANTICIPATED NOISE LEVEL (dBA @ 50 FT)
BACKGROUND	NONE	---		N/A	32 - 53
NORMAL PRODUCTION	4.0	99+% REMOVAL OF H2S FROM CONDENSER	7884 HR/YR	(b)	66 - 81
TURBINE BYPASS	4.0	99+% REMOVAL OF H2S FROM CONDENSER	613 HR/YR	(b)	66 - 81
STEAM STACKING	21.1	540,000 LB/HR OF STEAM @ 1950 PPM(W) H2S W/ 98% H2S REMOVAL	263 HR/YR	(b)	55
REINJECTION FAILURE	1.3	TOTAL H2S CONTENT IN BRINE SENT TO POND VENTED	48 HR	4 EVENT/YR	55
WELL WORKOVER	7.0	120,000 LB/HR OF STEAM @ 1950 PPM(W) H2S WITH H2O INJECT'N REMOVING 40% H2S & H2S ABATEMENT REMOVING 95% OF REMAINING H2S	120 HR/EVENT	4 EVENT/YR	64 - 85
WELL FLOW TESTING	14.6	150,000 LB/HR OF STEAM @ 1950 PPM(W) H2S WITH 95% H2S ABATEMENT	240 HR/EVENT	4 EVENT/YR	55
WELL VENTING	292.5	150,000 LB/HR OF STEAM @ 1950 PPM(W) H2S WITH NO H2S ABATEMENT	8 HR/EVENT	4 EVENT/YR	75 - 125
PIPELINE CLEANOUT	292.5	150,000 LB/HR OF STEAM @ 1950 PPM(W) H2S WITH NO H2S ABATEMENT	1 HR/EVENT	3 EVENT/YR	75 - 125
RUPTURE DISK EVENT	292.5	150,000 LB/HR OF STEAM @ 1950 PPM(W) H2S WITH NO H2S ABATEMENT	2 HR/EVENT	4 EVENT/YR	75 - 125
WELL BLOWOUT	292.5	150,000 LB/HR OF STEAM @ 1950 PPM(W) H2S WITH NO H2S ABATEMENT	(c)	(b)	75 - 125

(a) WORST YEAR REFERS TO THE MAXIMUM ANTICIPATED NUMBER OF EVENTS IN ONE YEAR
THE TOTAL NUMBER OF PLANNED WELLFIELD EVENTS IS:

WELL DRILLING: 20 TIMES WELL FLOW TESTING: 20 TIMES
WELL VENTING: 20 TIMES PIPELINE CLEANOUT: 6 TIMES

(b) THERE IS NO "WORST" YEAR FREQUENCY FOR THESE EVENTS

(c) THERE IS NO ESTIMATED DURATION FOR THIS EVENT

NOISE EXPOSURES

Anticipated noise levels were developed for the construction, operation and decommissioning phases of the project. The noise levels produced during the life of the project do not present a risk to the health or safety of the nearby residents. Noise levels from construction, normal power plant operation and decommissioning will be below the Geothermal Noise Level Guidelines at the nearby residences. Operations which are conducted 24-hours per day such as well drilling or well workovers may sometimes slightly exceed the nighttime levels as shown in Table 9-4. The noise levels shown do not include any noise attenuation due to terrain (foliage and natural barriers) so the actual levels may be lower than shown.

Planned events which will produce a high noise level, such as well venting, and pipeline cleanout, will be conducted only during daylight hours and will last less than 8-hours. Unplanned events which produce these high noise levels, such as a rupture disk event, may occur during either the daytime or nighttime but will not last for more than two hours.

Unlikely occurrences such as a well blowout will result in noise levels similar to those for well venting. These events may happen at any time and may extend for a longer period of time. The noise levels and anticipated durations of most wellfield and power plant events are shown in Table 9-3.

The anticipated levels of occupational exposures were also calculated. OSHA's standard for worker safety is 90 dBA without hearing protection for an 8-hour period. Noise levels for some activities exceed this standard, but none will be continuous for 8 hours. During certain operating conditions the noise levels may require that hearing protection be used by exposed workers.

EXPOSURE TO TRACE ELEMENTS

Arsenic is the only trace element which was identified as a potential risk. Prediction of the occupational arsenic exposure is not possible from the information currently available and the many variables involved. If the

TABLE 9-4

SUMMARY OF NOISE LEVELS

Activity	Noise Level (dBA) at: 50 feet	Nearby Residences(a) Daytime	Nighttime
Construction	89 - 94	<55	none (b)
Well Drilling	64 - 75	45 - 51(c)	45 - 51(c)
Well venting	75 - 125	58 - 91	none(b)
Normal Operation	66 - 81	<45	<45
Well Workover	75 - 85	45 - 54(c)	45 - 54(c)
Decommissioning	89 - 94	<55	none(b)

(a) The distance to nearby residences was determined to be 0.4 miles.

(b) Items marked "none" are not performed at night.

(c) Noise level varies depending upon which well pad is worked on. Wellpads E and F generally have the highest noise impacts due to their locations. Section 6 provides further details on anticipated levels at the residential tracts.

arsenic levels at the site exceed the OSHA action level of 5 ug/m^3 during an 8-hour period, then the federal requirements of 29 CFR (Code of Federal Regulations) 1910.1018 and Hawaii DOSH standards (Title 12, Subchapter 8) are applicable.

The concentration of arsenic in these geothermal fluids has been measured and the potential risk to nearby residents will be insignificant. Preliminary analyses of the brine and steam condensate reveals that the majority of the arsenic present remains in the brine. Analysis of catchment water has not shown any increase in arsenic or other trace element concentration from project activities to date.

The concentration of arsenic in the steam condensate is less than 0.01 parts per million by weight (ppm(w)) which is the detection limit of the analytical method used. The concentration of arsenic in the cooling tower water and drift were based upon a 0.01 ppm(w) basis as an upper limit. The Estimated Permissible Concentration (EPC) for arsenic is 0.005 ug/m^3 (Cleland and Kingsbury, 1977). The concentration of arsenic in the cooling tower drift (0.0039 ug/m^3) is less than this value. After the arsenic is dispersed in the air the levels will be below detection limits.

Monitoring of trace element concentrations i.e., arsenic, lead, mercury, etc. will be performed periodically during plant operation and maintenance activities. No buildup of arsenic has been observed at HGP-A.

The risks of exposure to radon-222 were also assessed. Radon is a naturally occurring element that results from the breakdown of rocks and soils containing radioactive particles. The measured concentrations of radon-222 in the geothermal steam ranged from 749 to 3010 pCi/liter of condensate. To put these values in perspective, the Hawaii Department of Health recently reported that radon levels in 14 of 18 drinking water wells tested were below 200 pCi/liter of water, while the other 4 wells varied from slightly over 200 to nearly 1000 pCi/liter. These levels were not considered to be a serious health risk according to the Health Department. (Yamaguchi, 1987)

Based upon the maximum concentration (3010 pCi/liter of condensate), the radon concentration in the cooling tower plume is calculated as being 0.17 pCi/liter of air. When the radon is dispersed into the atmosphere the ground-level concentration will be even lower. The radon ground-level concentration for steam stacking is approximately 0.003 pCi/liter of air. Residential exposures to less than 4 pCi/liter of air are not significant according to EPA guidelines.

HANDLING OF HAZARDOUS CHEMICALS

The hazardous chemicals used in significant quantities at the plant are liquid NaOH and H_2O_2. The H_2S abatement system chosen, reinjection, reduces the risks associated with handling of these chemicals by minimizing their use. The other H_2S abatement systems use larger quantities of these chemicals or require the use of other hazardous chemicals.

NaOH is a corrosive material and H_2O_2 is a strong oxidizing agent. Both materials must be handled carefully. Use of proper mixing techniques, clean, high quality hoses and connections and personal protective equipment (e.g., gloves, goggles, aprons, etc.) will greatly reduce the risk of accidental exposures. The risks associated with the employee handling of NaOH and H_2O_2 are minimal if proper training and handling techniques are used. Emergency showers and eyewash stations will be located in areas where chemical exposures may occur.

NaOH reacts violently with acids or acidic materials (Sax, 1979). A significant amount of heat is generated upon dilution of concentrated solutions. Care must be used in working with the material to avoid adding a small amount of water to a large amount of NaOH.

As a strong oxidizer, H_2O_2 is incompatible with many materials. Accidental mixing of H_2O_2 and acids or metals (such as iron) for example, may result in violent decomposition of the peroxide. The accompanying release of oxygen may result in a fire or the pressuring and rupturing of a sealed container (Sax, 1979).

Effects of skin or eye contact of either NaOH or H_2O_2 can be reduced through the prompt flushing of the contacted area with lots of water.

Risks to the public are minimal since they are only exposed in the event of a serious traffic accident during transport of the chemicals which damages the transporting truck to the extent that it leaks. Public safety agencies are able to deal with this type of accident and can confine the public risk.

EXPOSURES TO HIGH TEMPERATURE AND PRESSURE

The principal risk stems from contact with hot fluids or piping which are present at the geothermal project. To prevent public contact, measures will be taken to first, secure the property (e.g., chain-link fences around wellpads and power plant) and second, insulate the exposed pipelines. The insulation will ensure that exposed surfaces are no more dangerous than household hot water lines.

Employee exposures to high temperature and pressure steam are no worse (and possibly less) than similar exposures associated with a conventional steam power plant.

EXPOSURE TO TRAFFIC ACCIDENTS

During the construction phase of the project, vehicular traffic is expected to increase by 35 vehicular round trips per day. Traffic during normal power plant operation will drop to 10 - 18 vehicle round trips per day. This represents less than a one percent increase over existing traffic levels at the intersection of Highway 130 and Highway 132. Existing traffic levels at this intersection vary from 2000 to 3600 vehicles per day according to the County Planning Department. To prevent potential traffic congestion and accidents relating to PGV traffic, a right-hand turn lane will be added on Kapoho Road (Highway 132) to remove turning vehicles from the main traffic lanes. The risk to employees and the public is not significantly altered by the project.

9.3 MITIGATION OF IDENTIFIED RISKS

H_2S MITIGATION

H_2S will be controlled in an essentially closed loop system whereby more than 99 percent of the H_2S contained in the geothermal fluids will be dissolved in the cooling tower blowdown and reinjected back into the reservoir. A backup abatement system will be employed if the injection system malfunctions. The backup system will incinerate the gases and treat them with sodium hydroxide to produce nontoxic sulfites and bisulfite compounds. H_2S emissions will be negligible during drilling because mud drilling techniques will be used. A rock muffler with chemical abatement will treat H_2S emissions during well testing and steam stacking.

H_2S will be monitored throughout the construction, operation, and decommissioning phase of the project. During well drilling and plant operations, the air will be continuously monitored in strategic locations. Hand held H_2S monitors will also be used extensively throughout the plant for detection of H_2S exposures.

The following measures will be taken to protect the health and safety of both the workers and the public from exposures to H_2S:

- Use of conservative safety factors for design of process facilities and the related piping
- Minimize the amount of steam venting
- Select optimum weather conditions for needed well venting
- Design the process plant equipment with automatic instrumentation and controls to reduce the likelihood of a rupture disk event resulting from a process upset

H_2S is heavier than air and will displace air in confined spaces. H_2S concentrations in such spaces may reach levels much higher than the level of

release from the plant during normal operations. To avoid accidents associated with entrance into confined spaces, all employees entering such places will be required to wear protective personal equipment until appropriate ventilation or air exchange has been accomplished. Spot test units will be available to check for H_2S in those areas not having permanent detectors. H_2S monitors and emergency air units will be located in strategic places. Work crews will include backup personnel to observe workers in risk areas. Regular safety courses and employee training will be provided, and signs indicating high risk areas will be posted.

WELL BLOWOUT

The following mitigation measures are taken to ensure the integrity of the geothermal wells and prevent uncontrolled releases of H_2S to the atmosphere from well blowouts:

- Use of blowout preventers during drilling that can rapidly choke off the flow of fluids from the well
- Use of conservative safety factors in designing wells and wellhead equipment
- Installation of two strings of steel casing that are cemented in place from the surface to the reservoir cap rock
- Selection of premium grade casing materials and connections to strengthen the wellbore
- Specification of cement mixtures with high strength and insulating properties
- Close attention to procedures used during installation of cement
- Inspection and testing of the wellhead equipment regularly
- Surveys of the casing to inspect the condition

NOISE

Noise produced from construction, operating, and decommissioning the site will be minimized through various insulation techniques (see Section 6 for

details). Any personnel who are exposed to noise levels exceeding OSHA's workers safety limit (90 dBA for an 8 hour period without protective hearing equipment) will be required to wear protective hearing equipment. Such instances will be very rare.

EXPOSURE TO ARSENIC

Prior to construction and start-up, a baseline monitoring program for arsenic will be established to determine the occupational exposures and to determine if the OSHA action level is exceeded. Monitoring of arsenic concentrations will continue during operation, particularly during maintenance activities. In the event that the action level is exceeded, personnel protection equipment will be provided.

HAZARDOUS MATERIALS

Applicable federal regulations (e.g., OHSA, and EPA) and Hawaiian regulations (e.g., DOSH and DOH) will be incorporated into the procedures and standard policies of the facility. Applicable Department of Transportation (DOT) regulations (Title 49 CFR, Sections 171-178) will be incorporated into the procedures for delivery of any hazardous materials used on site. Transportation routes will be carefully selected and transportation will be scheduled to minimize the effects on the local population. The reinjection system is normally used for H_2S abatement and does not require NaOH; therefore, no deliveries are required. The highest normal usage of NaOH occurs when the Burner/Scrubber system is operating. The number of truck deliveries during Burner/Scrubber operation is less than two per day.

Only employees trained in the proper handling and use of hazardous materials will be allowed to work in hazardous material areas. All employees will be informed of the hazards of each compound and the appropriate emergency procedures in the event of an accidental contamination. Personal protective equipment, spill cleanup equipment, and emergency first aid stations (e.g., emergency eyewashes and showers) will be strategically located throughout the plant.

Secondary containment structures such as dikes or berms will be constructed around the NaOH and H_2O_2 storage tanks. These tanks will be segregated by distance from any incompatible material (e.g., NaOH and acids, solvents containing ketones, etc., H_2O_2 and strong acids, alcohols, glycols, etc.). Periodic inspection of these tanks will be performed according to regulatory requirements to determine any potential problems.

TRAFFIC

To mitigate potential traffic congestion and accidents relating to construction traffic on Kapoho Road (Highway 132) a right-hand turn lane will be constructed for vehicles turning into the site off Route 132.

9.4 EMERGENCY PREPAREDNESS PLANS

The project will utilize three emergency preparedness plans; one for well drilling and testing, which has already been approved by the County Civil Defense Director and is in effect; one for construction; and one for operation.

An outline of the plans that will be used during construction and operations has been developed (see Table 9-5). The plans will be issued prior to the construction phase and operations phase, respectively. The plans will provide a comprehensive explanation of prevention and emergency response measures. The plans will address: outside emergency services; emergency response measures; offsite authority notification; control measures; evacuation plans; media notification; personnel training; and emergency reporting and recordkeeping.

Table 9-5

PRELIMINARY EMERGENCY PLAN OUTLINE
FOR CONSTRUCTION AND OPERATIONS

Section	Comments
1. Introduction	Define purpose and scope of plans.
2. Facility Description and Operation	Identify potential emergency situations.
3. Outside Emergency Services	Describe coordination agreements with outside organizations and services available.
4. Emergency Response Measures	
4.1 Onsite Emergency Responsibilities	Define chain of command and specific responsibilities of security, maintenance, and management personnel.
4.2 Onsite Equipment and Systems	Identify onsite warning systems and proper responses. Describe emergency equipment/systems, location, use. Identify personnel trained in equipment/system usage.
4.3 Hazard Assessment	Provide a check list to help define the emergency, the selection of control measures, when to evacuate, and when to notify outside services and agencies.
4.4 Offsite Authority Notification	Define proper authorities to contact and notification requirements associated with various emergencies.
4.5 Control Measures	Identify steps to be followed to control emergency.
4.5.1 Chemical spills	
4.5.2 H_2S Hazardous Conditions	
4.5.3 Well blowout	
4.5.4 Equipment Failure and Pipe Rupture	Define control measures for equipment failure, such as mechanical, electrical, and tank or pipe rupture, which includes steam, brine, noncondensable gas.

Table 9-5 (continued)

PRELIMINARY EMERGENCY PLAN OUTLINE
FOR CONSTRUCTION AND OPERATIONS

Section	Comments
4.5.5 Fire 4.5.6 Contaminated Soil, Water, Other Materials 4.5.7 Other Emergencies	
4.6 Natural Hazards 4.6.1 Lava Flow 4.6.2 Earthquake 4.6.3 Hurricane	Identify response measures, warning signs and signals. Describe coordination agreements with the U.S.G.S. (Hawaii Volcano Observatory), the Hawaii Institute of Geophysics, the County and State.
4.7 Medical Emergencies	Identify medical facilities and transportation plans.
5. Evacuation Plan	Define procedures for emergency evacuation for lava flow, hurricane, etc. Includes meeting points and personnel roster.
6. Media Notification	Identify personnel who can make statement of what happened and what is the threat to the public. Identify personnel who are responsible for notifying the media.
7. Personnel Training	Provide procedures for emergency shutdowns, handling emergency equipment, spill prevention, evacuation, first aid and rescue.
8. Emergency Reporting and Recordkeeping.	Specify compliance measures with regulatory requirements. Describe reporting and recordkeeping procedures.

Section 10

SOCIOECONOMICS

This section describes the social and economic characteristics of Hawaii and Puna District residents. Then, the probable and potential impacts of the Puna Geothermal Venture (PGV) facility are discussed. Lastly, the section identifies the mitigation measures that are planned.

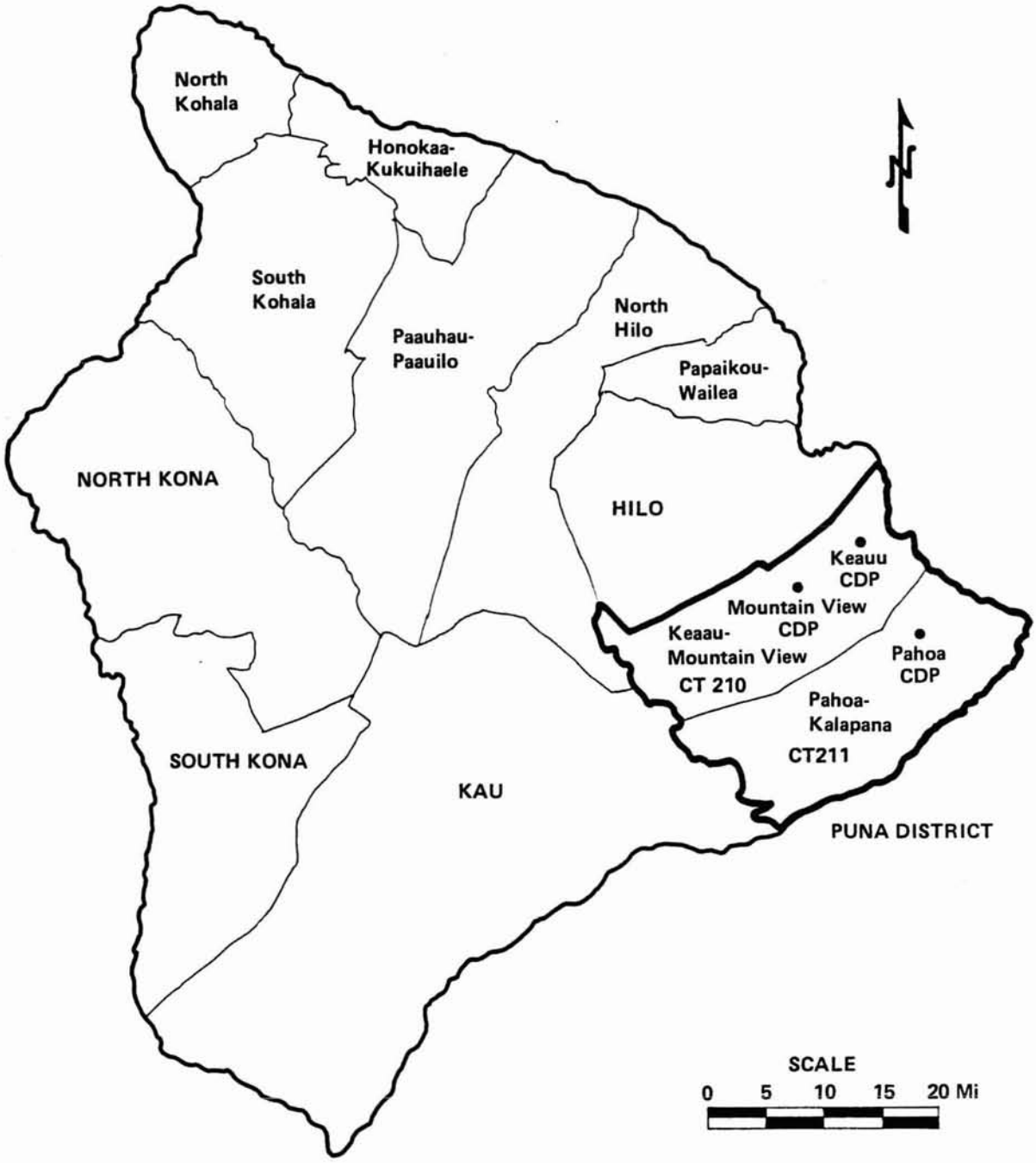
10.1 ENVIRONMENTAL SETTING

POPULATION CHARACTERISTICS

The Puna District comprises two census tracts: CT 210 (Keaau-Mountain View census division) and CT 211 (Pahoa-Kalapana census division). Published census information within these two tracts is also available for three Census Defined Places (CDPs): Keaau, Mountain View, and Pahoa. Pahoa is the closest town to the PGV project site. Figure 10-1 shows the location of the Puna District and its three CDPs.

Regional Population

Provisional population estimates prepared by the State Department of Planning and Economic Development (personal communication with DPED) indicate that the 1986 population was 109,200. The 1980 population of the Island of Hawaii was slightly in excess of 92,000 according to the 1980 census. The 1980 population represents a 45 percent increase over the 1970 population of 63,500. Between 1960 and 1970, the Island population increased only 3.5 percent. Between 1950 and 1960, the regional population increased 10.3 percent. The small population increase from 1950 to 1970 is explained by many residents leaving the island to find better economic opportunities in Honolulu or on the mainland.



ISLAND OF HAWAII

SOURCE: State of Hawaii, Department of Planning and Economic Development, STATISTICAL BOUNDARIES A-15. 1980:14

Figure 10-1

LOCATION OF THE PUNA DISTRICT, CENSUS TRACTS, AND CENSUS DEFINED PLACES

The Island of Hawaii comprises 2,583,680 acres -- about twice the size of the rest of the Hawaiian Islands combined -- and a population density of about 20 persons per square mile, the lowest of all Hawaii's counties. About 40 percent of the island's current population is concentrated around Hilo, the County seat.

During the 1970s, Island of Hawaii's demographic composition shifted in several important ways:

- The proportion of population under age 18 dropped from 36 percent in 1970 to 31 percent in 1980

- The average education level increased

- In-migration increased so that by 1980 one out of every four residents had not lived on the island five years previously (44 percent of the net population growth from 1970 to 1980 consisted of persons born outside the State of Hawaii)

The largest demographic change during the 1970s was the proportionate decline in Japanese residents and increase in (primarily) Caucasians and (secondarily) native Hawaiians. More than one-half of the island's population as of 1980 fell into one of the latter two ethnic groups (Table 10-1), and nearly eight out of every ten net additional residents from 1970 to 1980 were either Caucasian or Hawaiian (Table 10-2). Some of the apparent State-wide increase in native Hawaiian population may have been due to changed U.S. census recording procedures for persons of mixed ancestry and/or to the 1970s Hawaiian cultural renaissance, which is believed to have resulted in more part-Hawaiian people choosing to label themselves Hawaiian in 1980 than in 1970.

Population increase from 1970 to 1980 was particularly marked in the districts of North Kona (+184.5 percent) and Puna (+128 percent). Puna had the highest growth rate (+184.5 percent) of all districts on the island in the

Table 10-1

CENSUS DATA ON POPULATION AND DEMOGRAPHICS
PERCENTAGE COMPOSITIONS FOR VARIOUS LEVELS OF ANALYSIS

	Hawaii County		Puna District[a]		Keaau (CDP)		Mountain View (CDP)		Pahoa (CDP)	
	1970	1980	1970	1980	1970	1980	1970	1980	1970	1980
TOTAL POPULATION	63,468	92,053	5,153	11,751	951	775	419	540	924	923
	%	%	%	%	%	%	%	%	%	%
ETHNICITY										
Caucasian (White)	28.83	34.02	24.01	43.21	15.25	20.65	16.47	21.48	6.28	8.13
Hawaiian	12.30	18.77	8.77	14.99	N/A	7.74	N/A	8.15	N/A	20.15
Fillipino	16.47	13.81	22.36	16.73	N/A	33.68	N/A	13.52	N/A	25.46
Japanese	37.53	26.59	40.71	19.20	N/A	35.35	N/A	50.93	N/A	43.01
Chinese	2.90	1.82	1.65	1.41	N/A	1.03	N/A	2.59	N/A	0.87
Other	1.97	5.00	2.50	4.45	N/A	1.55	N/A	3.33	N/A	2.38
AGE										
Under 5 Years	8.58	9.09	7.78	10.19	8.31	6.19	4.30	6.85	7.36	9.10
5 to 17 Years	27.82	21.50	24.22	21.42	22.61	22.06	23.15	17.70	25.32	17.01
18 to 64 Years	54.40	59.22	54.94	58.74	57.62	56.26	57.28	58.33	53.03	58.83
65 and Older	9.20	10.19	13.06	9.65	11.46	15.48	15.27	17.04	14.29	15.06
PLACE OF BIRTH[b]										
Hawaii	76.99	70.54	72.08	58.85	N/A	63.13	N/A	71.26	N/A	57.00
Other U.S.A.	NC	29.07	NC	27.97	N/A	4.36	N/A	7.09	N/A	21.11
Foreign Country	10.83	9.41	13.61	13.18	N/A	32.51	N/A	21.65	N/A	21.89
RESIDENCE 5 YR. AGO[b]										
Same House	62.49	52.09	65.44	44.13	N/A	64.62	N/A	88.29	N/A	48.83
Elsewhere on Island	NC	22.65	NC	20.12	N/A	24.84	N/A	5.18	N/A	44.14
Different Island	NC	7.38	NC	9.36	N/A	3.01	N/A	0.00	N/A	3.26
Different State	NC	10.07	NC	14.76	N/A	1.76	N/A	0.00	N/A	0.00
Different Country	NC	2.81	NC	5.58	N/A	5.77	N/A	6.53	N/A	3.78
EDUCATION (Pop. 25+)[b]										
8 Years or Less	37.16	20.11	43.70	18.81	N/A	38.64	N/A	36.87	N/A	43.24
High School Grad.	31.60	35.52	28.74	36.01	N/A	26.37	N/A	35.28	N/A	22.16
College Grad., More	7.54	15.16	5.54	12.75	N/A	12.82	N/A	1.86	N/A	12.79

a) "Puna District" is comprised of census tracts 210 and 211.

b) Figures based on 15 percent sample; hence, numbers represent estimate. Percentages may be based on special populations.

"CDP" = "Census Designated Place" "N/A" = "Not Available" "NC" = 1970 categories or bases "Not Comparable" to 1980

Source: U.S. Bureau of the Census, 1970, 1980; State of Hawaii, Community Profiles for Hawaii, 1973; percentages computed by Community Resources.

Table 10-2

PUNA POPULATION AS A PERCENTAGE OF THE TOTAL ISLAND,
AND PUNA TOWN POPULATIONS AS PERCENTAGES OF TOTAL PUNA

	Puna District[a] as % of TOTAL ISLAND		Keaau (CDP) as % of ALL PUNA		Mountain View (CDP) as % of ALL PUNA		Pahoa (CDP) as % of ALL PUNA	
	1970	1980	1970	1980	1970	1980	1970	1980
TOTAL POPULATION	8.12%	12.77%	18.46%	6.60%	8.13%	4.60%	17.93%	7.85%
ETHNICITY								
Caucasian (White)	6.76%	36.22%	11.72%	3.15%	5.58%	2.28%	4.69%	1.48%
Hawaiian	5.79%	10.20%	N/A	3.41%	N/A	2.50%	N/A	10.56%
Fillipino	11.02%	15.47%	N/A	13.28%	N/A	3.71%	N/A	11.95%
Japanese	8.81%	9.22%	N/A	12.15%	N/A	2.19%	N/A	17.60%
Chinese	4.62%	9.93%	N/A	4.82%	N/A	8.43%	N/A	4.82%
Other								
AGE								
Under 5 Years	7.36%	14.30%	19.70%	4.01%	4.49%	3.09%	16.96%	7.02%
5 to 17 Years	7.07%	12.72%	17.23%	6.79%	7.77%	3.81%	18.75%	6.24%
18 to 64 Years	8.20%	12.66%	19.36%	6.32%	8.48	4.56%	17.31%	7.87%
65 and Older	11.53%	12.09%	16.20%	10.58%	9.51%	8.11%	19.61%	12.26%
PLACE OF BIRTH[b]								
Hawaii	7.60%	10.65%	N/A	7.75%	N/A	6.23%	N/A	7.42%
Other U.S.A.	NC	17.82	N/A	1.13%	N/A	1.10%	N/A	5.78%
Foreign Country	10.08%	17.88%	N/A	17.82%	N/A	7.10%	N/A	12.72%
RESIDENCE 5 YR. AGO[b]								
Same House	8.47%	10.43%	N/A	11.14%	N/A	9.95%	N/A	8.11%
Elsewhere on Island	NC	11.34%	N/A	8.38%	N/A	1.14%	N/A	14.34%
Different Island	NC	16.18%	N/A	2.18%	N/A	0.00%	N/A	2.27%
Different State	NC	18.71%	N/A	0.81%	N/A	0.00%	N/A	0.00%
Different Country	NC	25.35%	N/A	7.01%	N/A	5.18%	N/A	4.42%
EDUCATION (Pop. 25+)[b]								
8 Years or Less	10.39%	11.99%	N/A	16.29%	N/A	10.73%	N/A	18.53%
High School Grad.	8.03%	12.99%	N/A	5.81%	N/A	5.37%	N/A	4.96%
College Grad., More	6.50%	10.78%	N/A	7.97%	N/A	7.80%	N/A	8.09

• Different total reflecting sampling and/or special subpopulations

a) "Puna District" is comprised of census tracts 210 and 211.

b) Figures based on 15 percent sample; hence, numbers represent estimate. Percentages may be based on special populations.

"CDP" = "Census Designated Place" "N/A" = "Not Available" "NC" = 1970 categories or bases "Not Comparable" to 1980

Source: U.S. Bureau of the Census, 1970, 1980; State of Hawaii, Community Profiles for Hawaii, 1973; percentages computed by Community Resources.

period between 1980 and 1984, according to State population estimates. Puna's estimated 1984 population of 16,530 made it the third most populous of the island's nine districts, surpassed only by North Kona (18,226) and South Hilo (44,301).

Puna District Population

Puna's rapid population growth during the 1970s may have stemmed in large part from the abundant supply of relatively low-priced land for residential and/or agricultural purposes. Puna approaches the size of the Island of Oahu. Great portions of the district were subdivided during the land boom of the 1950s and 1960s. While many of these "ghost subdivisions" were, and still are, unimproved, scattered new houses have begun to appear throughout the district. Virtually all of Puna's population growth from 1970 to 1980 was outside the three urbanized settlements of Keaau, Mountain View, and Pahoa, so that the proportion of Puna's population living in these three CDPs fell from 44.5 percent in 1970 to 19.1 percent in 1980.

Demographic shifts in Puna from 1970 to 1980 were similar to, but more pronounced than, those shifts experienced by the island as a whole. Ethnically, Puna changed from a largely Japanese area to a largely Caucasian area. More than one-half of Puna's net population growth from 1970 to 1980 was not Hawaii-born. The proportion of Puna's population consisting of native Hawaiians increased from 9 percent in 1970 to 15 percent in 1980 (see Table 10-1). Ten percent of the island's Hawaiian population now resides in Puna (Table 10-3). In 1980, native Hawaiians were still only the fourth most populous ethnic group (1,762), following Caucasians (5,078), Japanese (2,256), and Filipinos (1,966).

The district's population actually grew somewhat younger during the 1970s despite a frequently expressed belief that Puna subdivisions are being filled by retirees. In 1970, people age 65 and older represented 13.1 percent of

Table 10-3

NET GROWTH COMPONENTS ANALYSIS FOR SELECTED CENSUS CATEGORIES

Changes	Hawaii County		Puna District	
Total 1970-80				
Overall population	28,585		6,598[a]	
Population 25 or older	19,203		3,837	
Employed civilian labor force	12,970		2,026	
Number of families	8,133		1,738	
Year-round occupied housing units	11,977		2,309	
Selected Categories	**Change (Raw Number)**	**Total Change (%)**	**Change (Raw Number)**	**Total Change (%)**
Ethnicity (overall population)				
Caucasian (white)	13,018	45.5	3,841	58.2
Hawaiian	9,465	33.1	1,310	19.9
Filipino	2,255	7.9	814	12.3
Place of birth (overall population)				
Hawaii	16,072	56.2	3,203[1]	48.1
Education (population 25 or older)				
College graduate or more	5,541	28.9	709	18.5
Occupation (employee civilian labor force)				
Service	2,181	16.8	339	16.7
Industry (employee civilian labor force)				
Construction	809	6.2	313	15.4
Retail	2,951	22.8	258	12.7
Poverty (number of families)				
Families below poverty level	915	11.3	306	17.6
Tenure (year-round occupied housing units)				
Renter-occupied	4,061	33.9	617	26.7
Housing conditions (year-round occupied units)				
1.51 or more persons/room	326	2.7	188	8.1

(a) Because place of birth was based on sample rather than full enumeration, the 1970-80 total change for Puna is calculated as 6,658 rather than 6,598.

Source: U.S. Bureau of the Census, 1970, 1980; State of Hawaii, Dept. of Planning an Community Development, 1973; percentages computed by Community Resources.

Puna's population; in 1980, this age group represented only 9.7 percent. The average educational level in Puna rose during the 1970s, but, in 1980, the percentage of persons with college degrees was still slightly lower in Puna than for the island as a whole.

The town of Pahoa, which is the nearest CDP to the project site, contained 923 people in 1980, a figure almost identical to its 1970 population. Compared with the Puna District as a whole, Pahoa CDP residents were much more likely to:

- Be of Japanese ancestry (43.0 percent versus 19.2 percent)
- Be 65 or older (15.1 percent versus 9.7 percent)
- Be foreign-born (21.9 percent versus 13.2 percent)
- Have moved recently from elsewhere on the island (44.1 percent versus 20.1 percent)
- Not to have lived off-island five years previously (7.0 percent versus 29.7 percent)

No separate census data are available for the subdivisions surrounding the project site. Indirect evidence from hearings or other public events suggests that residents demographically resemble the Puna-wide population (i.e., tend to be Caucasians new to the Puna area within the past 10 to 15 years). The total population in these subdivisions is not currently known. The number of lots in each subdivision was obtained through tax maps or 1984 aerial photographs and is listed below:

Subdivision	Number of Lots
Leilani Estates	2,266
Lanipuna Gardens	110
Nanawale Estates	4,289
Hawaiian Holiday Estates (Nanawale Farm Ranch Lands)	88
Kapoho Estates	10
Pohoiki Bay Estates	14

Some population estimates may be made for Leilani Estates (the most populous area in the immediate vicinity of the project) based on a 1984 State of Hawaii Department of Health Research Division survey on possible health impacts of geothermal development (Department of Health, 1984). State employees counted 150 apparent residential structures. The survey was based on interviews with persons in 135 of these households (the remainder refused to be interviewed or were not at home). A total of 350 persons lived in these 135 households, for an average of 2.59 persons per household. The estimated Leilani Estates population in early 1984 was 394 based on this survey and projections to the full 152 households.

District Population Trends

Population increased substantially between 1970 and 1980 both throughout the island and in the Puna District. The new population resulted in large part from in-migration. The ethnic composition of the population became relatively less Oriental and relatively more Caucasian and native Hawaiian. These trends are likely to continue.

Puna will continue to have great appeal to people seeking an isolated, natural environment and having lifestyles or circumstances that permit a choice of areas in which to live (e.g., retirees or participants in either a subsistence or underground economy). Their demand for Puna land may be more affected by broad national and State-wide economic considerations than by the local economy.

A substantial part of the residential demand for Puna homesites has historically come from more ethnically diverse people who must find nearby work to support themselves. This demand will be greatly affected by local economic conditions. A level or declining economy in eastern Hawaii will result in level or declining residential property costs in the employment center of Hilo, somewhat reducing the purely economic appeal of living in Puna. It will also reduce the overall new demand for residential development in eastern Hawaii. However, as is discussed in other sections of this report, there is reason to believe that the economy of eastern Hawaii will improve in the future.

LABOR FORCE

Island of Hawaii's labor force grew from 25,889 to 41,006 between 1970 and 1980, an increase of 58.4 percent, or approximately 4.7 percent per year, compounded. The labor force participation rate held steady at about 60 percent over the same period. The growth rate slowed somewhat during the 1980s to an average of 2.8 percent per year. By the end of 1984, the labor force stood at an estimated 46,850 (DPED, 1985).

Economic problems affecting both agriculture and tourism have prevented the number of jobs from increasing as rapidly as the population. Consequently, the County-wide unemployment rate increased from 2.7 percent in 1970 to 9.8 percent in 1982. The unemployment rate as of May 1987 decreased to 6.6 percent (State Department of Labor, Research and Statistics Office, personal communication). The Puna District's labor force participation rate in both 1970 and 1980 was lower than that of the Island as a whole, and its unemployment rate was higher. The 1980 census-defined unemployment rate of 12.3 percent for Puna was nearly twice the island-wide figure of 7.0 percent.

The island has gradually shifted from an agricultural to a tourism-based economy for the past several decades. The 1980 work force was primarily concentrated in nonmanual occupations such as technical/sales/administrative

(26.1 percent), managerial/professional (20.1 percent), and service jobs (16.5 percent). Industries employing island workers showed some evidence of shifting during the 1970s, with proportionately more workers in 1980 employed in retail, financial/insurance/real estate, and public administration (Table 10-4).

Compared with island-wide totals, proportionately more 1980 Puna workers were engaged in manual occupations, such as farming/fishing/forestry and precision/craft/repair workers, or as operators/fabricators/laborers. This condition was particularly true for working residents of Pahoa and Mountain View, where 35 to 40 percent of the labor force is involved in farming-related work. One out of four of Puna's farm industry workers lived in the Pahoa CDP (Tables 10-4 and 10-5) as of 1980. Occupational percentages have most likely changed since the Puna Sugar Company ceased operations in 1985 on the Big Island.

Household Heads

The 1982 Puna Community Survey sponsored by the County and the State of Hawaii provides additional information about work patterns of heads of households (SMS Research, 1982a and 1982b). Using categories based mostly on the official U.S. Standard Industrial Classifications, the survey found the main work activities of Puna household heads to be as follows:

Categories Selected for Highest Percentages or Relevance to Project (778 Households Sampled)	%
Retired	23
Unemployed/does not work	8
Construction	12
Sugar	7
Other agriculture	13
Government	8
Drilling/geothermal	1

Table 10-4

CENSUS DATA ON LABOR FORCE CHARACTERISTICS
PERCENTAGE COMPOSITIONS FOR VARIOUS LEVELS OF ANALYSIS

	Hawaii County		Puna District[a]		Keaau (CDP)		Mountain View (CDP)		Pahoa (CDP)	
	1970	1980	1970	1980	1970	1980	1970	1980	1970	1980
POTENTIAL LABOR FORCE (Aged 16 or Above)	43,075	67,205	3,681	8,367	N/A	646	N/A	428	N/A	701
Not in Labor Force	39.46%	38.67%	42.87%	44.68%	N/A	41.33%	N/A	47.90%	N/A	41.23%
Armed Forces	0.43%	0.31%	0.00%	0.31%	N/A	0.00%	N/A	0.00%	N/A	0.00%
Civilian Labor Force	60.10%	61.02%	57.13%	55.01%	N/A	58.67%	N/A	52.10%	N/A	58.77%
CIVILIAN LABOR FORCE	25,889	41,006	2,103	4,603	N/A	379	N/A	223	N/A	412
Unemployed	2.74%	6.96%	4.28%	12.25%	N/A	5.80%	N/A	4.04%	N/A	3.64%
TOTAL EMPLOYED CIVILIAN LABOR FORCE	25,180	38,150	2,013	4,039	N/A	357	N/A	214	N/A	397
OCCUPATION										
Service	16.29%	16.47%	9.29%	13.02%	N/A	19.89%	N/A	4.21%	N/A	8.31%
Managerial/Profess.	NC	20.05%	NC	15.42%	N/A	11.48%	N/A	14.95%	N/A	7.81%
Technical Sales & Administrative	NC	26.10%	NC	21.64%	N/A	17.09%	N/A	13.55%	N/A	19.65%
Farm, Fish, Forestry	NC	10.29%	NC	15.82%	N/A	10.64%	N/A	33.64%	N/A	36.27%
Precision, Craft, Repair	NC	12.69%	NC	15.15%	N/A	9.24%	N/A	15.82%	N/A	10.33%
Operators, Fabricators, Laborers	NC	14.39%	NC	18.94%	N/A	31.65%	N/A	16.82%	N/A	17.63%
INDUSTRY (Selected)										
Agriculture, Forest, Fish, Mining	NC	11.20%	NC	16.32%	N/A	10.36%	N/A	46.26%	N/A	40.30%
Construction	10.60%	9.11%	7.35%	11.41%	N/A	3.36%	N/A	0.00%	N/A	0.00%
Nondurable Mfg.	13.34%	6.66%	19.08%	8.27%	N/A	37.82%	N/A	4.21%	N/A	3.27%
Retail Trade	14.82%	17.52%	13.51%	13.12%	N/A	10.64%	N/A	9.81%	N/A	4.79%
Financial, Insurance, Real Estate	2.80%	5.70%	2.43%	4.95%	N/A	2.24%	N/A	0.00%	N/A	4.03%
Education	7.61%	8.10%	6.51%	7.95%	N/A	9.80%	N/A	7.48%	N/A	5.29%
Public Adminis.	6.49%	7.26%	5.71%	8.27%	N/A	2.80%	N/A	11.21%	N/A	5.04%

a) "Puna District" is comprised of census tracts 210 and 211.

b) All figures based on 15 percent sample; hence, numbers represent estimate.

"CDP" = "Census Designated Place" "N/A" = "Not Available" "NC" = 1970 categories or bases "Not Comparable" to 1980

Source: U.S. Bureau of the Census, 1970, 1980; State of Hawaii, Community Profiles for Hawaii, 1973; percentages computed by Community Resources.

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Table 10-5

PUNA POPULATION AS A PERCENTAGE OF THE TOTAL ISLAND,
AND PUNA TOWN POPULATIONS AS PERCENTAGES OF TOTAL PUNA

	Puna District[a] as % of TOTAL ISLAND		Keaau (CDP) as % of ALL PUNA		Mountain View (CDP) as % of ALL PUNA		Pahoa (CDP) as % of ALL PUNA	
	1970	1980	1970	1980	1970	1980	1970	1980
POTENTIAL LABOR FORCE (Aged 16 or Above)	8.55%	12.45%	N/A	7.72%	N/A	5.12%	N/A	8.38%
Armed Forces	0.00%	12.50%	N/A	0.00%	N/A	0.00%	N/A	0.00%
Civilian Labor Force	8.12%	11.23%	N/A	0.23%	N/A	4.84%	N/A	0.95%
CIVILIAN LABOR FORCE	8.12%	11.23%	N/A	8.23%	N/A	4.84%	N/A	8.95%
Unemployed	12.69%	19.75%	N/A	3.90%	N/A	1.60%	N/A	2.66%
TOTAL EMPLOYED CIVILIAN LABOR FORCE	7.99%	10.59%	N/A	8.94%	N/A	5.30%	N/A	9.83%
OCCUPATION								
Service	4.56%	8.37%	N/A	13.50%	N/A	1.71%	N/A	6.27%
Managerial/Profess.	NC	8.15%	N/A	6.58%	N/A	5.14%	N/A	4.98%
Technical Sales & Administrative	NC	8.78%	N/A	6.98%	N/A	3.32%	N/A	8.92%
Farm, Fish, Forestry	NC	16.27%	N/A	5.95%	N/A	11.27%	N/A	22.54%
Precision, Craft Repair	NC	12.64%	N/A	5.39%	N/A	5.88%	N/A	6.70%
Operators, Fabricators, Laborers	NC	13.94%	N/A	14.77%	N/A	4.71%	N/A	9.15%
INDUSTRY (Selected)								
Agriculture, Forest, Fish, Mining	NC	15.43%	N/A	5.61%	N/A	15.02%	N/A	24.28%
Construction	5.55%	13.26%	N/A	2.60%	N/A	0.00%	N/A	0.00%
Nondurable Mfg.	11.43%	13.15%	N/A	40.42%	N/A	2.69%	N/A	3.89%
Retail Trade	7.29%	7.93%	N/A	7.17%	N/A	3.96%	N/A	3.58%
Financial Insurance, Real Estate	0.96%	9.20%	N/A	4.00%	N/A	0.00%	N/A	0.00%
Education	6.84%	10.39%	N/A	10.90%	N/A	4.98%	N/A	6.54%
Public Adminis.	7.04%	12.05%	N/A	2.99%	N/A	7.19%	N/A	5.99%

a) "Puna District" is comprised of census tracts 210 and 211.

b) Figures based on 15 percent sample; hence, numbers represent estimate. Percentages may be based on special populations.

"CDP" = "Census Designated Place" "N/A" = "Not Available" "NC" = 1970 categories or bases "Not Comparable" to 1980

Source: U.S. Bureau of the Census, 1970, 1980; State of Hawaii, Community Profiles for Hawaii, 1973; percentages computed by Community Resources.

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The survey also inquired about place of work for the household's chief wage earner, with the following results:

Job Location	%
Home/does not work	30
Puna	32
Hilo area	27
Keaau area	1
Other Island areas	7
Other reply	2
Does not know/refused	1

Labor Force Trends without the Project

The pattern of Puna population growth suggests that Puna residents will continue to have a lower-than-average participation rate in the labor force and a higher-than-average unemployment rate for those who do participate. Occupations and industries of historical interest to Puna residents have tended to be of an outdoors nature, and this interest can be expected to continue if appropriate opportunities are found.

The Puna Sugar Company completed its phased shutdown in December 1984. The shutdown began on April 1, 1982, with the release of 121 workers. Only 2 percent had found new employment as of late May 1982. The remainder of the employees were released between December 1982 and December 1984. Sixty-four employees were retired (Department of Labor and Industrial Relations, 1983; personal communication with Mr. J. Melrose, Agricultural Property Manager, AMFAC, 1986).

INCOME AND POVERTY/AFFLUENCE INDICATORS

The Island of Hawaii's median 1980 family income of $19,132 was significantly less than the State-wide median of $22,750. The percentage of families below the official poverty level increased slightly from 9.7 percent in 1970 to 10.3 percent in 1980 (Table 10-6).

Table 10-6

CENSUS DATA ON FAMILY INCOME
PERCENTAGE COMPOSITIONS FOR VARIOUS LEVELS OF ANALYSIS

	Hawaii County		Puna District[a]		Keaau (CDP)		Mountain View (CDP)		Pahoa (CDP)	
	1970	1980	1970	1980	1970	1980	1970	1980	1970	1980
TOTAL FAMILIES	14,692	22,825	1,226	2,964	N/A	178	N/A	166	N/A	219
	%	%	%	%	%	%	%	%	%	%
FAMILY INCOME (selected categories)										
less than $10,000	51.65%	22.21%	63.87%	28.24%	N/A	10.67%	N/A	19.28%	N/A	26.94%
less than $20,000	NC	52.56%	NC	61.00%	N/A	38.76%	N/A	56.02%	N/A	58.45%
more than $25,000	5.13%	33.83%	2.69%	25.30%	N/A	44.94%	N/A	27.71%	N/A	31.96%
more than $50,000	1.01%	5.96%	.49%	4.69%	N/A	0.00%	N/A	9.64%	N/A	17.81%
BELOW POVERTY LEVEL:	9.73%	10.27%	9.87%	14.41%	N/A	4.49%	N/A	10.84%	N/A	15.07%
MEDIAN FAMILY INCOME:	$9,750	$19,132	N/A	N/A	N/A	$23,750	N/A	$18,913	N/A	14,132
	(Census Tract 210:)		$8,371	$18,015						
	(Census Tract 211:)		$7,603	$13,043						

a) "Puna District" is comprised of census tracts 210 and 211.

b) All figures based on 15 percent sample; hence, numbers represent estimate.

"CDP" = "Census Designated Place" "N/A" = "Not Available" "NC" = 1970 categories or bases "Not Comparable" to 1980

Source: U.S. Bureau of the Census, 1970, 1980; State of Hawaii, Community Profiles for Hawaii, 1973; percentages computed by Community Resources.

In line with its comparatively higher unemployment rate, the Puna District appears to have even greater income and poverty problems than the island as a whole. Median family incomes were lower than County-wide medians in both 1970 and 1980 (Table 10-7). Median family incomes in upper Puna (CT 210) trailed island-wide medians only slightly, but the median for lower Puna (CT 211, site of the PGV project) was only 78 percent of the Island-wide median in 1970 and just 72 percent of the Island-wide median in 1980.

Based on baseline economic trend projections without the proposed project, the foreseeable economic future for the eastern portions of the island does not hold forth the prospect of any immediate prosperity. Incomes in Puna will probably continue to trail those for the Island, and families qualifying for poverty status will probably continue to be proportionately more numerous in Puna than in other populated parts of the island.

HOUSING SUPPLY

The supply of year-round housing units on the island grew from 18,972 in 1970 to 33,954 in 1980. This 10-year increase of 79.0 percent was much greater than either the 45.0 percent increase in overall population or the 55.4 percent increase in family units. However, census definitions of housing units include condominium units for resort use or simple investment purposes, which are partially responsible for the apparent 13.9 percent increase in supply and vacancy rates in 1980.

Still, the 69.4 percent increase in year-round occupied housing units (from 17,260 to 29,237) also exceeds the growth in both overall population and family units, thereby indicating fewer persons per occupied housing unit. General improvements in island housing over the 1970s are also indicated by the increased percentages of owner-occupied units (56.9 percent in 1970 versus 60.7 percent in 1980) and decreases in the percentages of units lacking some plumbing and/or having crowded conditions (Table 10-8).

Table 10-7

PUNA FAMILY INCOMES AS A PERCENTAGE OF THE TOTAL ISLAND,
AND PUNA TOWN INCOMES AS PERCENTAGES OF TOTAL PUNA

	Puna District[a] as % of TOTAL ISLAND		Keaau (CDP) as % of ALL PUNA		Mountain View (CDP) as % of ALL PUNA		Pahoa (CDP) as % of ALL PUNA	
	1970	1980	1970	1980	1970	1980	1970	1980
TOTAL FAMILIES	8.34%	32.99%	N/A	6.01%	N/A	5.60%	N/A	7.39%
FAMILY INCOME (Selected Categories)								
Less Than $10,000	10.32%	16.51%	N/A	2.27%	N/A	3.82%	N/A	7.05%
Less Than $20,000	NC.00%	15.07%	N/A	3.82%	N/A	5.14%	N/A	7.08%
More Than $25,000	4.38%	9.71%	N/A	10.67%	N/A	6.13%	N/A	9.33%
More Than $50,000	4.05%	10.21%	N/A	0.00%	N/A	11.51%	N/A	28.06%
BELOW POVERTY LEVEL:	8.46%	18.21%	N/A	1.87%	N/A	4.22%	N/A	7.73%
MEDIAN FAMILY INCOME:	N/A	N/A	N/A (more than 100%)		N/A	(more than 100%)	N/A (more than 100% of lower Puna)	
(Census Tract 210:)	85.86%	94.16%						
(Census Tract 211:)	77.98%	72.36%						

a) "Puna District" is comprised of census tracts 210 and 211.

Note: All figures based on 15 percent sample; hence, numbers represent estimate.

"CDP" = "Census Designated Place" "N/A" = "Not Available" "NC" = 1970 categories or bases "Not Comparable" to 1980

Source: U.S. Bureau of the Census, 1970, 1980; State of Hawaii, Community Profiles for Hawaii, 1973; percentages computed by Community Resources.

Table 10-8

CENSUS DATA ON HOUSING STOCK
PERCENTAGE COMPOSITIONS FOR VARIOUS LEVELS OF ANALYSIS

	Hawaii County		Puna District[a]		Keaau (CDP)		Mountain View (CDP)		Pahoa (CDP)	
	1970	1980	1970	1980	1970	1980	1970	1980	1970	1980
TOTAL YEAR-ROUND HOUSING UNITS	18,972	33,954	1,829	4,404	260	261	120	186	303	301
vacant:	9.02%	13.89%	16.79%	13.01%	2.69%	1.92%	5.00%	5.38%	6.27%	5.65%
	%	%	%	%	%	%	%	%	%	%
TOTAL YEAR-ROUND OCCUPIED UNITS	17,260	29,237	1,522	3,831	253	256	114	176	284	284
TENURE										
owner-occupied	56.87%	60.65%	75.56%	74.18%	74.31%	64.06%	82.46%	77.27%	67.96%	64.08%
renter-occupied	43.13%	39.35%	24.44%	25.82%	25.69%	35.94%	17.54%	22.73%	32.04%	35.92%
SELECTED CONDITIONS										
lacking some plumbing	17.06%	8.12%	31.87%	16.26%	10.18%	5.08%	4.39%	2.84%	43.66%	10.21%
1.51 or more persons/room	6.52%	4.97%	5.65%	7.15%	4.35%	3.52%	4.39%	9.09%	7.75%	8.10%
NUMBER OF OWNER-OCCUPIED NON-CONDO-MINIMUM UNITS FOR WHICH VALUE DATA AVAILABLE	NC	15,703	NC	2,526	NC	162	NC	114	NC	150
MEDIAN VALUE:	$24,800	$70,300	N/A	N/A						
	(Census Tract 210:)		$16,600	$54,200	$15.00	$54,200	$10,000	$56,600	$15,000	$59,700
	(Census Tract 211:)		$19,200	$47,600	$19.99		$14,999		$19,999	
NUMBER OF RENTER-OCCUPIED CASH RENTAL UNITS FOR WHICH RENTAL DATA AVAILABLE	NC	9,667	NC	727	NC	78	NC	22	NC	74
MEDIAN RENT:	$54	$223	N/A	N/A	$0-$40	$110	$40-$59	$165	$0-$40	$135
	(Census Tract 210:)		$53	$232						
	(Census Tract 211:)		$0-$30	$260						

a) "Puna District" is comprised of census tracts 210 and 211.

b) Figures based on 15 percent sample; hence, numbers represent estimate. Percentages may be based on special populations.

"CDP" = "Census Designated Place" "N/A" = "Not Available" "NC" = 1970 categories or bases "Not Comparable" to 1980

Source: U.S. Bureau of the Census, 1970, 1980; State of Hawaii, Community Profiles for Hawaii, 1973; percentages computed by Community Resources.

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The percentage of the island's total housing located in Puna is approximately the same as the percentages of overall population and total family units (i.e., 13 percent). The vacancy rate is about the same as that for the island as a whole, though Puna has fewer condominium units. Thus, it appears that gross housing supply in Puna is similar to that of the rest of the island.

Puna has had more owner- than renter-occupied units for the past two census periods (a 3:1 ratio in both 1970 and 1980), with the owner-occupied percentage exceeding the island-wide percentage. Rentals have constituted a slightly higher proportion (about one-third) of the occupied units in the Pahoa CDP.

Some of the dollar-related statistics (Tables 10-8 and 10-9) reflect Puna's income and poverty problems. Median values of owner-occupied housing units in 1980 were significantly lower for Puna than for the island as a whole. The 1980 median was just two-thirds of the island-wide median value in lower Puna (CT 211) where the PGV project would be located. However, for the same area, median rents were 16.6 percent higher than the island-wide median rental figure. Puna rentals in 1970 were cheaper than average rentals elsewhere on the island.

Puna's housing stock has been generated primarily through custom home construction in land subdivisions. While there is much speculation in Puna land by absentee buyers and sellers, there have been few, if any, "speculation" home developments. Future housing development in Puna will probably continue to be a direct function of the number of people who both wish to, and are economically able to, purchase land and build houses in the district. Population has generated housing development in Puna, rather than vice-versa. No proposals for major residential home development in Puna have yet been made. The general prospect is for continued development of single homes on scattered lots.

Table 10-9

PUNA HOUSING STOCK AS A PERCENTAGE OF THE TOTAL ISLAND,
AND PUNA TOWN HOUSING AS PERCENTAGES OF TOTAL PUNA

	Puna District[a] as % of TOTAL ISLAND		Keaau (CDP) as % of ALL PUNA		Mountain View (CDP) as % of ALL PUNA		Pahoa (CDP) as % of ALL PUNA	
	1970	1980	1970	1980	1970	1980	1970	1980
TOTAL YEAR-ROUND HOUSING UNITS	9.64%	12.97%	14.22%	5.93%	6.56%	4.22%	16.57%	6.83%
Vacant:	17.93%	12.15%	2.28%	.87%	1.95%	1.75%	6.19%	2.97%
TOTAL YEAR-ROUND OCCUPIED UNITS	8.82%	13.10%	16.62%	6.68%	7.49%	4.59%	18.66%	7.41%
TENURE								
Owner-Occupied	11.72%	16.03%	16.35%	5.77%	0.17%	4.79%	16.78%	6.40%
Renter-Occupied	5.00%	8.60%	17.47%	9.30%	5.38%	4.04%	24.46%	10.31%
SELECTED CONDITIONS								
Lacking Some Plumbing	16.47%	26.23%	9.48%	2.09%	1.03%	.80%	25.57%	4.65%
1.51 or More Persons/Room	7.64%	18.87%	12.79%	3.28%	5.81%	5.84%	25.58%	8.39%
NUMBER OF OWNER-OCCUPIED NON-CONDO-MINIMUM UNITS FOR WHICH	NC	16.09%	NC	6.41%	NC	4.51%	NC	5.94%
MEDIAN VALUE:	N/A	N/A	(7--ca. 100% of CT 210)	99.09% (of CT 210)	(7--ca. 75% of CT 210)	103.47% (of CT 210)	(7--less than all CT 211)	125.42% (of CT 211)
(Census Tract 210:)	66.94%	77.81%						
(Census Tract 211:)	77.42%	67.71%						
NUMBER OF RENTER-OCCUPIED CASH RENTAL UNITS FOR WHICH RENTAL DATA AVAILABLE	NC	7.52%	NC	10.73%	NC	3.03%	NC	10.18%
MEDIAN RENT:	N/A	N/A	(7--ca. 50% of CT 210)	47.41% (of CT 210)	(7--ca. 100% of CT 210)	71.12% (of CT 210)	(7--less 130% of CT 211)	1.92% (of CT 211)
(Census Tract 210:)	98.15%	104.04%						
(Census Tract 211:)	(ca. 50%)	116.59%						

a) "Puna District" is comprised of census tracts 210 and 211.

"CDP" = "Census Designated Place" "N/A" = "Not Available" "NC" = 1970 categories or bases "Not Comparable" to 1980

Source: U.S. Bureau of the Census, 1970, 1980; State of Hawaii, Community Profiles for Hawaii, 1973; percentages computed by Community Resources.

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ECONOMIC BASE

Tourism

The Island of Hawaii visitor industry, which grew robustly during the 1970s, is just emerging from difficult times in the early 1980s. Westbound visitor arrivals to the island grew from 446,000 in 1970 to a high of 860,000 in 1979. However, a general softening of the tourism market and increased competition from other destination areas resulted in three years of declining arrivals to the Big Island. As a result, the westbound visitor total in 1982 was only 678,000, a 20 percent drop. Since 1982, however, the number of persons visiting the Big Island has begun to increase. The number of hotel rooms on the Big Island has been relatively stable over the past four years at just over 7,000, or more than twice the number existing in 1970.

The center for this growth is expected to be in the South Kohala/North Kona area in West Hawaii. The number of rooms will soon increase sharply with several major projects now under way in South Kohala on the Island's west side. The resulting increase in visitor spending should serve as a major boost to the economy (County of Hawaii, 1986).

The major visitor attractions in the Puna District are Hawaii Volcanoes National Park, the eruptions of Kilauea Volcano, and the black sand beach at Kalapana in lower Puna. The Volcano House, a 36-room hotel in the National Park, and Kalani Honua, a hostel-type operation with dormitory accommodations, are the only tourist-related facilities in the district. A significant number of tourists, however, pass through lower Puna on sightseeing excursions and/or on their way to Hawaii Volcanoes National Park, which is the single most popular visitor attraction on the island.

Agriculture

The sugar industry has historically played a major role in the economy of the State of Hawaii, and Hawaii County has been the State's largest producer. Hawaii County had 70,900 acres devoted to sugarcane in 1984, or 37.6 percent of the 188,400 acres of sugar land in the State. The number of acres in cane and the number of jobs in the sugar industry have been declining both State-wide and in Hawaii County (DPED, 1985).

Agriculture continues to be a major economic activity in the County of Hawaii. Though acreage in traditional crops such as sugar and coffee declined between 1978 and 1984 by 23.4 percent and 13 percent, respectively (Table 10-10), acreage in selected horticultural and orchard crops increased 31 percent over the same seven-year period. Sugar continued to predominate in value of production, with 1984 sales of $94 million. Sugar is more than three times greater than the second-ranked crop of macadamia nuts, which had 1984 sales of $25.9 million. It should be noted that the value of sugar sales increased 37 percent over the seven-year period, whereas the value of macadamia nut sales more than doubled during the same period.

The Puna District has long been a major sugar-producing area, with AMFAC's Puna Sugar Company the primary employer. Although it is anticipated that sugar will continue to play an important role in the County of Hawaii's economy (58 percent of total crop sales in 1984), production in the Puna District has virtually disappeared since the unprofitable Puna Sugar Company ceased operations in December 1984. Closing the plantation took approximately 15,000 acres out of sugar production and resulted in the cumulative loss of approximately 485 jobs after the phasedown period (Soriano et al, 1982a and 1982b).

Table 10-10

ACREAGE AND SALES VALUE FOR SELECTED AGRICULTURAL CROPS
(Hawaii County, 1978 and 1984)

Crop	Acres Thousands 1978	Acres Thousands 1984	Value ($ Millions) 1978	Value ($ Millions) 1984
Sugarcane	92.6	70.9	68.6	94-0
Macadamia nuts	10.1	15.5	11.2	25.9
Flowers and nursery products	0.7	0.9	8.6	16.9
Papaya	1.7	2.1	5.7	7.5
Coffee	2.3	2.0	2.1	4.7

Source: Hawaii Agricultural Reporting Service, 1983, pp. 3, 8, 16, 19, 29, and 38, State of Hawaii Department of Planning and Economic Development, 1985, p. 502.

Compiled by Community Resources, 1986

AMFAC operates a small power plant at the closed Puna Sugar Company mill in Keaau. The company has a firm contract to supply varying amounts of electrical energy to the Hawaii Electric Light Company (HELCO) electrical grid until the end of 1991. The generator at the mill plant was powered by bagasse, a sugarcane waste product. Now that bagasse is no longer available, AMFAC has arranged with an independent contractor to provide wood chips as an alternative to the use of fossil fuel. This small-scale operation employs 14 people in wood chipping and 25 people at the power plant.

Diversified agriculture has become more important in both relative and absolute terms with the cessation of sugar operations in Puna and the consequent release of acreage for other purposes. Papaya, macadamia nuts, bananas, and flower and foliage production have become the primary commercial agricultural activities in the district since sugar production ceased according to landowners and corporations doing business in the district. A large percentage of the district's papaya and macadamia nut acreage is located in lower Puna. This acreage is expected to expand with the planned opening of Hawaiian Holiday's papaya and hay farm on 2,500 acres of Shipman land. The venture will begin with hay production, to be followed by papaya planting. The two crops will be rotated periodically.

A joint venture comprising AMFAC Hawaii, Hershey Foods, and Kakela Enterprises has recently announced plans to test the commercial feasibility of growing cocoa in Hawaii. The venture will have three phases. Phase I will test a 50-acre site on Maui and/or the Big Island and will last two years. Phase II will involve a 350-acre commercial test farm on Maui, the Big Island, and/or Kauai. Phase III will involve independent farmers on 30-acre plots, totaling 3,000 to 6,500 acres of AMFAC land State-wide. AMFAC has mentioned its Puna lands as a potential site if the initial tests are successful. An additional advantage for the Puna area might be the availability of geothermal heat to be used in the drying of the cocoa beans.

Science

Scientific research and development, such as the telescope development on Mauna Kea and the OTEC program at Keahole, North Kona, are emerging components of Hawaii County's economy. Recently,the world's largest telescope was installed on the Big Island. Astronomy research has generated over $52 million in capital investments from outside Hawaii, employed numerous short-term construction workers, and created a total of 106 full-time jobs over the past 10 to 15 years (State of Hawaii, Department of Labor and Industrial Relations, 1983; personal communication with Mr. J. Melrose, Agricultural Property Manager, AMFAC, 1986). Astronomy is the Island's major, and most successful, high-technology industry; continued growth of this activity may encourage companies engaged in complementary high-technology activities (e.g., electronics manufacturing) to locate there.

Industry

Most industrial activities in Puna are related to the agricultural industry, such as processing of sugar, macadamia nuts, and papaya, and generation of electrical power from wood chips. AMFAC Tropical Products (formerly Puna Papaya) operates a processing plant at Keaau that employs 150 people. In addition to papaya, the plant processes guava supplied by local growers. It has sufficient capacity to process all of the papaya and guava produced on the island in the foreseeable future. A macadamia nut processing plant is also located near Keaau.

Other primary and secondary economic generators in the Puna area include:

- Retail trade and cottage industries
- Two small-scale visitor facilities (Volcano House and Kalani Honua)
- Commercial fishing
- Real estate sales

Various government agencies are also major employers in the Puna District.

W. H. Shipman, Ltd. is developing a light industrial park in Keaau. This park is located along Highway 11, north of Keaau about 6.5 miles from the airport and harbor in Hilo. Industrial zoning has been obtained for the project, and water lines are being laid. In the Shipman project, 450 acres of land are to be developed in annual increments of approximately 50 to 60 acres. The park is intended to be used for light industrial activities, warehouses, and high-technology research facilities. Several local and foreign businesses have expressed interest in locating there. The rate of development is expected to be very low given current economic conditions and the substantial supply of vacant industrially zoned land in Hilo.

Commercial Activities

Commercial activities are located in Keaau, Pahoa, Kurtistown, Mountain View, Glenwood, Volcano, and Kalapana. A neighborhood shopping center has recently been completed in Keaau; however, most of the commercial uses in the district are still family-operated businesses serving the adjoining communities (Planning Department, 1979). Puna residents do the majority of their shopping in Hilo and at the new regional center in South Hilo because of the wide variety of stores and merchandise.

VALUES AND ATTITUDES

Community Values

Puna's residents view themselves primarily as rural and, more specifically, as people who have intentionally chosen such a lifestyle. Table 10-11 lists the best features of life in Puna, as volunteered by the residents of Puna.

Table 10-11

BEST FEATURES OF LIFE IN PUNA
AS VOLUNTEERED
BY PUNA RESIDENTS

Item	Percentage of Respondents[a]
Population/development (generally lack of such features; e.g., country atmosphere, rural area, uncrowded, etc.)	49
Other physical/environmental (climate, beauty, etc.)	40
Social/lifestyle factors	33
Personal associations/commitments	19
Economic attributes (cheap housing, land, prices)	11
Location/convenience factors (close to Hilo, work, ocean)	11

(a) Percentages can total more than 100 percent because of multiple responses. Sample size = 778.

Source: SMS Research, 1982a, p. 22.

Several factors qualify the residents' self-image, however, and make it unique. First, Puna is close to Hilo. Many Puna residents work in Hilo and also use the city for recreation, shopping, and government business. In that respect, Puna residents can be considered more suburban than rural. A second qualification is the strong influence of Puna's newcomers. No known study has specifically focused on this group in order to understand how they view their lives and lifestyles. A third qualification is the general resurgence of a distinctly native Hawaiian set of values among some residents, which may also strongly influence people's opinions and aspirations.

Certain frequently encountered community values may be particularly relevant to any proposed development in Puna. These values include:

- Family. The concept of intact and extended families is of critical value

- Slow pace. Puna's rural quality contributes to the slow pace of life

- Land. Subdivision activities have allowed for 1- to 5-acre parcels for residents to grow their own food and to produce crops that can be marketed to supplement their income

- Living off the land. Because Puna is largely undeveloped, people can enjoy a variety of activities within the district that are consistent with the Puna lifestyle image; i.e., hunting, fishing, and foraging for plants.

- The last frontier. Many of the district's newer residents view Puna as the frontier boundary of Hawaii. Its undeveloped character, from their point of view, is associated with the frontier values of rugged independence and self-sufficiency. Living in an active volcanic area adds to this feeling of frontier living. This last point is perhaps best indicated by citizen reactions during recent lava flows near Kahuahu and Kalapana.

These values help define what Puna residents might mean by the term "rural." Other, sometimes contradictory, lifestyle values are also operating in the community. For example:

- Jobs. People in Puna are seriously concerned about the district's economic future. A commonly reported problem in the 1982 survey was lack of opportunity.

- Services. Although the Puna lifestyle image is one of independence and a pioneering spirit, the residents are demanding better infrastructure and services.

- Education. People in the Puna area place a high value on education. Education is usually associated with upward mobility and economic success.

- Underground economy. Marijuana is the economic backbone of Puna's underground economy. It is surmised that marijuana provides a high cash income for those engaged in its production based on anecdotal information and periodic newspaper reports.

These present values can be expected to persist in the future with or without the proposed project.

Attitudes Toward Geothermal and Other Development

A 1987 survey (Barbara Sunderlund & Associates, 1987) found that 84 percent of Hawaii residents favor geothermal development. Of the Big Island resident, 77 percent favored geothermal development. Even in the eastern part of the Island where the PGV facility is located, 78 percent of the population favored geothermal development.

A recent survey on energy issues was conducted in 1987 (SMS Research Inc., 1987) for the DPED. Telephone interviews were conducted with 901 people: 600 Oahu residents, 100 Kauai residents, 100 Maui residents, and 101 from the Big Island. Three questions were asked:

- What is Hawaii's primary source of electricity?

- Opinions about oil crisis in the future.

- Awareness and opinions of a possible undersea cable to send geothermal electricity from the Big Island to Oahu.

Hawaii's residents recognized the importance of oil to the State's energy needs. More than two out of five people interviewed believed that oil is Hawaii's primary source of electricity, including 48 percent of the Big Island respondents.

A general perception existed that an oil crisis will occur in the next 10 to 15 years. More than 40 percent believed that an oil crisis is "very likely", and 33 percent said it is "somewhat likely." If the crisis does occur, it is expected that Hawaii will be hit harder than the rest of the country. This belief was offered by more than 60 percent of the sample.

Less than 40 percent of the respondents were aware of government programs to develop an undersea electrical power cable. The reaction to the cable was very favorable, with very few people expressing opposition, Though 15 percent did not give an opinion, almost three our of four people were either somewhat favorable, or very favorable toward the idea. Big Island respondents were no different from others in this regard, with 71 percent expressing a positive opinion.

A 1986 survey on attitudes toward geothermal development was a telephone poll commissioned by the Hawaii Energy Division (SMS Research, 1986). A total of 227 Big Island residents -- including a disproportionate sub-sample of 103 in the Puna District -- were asked about opinions on three geothermal options: (a) small-scale: a 25 (MW) development from two plants "in the Kapoho area" with use limited to the Big Island; (b) large-scale: 100 MW to meet all Big Island electrical needs from several plants "in the Kapoho area and further up in the Puna forest"; (c) export to Oahu: 500 MW for export to Oahu via

undersea cable after the year 2000 from development of several sites, "each on several hundred acres," probably in the Kapoho area and the Puna Forest Reserve. Results are shown in Table 10-12.

Table 10-12

ATTITUDES TOWARD GEOTHERMAL DEVELOPMENT

	Small-Scale		Large-Scale		Export to Oahu	
	Puna %	Island Total %	Puna %	Island Total %	Puna %	Island Total %
In favor	66	65	43	47	37	40
Opposed	17	12	29	23	36	32
Depends	14	19	23	23	21	21
Don't Know/ Refused	3	4	5	7	6	8
(Base:)	(103)	(227)	(103)	(227)	(103)	(227)

The overall pattern suggests strong support -- both in Puna and islandwide -- for "small-scale" development such as the presently proposed project. Sixty-six percent of the respondents were in favor of a small-scale geothermal power plant, while only 17 percent were opposed. Asked to explain reasons for their answers, most people in favor mentioned need for energy alternatives and economic advantages, while opponents and people who said "it depends" were primarily concerned about environmental impacts.

An older survey that addressed geothermal development was sponsored by the County Planning and Housing Departments. It was a planning survey with an island-wide sample of 1,055 resident, including a Puna subsample of 117 persons (Hawaii Opinion, Inc., 1983). One question dealt indirectly with geothermal development. The question was: If you had $10 million to help industries on the Big Island, how would you use the money? That is, which industries would you put the money into and how would you divide it up? Respondents could allocate this hypothetical money among eight industries, plus an "other industries" category.

Island-wide, 41 percent said that they were willing to help geothermal-related industries. This response was sixth behind diversified agriculture (75 percent), tourism (73 percent), aquaculture/fishing (65 percent), construction (53 percent), and sugar (49 percent). Geothermal-related industries fell to seventh place within the Puna subsample, tied with heavy industry at 24 percent each. This response may indicate that Puna residents tend to view geothermal activities and heavy industries as similar (Hawaii Opinion, Inc., 1983).

A 1982 survey of Puna (SMS Research, 1982a) dealt with attitudes of residents about future development and, more specifically, their opinions about geothermal energy development. This research was conducted prior to the Kahauale'a contested case hearings on geothermal development held before the BLNR and prior to the lawsuit, Puna Speaks et al. vs. Hodel et al. The hearings and the lawsuit received island wide and Statewide publicity. Such publicity could have affected public opinion.

Most area residents in 1982 clearly preferred a future economic scenario based on agriculture (Table 10-12). The form of agricultural development desired is vague, but is consistent with Puna's past history and contemporary values. A minority favored industrial growth and more intensive tourism development. Puna residents wanted more jobs and better services but were not, according to the survey, willing to gain such benefits through industrialization. Most people feared that industrialization would bring encroachment, pollution, and loss of rural character.

Most Puna residents were aware of existing geothermal wells, but fewer than 20 percent of those persons surveyed reported personal impacts: those who felt personally affected reported a negative impact. Reports of impacts decreased the farther the respondents lived from existing wells.

Native Hawaiian Values

The Puna Hui Ohana, an organization of the Puna Hawaiian community, prepared an assessment of geothermal development impact on native Hawaiians in the

lower Puna District (Puna Hui Ohana, 1982). According to the Ohana assessment, many of these Hawaiians are attempting to discover and define their own Hawaiian identity while still believing that they must cling to their culture secretly in order to participate in, and be accepted by, the Western culture. They perceive that negative changes are taking place all around them and that Caucasian in-migrants are taking over their culture.

Other concerns expressed in the assessment include the following perceived possibilities:

- Large-scale geothermal development may result in a loss of access to large areas of undeveloped land that the Hawaiians use for traditional cultural activities such as food and maile gathering and hunting.

- Geothermal development may encourage a large increase in population that could severely strain public services and infrastructure.

- Geothermal development may increase the potential for social conflict in lower Puna as relatively highly paid newcomers with different values from the current residents compete for the use of physical resources and social status.

- Increased geothermal development may change native Hawaiian attitudes regarding interpersonal relationships and the relationship to nature and the supernatural.

Hawaiians have, in recent years, mobilized political and legal resources to stop a perceived loss of cultural identity. Some of these activities involve questioning ownership of various lands and resources, including geothermal energy, and questions of religious right.

10.2 ENVIRONMENTAL IMPACTS OF THE PROPOSED ACTION

The development of the PGV facility will generate a number of positive economic and social impacts. These impacts include jobs, capital expenditures,

State and County revenues from taxes and permits, and increased energy self-sufficiency.

EMPLOYMENT IMPACTS

Construction of the power plant and related facilities will be phased over approximately 4 years and will require approximately 50 work years of labor. Average annual employment during construction is 23 workers. The normal drilling crew will be 36 employees. Peak construction employment on the power plant may be up to 100 people. Approximately 19 employees will be required for operation and maintenance of the facility (Bechtel National, Inc., 1983). The total annual employment impact on the facility includes indirect and induced jobs. Table 10-13 summarizes the employment impacts. Based on a state employment multiplier, the total employment generated from the project will be 44 jobs during the 4-year construction phase, and 45 jobs during the remaining life of the project.

Many of the skills required for construction and operation are available in the Hawaii County and/or State labor market; only a few jobs requiring highly specialized skills will be performed by mainland workers (DPED, 1982b). Preference will be given to local workers, whenever possible. Former Puna Sugar Company employees represent a particularly valuable resource as labor. Although no public agency has monitored their current employment status, it is possible that some of these employees may still be available to work on the PGV project. Training will be provided to employees as needed.

Table 10-14 lists the labor skills required for construction of the power plant and ancillary facilities. The needed job classifications for the operation and maintenance phase of the project include administrative and support staff, such as clerical, materials, technical, maintenance, and operations personnel. Specialized skills will also be required to perform routine geothermal well maintenance.

Table 10-13

TOTAL ANNUAL EMPLOYMENT IMPACT OF THE PGV FACILITY: NUMBER OF JOBS[a]

Item	Impacts			
	Direct	Indirect	Induced	Total
Construction	23	8	13	44
Operation and maintenance	19	7	19	45

(a) The analysis does not include the employment impacts of drilling replacement wells over the 35-year life of the power plant.

Sources: Direct construction employment derived from information supplied by the developer (Bechtel National, Inc., 1983).

Direct operation and maintenance employment from the State of Hawaii, Department of Planning and Economic Development 1982b, p. 8-5.

Simple employment multipliers (direct and indirect jobs per additional direct job) of 1.3525 for the construction industry and 1.3721 for the electricity, gas, and sanitary services sector from State of Hawaii, Department of Planning and Economic Development et al., 1975, p. 23.

Total employment multipliers (direct and indirect and induced jobs per additional direct job) of 1.9054 for the construction industry and 2.3863 for the electricity, gas, and sanitary services sector, ibid.

Table 10-14

REQUIRED LABOR SKILLS FOR POWER PLANT CONSTRUCTION

Administrators	Ironworkers
Equipment operators	Laborers
Drivers	Masons
Boilermakers	Painters
Carpenters	Pipefitters, plumbers
Millwrights	Roofers
Concrete workers	Sheetmetal workers
Electricians	Mechanics
Fence erectors	Welders
Glaziers	Well drillers

Source: Department of Planning and Economic Development, 1982b p. 8-2.

INCOME AND ECONOMIC OUTPUT

Economic activity generated by the project will have an effect on the total economic output and personal income of Hawaii County. Two sources of project expenditure will affect the County:

- Capital expenditures, which are comprised primarily of expenditures on goods, services, and wages involved in the construction phases of the proposed project

- Operating expenditures, which include salaries paid to permanent employees as well as annual expenditures on goods and services for the operation and maintenance of the facility

Capital costs are estimated to be $60 million. Much of the capital expenditures will go towards large construction equipment and material, which will need to be purchased off-island. Smaller construction equipment (e.g., bulldozers) is available on the Island and will be utilized wherever feasible. It is estimated that about 50 percent ($30 million) of the capital costs will be expended on the Island of Hawaii.

Personal income on the Island generated by the capital expenditures is estimated to total $12.6 million based on the DPED's income coefficient of 0.4189 (DPED, 1975).

During the operation and maintenance phase of the project, annual operation and maintenance (O&M) costs are predicted to be $3.3 million. O&M costs include labor and spare parts. Approximately 75 percent ($2.5 million) of the expenditures will contribute to the Island's economy.

Personal income on the Island that is produced by the O&M expenditure is estimated to be $1.1 million per year (based on an income coefficient of 0.4396 for the electrical, gas and sanitary service sector; DPED, 1975).

Throughout the 35-year life of the project, capital expenditures will be made for proper maintenance of the facility. For example, makeup wells will be drilled; well workovers will be performed; and well casing may be replaced. These capital costs are in addition to the $60 million needed for plant start-up. They are classified as operating expenses.

The current estimate for the additional capital costs is $2.2 million per year. Much of the needed equipment will be obtained off of the Island because of its highly specialized nature. It is likely that 30 percent ($660,000) of the expenditures will be made on the Island.

Total output and total personal income generated by the facility is more than the direct effects; it includes indirect and induce effects. The DPED (1975) estimates that the total output multiplier is 2.0063 for the construction industry and 2.0579 for the electrical, gas, and sanitary service sector. Total annual output on the Island during construction is therefore $60.2 million ($30 million x 2.0063); total annual output on the Island during operations and maintenance (excluding the effects of capital investments during O&M) is $5.1 million (2.5 x 2.0579). Similarly, the total income coefficient that the DPED (1975) calculated for the construction industry is 0.5429. The total income coefficient for the electricity, gas, and sanitary service sector is 0.56978.

A summary of the economic impacts that will result from the PGV project is presented in Table 10-15.

Other Economic Impacts

Property tax will be the primary source of County revenues from the project. Other revenue will be received from motor fuel tax, licenses, and permits. In addition, indirect and induced revenues may result from the increased demand for, and production of, local goods and services to meet the operational requirements of the geothermal facility.

The State will also derive revenues from the proposed development, including the gross excise tax, corporate and personal income taxes, permit

Table 10-15

SUMMARY OF ECONOMIC IMPACTS ON THE ISLAND OF HAWAII
GENERATED BY THE PGV FACILITY

CONSTRUCTION	IMPACT
Capital Expenditures on Island	$30.0 million
Total (direct, indirect, induced) economic contribution generated [a]	$60.2 million
Average number of direct jobs	23 jobs
Total (direct, indirect, induced) number of jobs generated [a]	44 jobs
Annual personal income (direct, indirect) generated [a]	$12.6 million
Total (direct, indirect, induced) annual personal income generated [a]	$16.3 million
OPERATION	
Expenditures on Island	$3.2 million
Total (direct, indirect, induced) annual economic contribution generated [a]	$6.6 million
Number of direct jobs	19 jobs
Total (direct, indirect, induced) jobs [a]	45 jobs
Annual personal (direct, indirect) income [a]	$1.4 million
Total (direct, indirect, induced) annual personal income generated [a]	$1.8 million

(a) Output multipliers and income coefficients obtained from State of Hawaii, DPED et al, 1975

fees, and royalties from the geothermal resource. A portion of the State tax collections is expected to be returned to Hawaii County through grants-in-aid or transfer payments.

Hawaii's contribution to geothermal projects from 1972 to 1988 totals $4.2 million (KFC Airport, Inc., 1985). Federal contributions for this period exceeded 13.4 million. Private sector funding for geothermal projects in Hawaii was 73.4 million during this period. The proposed project has benefited from State and Federal research and development expenditures, but it is impossible to allocate these costs to any one particular development.

In summary, development of the proposed facility will generate a number of economic impacts that will affect the Island of Hawaii. The majority of these impacts are economically positive.

STATE-WIDE AND ISLAND-WIDE ENERGY IMPLICATIONS

The State of Hawaii depends on imported petroleum for over 90 percent of its energy. State energy prices are among the highest in the nation and are over six times their value in the early 1970s. It is estimated that the State spends over $1.6 billion per year on imported oil, which is equivalent to about 10 percent of the gross State product (DPED 1985). Geothermal development would reduce the State's dependence on expensive, imported fuel oil. Electrical energy produced from the PGV project will allow Hawaii Electricl Light Company (HELCO), to reduce its use of imported oil by approximately 250,000 barrels per year.

OTHER ECONOMIC IMPACTS

Spinoff Activities

Spinoff economic activities as a result of the development and operation of the PGV plant will be minimal, though research on the East Rift Zone geothermal reservoir may be stimulated. The existing HGP-A well can provide only limited

data on the nature and extent of the geothermal resource it taps. The operation of six additional production wells will provide the multiple sites needed to conduct drawdown experiments and other studies.

The long-run electric price stability of geothermal generation could encourage business to locate in Hawaii County, especially energy-intensive businesses. It could attract research and development firms that might be interested in various aspects of geothermal electricity production or in other commercial applications of the resource. The County and State are sponsoring practical research into direct uses of geothermal energy. PGV has already contributed a $30,000 grant to support this local effort.

Two potential spinoff activities from geothermal power are direct use of geothermal heat for papaya processing (Hawaiian Dredging and Construction Company, 1980) and the use of by-products that are generated from certain abatement systems (Thomas, 1982). Neither of these spinoff activities will occur at the PGV facility. Though direct use of geothermal heat for papaya processing is marginally feasible for the existing AMFAC plant at Keaau, there is no need for an additional papaya processing plant. The second potential spinoff activity is not applicable to the PGV facility because the primary and backup abatement systems at the facility do not generate any products or by-products. Some geothermal power plants use pollution control technologies that generate large amounts of sulfur, which can be sold and used in other sectors.

Diversified Agriculture

Diversified agriculture is expected to continue to expand in Puna. Agriculture is compatible with geothermal development. In this respect, it is preferable to residential development near the facility. As discussed earlier, the agricultural base of the Puna District is shifting from extensive crops such as sugar to more intensive operations. Though the proposed project site is located on agriculturally zoned land, little of the land it occupies is actually suitable for cultivation. Moreover, there is a sufficient supply of land in other areas of Puna to support a viable, growing agriculture industry.

Population, Labor Force, Income, and Housing

Indirect population impacts should be small because employment generated by this project is expected to be largely supplied by the existing labor force and no major secondary industrial activities are anticipated. Geothermal drilling personnel for the three existing wells on-site were predominantly Big Island residents. Only a few construction personnel will be needed from other parts of Hawaii or the mainland; therefore, the population growth impact will be modest. The operational-phase employment of 19 persons will have even less effect.

The composition of the Island of Hawaii and Puna labor force will not be affected, and the types of jobs provided by the project will be compatible with the occupational skills and backgrounds of Puna's current labor force. The mechanical nature of the geothermal construction and maintenance jobs will generally match the skills of employees who were discharged from the Puna Sugar Company.

Anticipated income for project workers is likely to be, on average, somewhat higher than current median income for residents of the island in general or of Puna in particular.

The area housing supply is expected to be adequate for the projected work force in both construction and operational phases, since most of the workers will be native to the area. The impacts of the project on housing values was a concern of many residents who commented on the Notice of EIS preparation. PGV undertook an assessment of worst-case impacts on housing and land values in the vicinity of the site (Decision Analysts Hawaii, 1987). The study concluded that the potential impacts under worst-case assumptions would be significant decreases (50 to 75 percent) in housing values of homes that are located within 0.5 miles of the power plant. Current estimates indicate that only two homes are located less than 0.5 miles from the power plant. The assessment was based on the effects of the HGP-A facility. The determining factor of housing value effects was H_2S emissions, which has a noxious smell like rotten eggs. The design and pollution abatement technology of the PGV facility is very different than the HGP-A facility. H_2S emissions are expected to be negligible during

normal operations. Thus, the PGV facility is not expected to adversely affect housing values.

Lifestyle

The PGV project will have little, if any, tangible impact on Puna's wealth or general lifestyle. For some people, however, it may have symbolic importance. The project is Hawaii's first commercial application of geothermal technologies that have developed over the past decade. This symbolizes progress, opportunity, and economic development to some people. For others, it may mean unwanted industrialization and encroachment on the traditional rural atmosphere and slow pace of life.

10.3 PROPOSED MITIGATION MEASURES

COMMUNITY INVOLVEMENT PROGRAMS

Puna residents have shown a strong desire to be involved in geothermal planning. Because the government's role in geothermal power is more regulatory than action-oriented, private developers are in a better position to involve community groups in meaningful ways. Encouragement of community involvement in the project has been studied and implemented as a potential mitigation for resident apprehension about geothermal development. The following organizations have already been active in providing a local forum for discussion of geothermal development:

- State Geothermal Advisory Council
- Mayor's Advisory Committee
- Big Island Business Council
- Hawaii Island Economic Development Board
- Hawaii Island Chamber of Commerce

- Puna Geothermal Venture Advisory Committee

Most community residents support the usefulness of economic spinoff activities from geothermal development (SMS Research, 1982a).

COMMUNITY EDUCATION PROGRAMS

Many community fears about geothermal development are based on misinformation, potential industry spinoffs, and/or the ultimate State-wide export of geothermal power. State and County government planners can help allay these concerns by developing a blueprint for a planning and management process. This process should specify exact studies and management decisions to be undertaken if the present initial geothermal development does lead to a second generation of development for Puna. This plan will reassure the community that concerns will be addressed at the proper time rather than being continuously dismissed as "not yet relevant." It should also outline the role community members can play in broader geothermal development planning. The Mayor's advisory committee has proposed a geothermal education plan which is being evaluated by DBED and other agencies.

Section 11

CULTURAL RESOURCES

This section provides an overview of the historical cultural setting of the region and examines the project's potential effects on its cultural resources. The topics covered include:

- Political history, religious history, population trends and land divisions
- The archeological artifacts of past societies that are present
- Native Hawaiian religious beliefs relevant to the development of the geothermal resource.

11.1 HISTORICAL SURVEY

POLITICAL HISTORY

According to Barrere (1959), Puna has not played an important political role in the island's history. Unlike the other districts, there was no great family in Puna whose support was sought by chiefs seeking to enhance their power. Puna's lands were desirable, but political control was typically exercised by the chiefs of the adjacent districts of Kau and Hilo.

By 1475 A.D., the Island of Hawaii was divided into six district kingdoms. The king of each of these was autonomous within his own district, but all acknowledged Liloa as the supreme chief of the island. When Liloa died, the districts refused to acknowledge his son, Umi, as the heir to this position, but Umi was able to reclaim overall leadership in battle against the other kings.

Imaikalani is the first chief of Kau known to have had power over parts of Puna. This power continued until the time of Keawei-Kekahi-alii-o-ka-moku. At that time the I family of Hilo extended its control over parts of Puna, but the remainder is believed to have continued to be controlled by the chief of Kau.

Puna appears to have a brief period of semi-autonomous rule under Chief Imaikalani. A civil war took place on Hawaii between approximately 1782 and 1792, which Kamehameha won, thus uniting the island.

RELIGIOUS HISTORY

Puna was an important traditional Hawaiian religious center. Paao established his line of priesthood there, a line that continued until after the death of King Kamehameha I in 1819 (Beckwith, 1979). Paao constructed his first heiau, or place of worship, there and numerous other heiau were also built (Thrum, 1907a,b). One of these, Kukii, was located in Kapoho, and another heiau was reported present at Pohoiki near Kapoho. These sites are several miles from the project site. See also Section 11.3, Native Hawaiian Religious Beliefs and Practices.

LAND COMMISSION AWARDS IN THE MID-NINETEENTH CENTURY

There was no concept of private land ownership in the traditional Hawaiian culture. Even the chiefs did not "own" the land in the western sense; rather, they exercised a trusteeship in the names of the nature gods, Kane and Lono. When each new high chief ascended the throne, there was a turnover in the proprietorship of the subdistricts; supporters of the new chief would be rewarded by being given control over them. Kamehameha I followed this practice when he unified the island chain, but neither Liholiho or Kauikeaouli (Kamehameha II and III) redistributed control when they became king. When private ownership was institutionalized by the Great Mahele (see below) the practice ceased forever.

The western concept of private ownership was made the law of the land in the 1850s through a series of laws known collectively as the Great Mahele. These laws changed the concept of control from one of "stewardship" to one of "ownership." In the process, some individuals received large land awards. Some of the larger Land Commission Awards in the vicinity of the project site included:

- 5,592 acres at Keahialaka adjacent to Kapoho was awarded to W. C. Lunalilo (who was king of the Hawaiian Islands from 1873 to 1874)

- 4,060 acres at Kapoho awarded to C. Kanaina, father of W. C. Lunalilo

- 2,902 acres of Puna land were awarded to Hazaleleponi Kalama (the adopted daughter of C. Kanaina and Miriam Ke-kakulu-ohi and wife of Kau-i-ke-aouli (Kamehameha III).

POPULATION ESTIMATES

It is estimated that as many as 300,000 persons may have inhabited the Hawaiian Islands in 1778 when Captain James Cook became the first westerner to land there. Schmitt (1968) estimates that from 100,000 to 150,000 of these lived on the Big Island. Diseases and social disruption which followed the westerners' arrival quickly decimated the population. In 1831-32, when the first official census of the Hawaiian Kingdom was carried out, the population of the Big Island was only 45,792; by 1866 it was below 20,000. The population climbed slowly between then and 1920, largely as the result of in-migration, before stabilizing for the following 50 years. The 1986 population was approximately 109,200.

11.2 ARCHEOLOGICAL RESOURCES

Archeological research has been conducted in the Puna area since the early 1900s. In the Hawaiian Islands, early archeological research concentrated on the major stone structures related to religious practices, such as heiau. This interest broadened to the study of petroglyphs and, by the 1930s, more comprehensive surveys of archeological sites were conducted (Newman, 1968).

Though the Puna District has been the subject of numerous archeological studies, the major concentration of research has been along the coastal areas. (Rogers-Jourdane, 1984) Five sites have been recorded by the State for Kapoho. The Kapoho petroglyphs (State Site No. 50-10-46-2501) are located on the south side of Kapoho Crater, approximately 3.5 miles east of the project area. Ka Eolua Kahawali (State Site No. 50-10-46-5245), a cinder cone that in legend was the site of a sledding contest between the Puna Chief Kahawali and Pele, is located about 1.5 miles east of the project area (Green, 1928). Two site complexes consisting of walled enclosures and platforms (State Site Nos. 50-10-46-4254 and -4255) are located on Kapoho Point, about 5 miles east of the project area. Also located on the coast, at Cape Kumukahi, 5 miles to the east, are two possible grave sites (State Site No. 50-10-46-4251). Two other sites, Kukii Heiau (State Site No. 50-10-46-2500) and the Kings' Pillars (State Site No. 50-10-46-4250) are located in the ahupuaa's adjacent and to the north of Kapoho. These sites are located from 4 to 5 miles east of the project area. Major archeological studies for the Puna District are listed in Appendix B.

At the request of PGV, the Department of Anthropology of the Bernice Pauahi Bishop Museum performed an archeological reconnaissance survey of specified lands (Tax Map Key 1:4:01:1, 2, 19) in the Kapoho area in January 1984 (Rogers-Jourdane, 1984). The purpose of the survey was to determine the presence or absence and general nature of any archeological resources evident on the surface of the project area. The nature and results of the survey are summarized below. A copy of the study can be reviewed by the public at the Historic Sites Section of the Department of Land and Natural Resources (DLNR). The DLNR reviewed the study and concluded that the project will not have an effect on historic sites.

The survey included a systematic walk-through of the 17-acre site area. The area within a 1-mile radius of the immediate survey area was also investigated on a less intensive basis. No archeological sites were located during the reconnaissance survey.

No further archeological work is planned prior to development because of the lack of surface remains and the highly unlikely event that subsurface remains will be encountered during the construction phase of this project,

However, if construction activities expose any cultural remains, PGV will consult with the State Historic Preservation Office, and a qualified archeologist will be contracted to monitor further work and implement any necessary mitigation procedures.

11.3 NATIVE HAWAIIAN RELIGIOUS BELIEFS AND PRACTICES

Some Hawaiians have strong cultural and religious feelings about traditions. This section describes some of the traditional Hawaiian beliefs, legends, and customs of the Puna District, including those of the volcano goddess Pele.

As is true with many other native societies in the Pacific and other parts of the world, history was passed down through the Hawaiian generations orally and through dance by legends and stories.

The Hawaiians had a knack for naming places and things for what they observed them to be or the activities that took place there. Many of these names have survived and can tell us what the old Hawaiians thought of the geothermal manifestations surrounding them. For example, Puu Honuaula - the place of red earth - refers probably to the red iron oxide exposed by the volcanic activity. Puu Pilau - the smelly hill - may have meant the existence of a fumarole or a sulfur vent. Kai Wela Wela - the place of hot, hot water. Kaapahu - a place where the bowels were bound up - has been shown to us in the behavior of the lava tube system in the most recent eruption on the flank of Kilauea.

Religious beliefs permeated every aspect of traditional Hawaiian culture, and the distinction between religious beliefs and secular life that characterizes much present western culture did not exist. The native Hawaiians worshipped a large pantheon of greater and lesser gods and goddesses, one of the most important of whom was Pele, the Hawaiian goddess of volcanoes.

According to some Hawaiian folklore, Pele's home is the Halemaumau fire pit of the Kilauea Volcano. Some native Hawaiians recognize Pele as a goddess in her body forms of lava, magma, heat and steam and believe Pele is responsible for volcanic eruptions and the landscape of the Hawaiian Islands. The Puna District has played an important role in Pele history, belief and religion. Hawaiian chants and hula, both of which have been important in the Puna District, frequently focus on Pele and the Puna District and the Island of Hawaii. Numerous places in the Puna District are reportedly important to Pele, Hawaiian beliefs and customs. These places are contained in Pele stories, chants and legends.

During considerations of geothermal permitting matters by BLNR in 1985 and 1986, a number of people presented information about Native Hawaiian religious beliefs and practices. The BLNR has summarized this testimony in its decision and order.

The paragraphs below outline the comments made during these hearings; these comments may better describe these complex cultural matters in relation to the development of geothermal energy. (References to specific testimony or exhibits presented have been deleted, and editorial changes made, for clarity).

The current day practice of Native Hawaiian religion includes the worship of the goddess Pele. Many Native Hawaiians regard Pele as an akua (god) or as aumakua (family or personal god). Some Native Hawaiians also identify themselves as the bloodline of Pele. Hawaiians who actively worship the goddess Pele have been identified as "Pele practitioners."

Pele practitioners believe Pele is a living god, whose presence is manifested in periodic and frequent volcanic eruptions. Pele is believed to also be present in the sacred area surrounding the Kilauea Volcano in kinolau (alternate body forms) such as ferns, certain shrubs and trees, and certain volcanic land forms or features, such as significant pu'u (hills). Pele practitioners believe that the area of active volcanism is in fact

Pele's physical body, her home or abode. They testified that some individuals believe Pele's home encompasses an area extending from Mauna Loa through the Ka'u and Puna districts to the ocean, including the entire area of the Kilauea Volcano and the East and Southwest Rift Zones. There was testimony that Pele is also the heat, water, steam, smoke, and vapor present in and throughout the Kilauea Volcano and its rift zones.

Other Hawaiians currently believe that the development of geothermal energy is not counterproductive to native Hawaiian culture and heritage. One person testified that, "...as a Hawaiian who shares the love of this land with others, cognizant of my heritage and traditions, I feel my ancestors would be proud to know that we are trying to use our natural resources in the best way possible. The Hawaiian of times past, with his astute knowledge of all things and through the proper observances of established laws, used all of the natural resources available in their limited way to do the most good for the most people."

Historical accounts of native Hawaiian activity show that early Hawaiians did use geothermal steam for cooking food for non-religious purposes. Early Hawaiians are recorded using steam emanating from fissures along the rift zone for personal uses as well as religious uses. William Ellis, in his journals, notes that the ground in the vicinity of Kilauea throughout the whole plain was so hot that those who came to the mountains to gather wood and to fell trees and hollow them for canoes "always cooked their own food, whether animal or vegetable, simply by wrapping it in fern leaves and burying it in the earth," a method quite similar to the Hawaiian imu (an underground oven). Handy and Handy, in their "Native Planters in Old Hawaii" describe how whole trunks of hapu'u pulu (fern trees) were thrown into steam fissures, covered with leaves, and when cooked, were split open and the starch core used as food for pigs.

Testimony of some indicated, however, that they believe that geothermal exploration and development will threaten and probably prevent the continuation of all essential ritual practices associated with Pele and thereby impair the ability of Pele practitioners to train young Hawaiians

in the traditional Hawaiian beliefs and practices. They believe, therefore, that Hawaiian religion and culture will not be conveyed to future generations and will, therefore, die. They believe that geothermal exploration and development is an offense against Pele, a desecration of her body and being, because this activity involves drilling into Pele's body and removing her energy. They believe this activity will take Pele and kill her forever.

However, Mr. Don Mitchell, a noted author on Hawaiian history, does not believe that ancient Hawaiian beliefs were specifically against the use of steam, but that it is only a recent interpretation of Hawaiian theology. He believes that lava and volcanic eruptions are closely associated with Pele, but that steam was not referred to in early discussions of Pele.

After hearing comments, receiving exhibits and viewing some of the chants and hula that tell the stories of Pele and express the feelings of Hawaiians for Pele, the Board concluded that there are a variety of religious beliefs held by Native Hawaiians. Many beliefs are very strongly held. Some have well recognized traditions and practices. Testimony presented by Pele practitioners represents their faith and personal beliefs which appear to be strongly held. The Board concluded that the religious concerns of Native Hawaiians deserve respect and that care should be exercised not to harm religious practices.

The Hawaiian culture, and particularly its spiritual underpinnings, changed rapidly in the late eighteenth and early nineteenth centuries. Part of this was due to forces unleashed by the islands' unification under King Kamehameha I, but part of it was due to the spread of western influence in the years following Captain Cook's rediscovery of Hawaii in 1778.

Traditional religious practices were officially abandoned by the alii or ruling class, following the death of Kamehameha I in 1819, and most Hawaiians had converted to Christianity by the end of the nineteenth century. The traditional beliefs did not disappear entirely, however. Some individuals continue to believe in the old religion and to adhere to at least some of its

practices. Pele was one of the most beloved of the traditional gods, and some Hawaiians continue to "Hookupu" (give gifts) to her. Traditional offerings include red fern frond, pork, small fish, bananas, lehua flowers, and red ohelo berries.

Such beliefs and worshipping practices are very private; worship is personally, not publicly, practiced. Most believers are reluctant to discuss their religion, especially sacred, traditional knowledge in the fear that people will misunderstand or ridicule their beliefs. Most Hawaiians, including Pele worshipers, have strong feelings for the land, the sea, and each other. In a word, one native scholar called it "lokahi", meaning harmonizing one's self with others, all of nature, and the cosmos.

When Pele is not creating a lava flow, causing earthquakes, or resting, she reportedly assumes human form and enters into the world of people. The talented and articulate writer, Pierre Bowman, described his personal encounter with Pele and his family's approach to the beliefs and myths of Pele in a feature article that appeared in June 1986 in the Honolulu Star-Bulletin. Excerpts are below.

> "I was in third grade, and my Aunt Nina, who has always been extraordinarily persuasive, convinced my mother that a Big Island visit would be enriching for her nephew - especially because the volcano was erupting....
>
> "Will we go see the volcano now?" I asked.
>
> "Oh, no," replied Aunt Nina. "My friends are coming for dinner, and then they'll stay overnight. We'll go tomorrow." ...
>
> ... The grown-ups started slowly in the morning. I figured it had something to with the martinis and Manhattans. Gradually, cardboard cartons were packed with food and bed linens. Gradually, the morning slipped by. Finally, in mid-afternoon, we all got into the olive-drab Pontiac and drove to Hale Loke, just outside the border of the Volcanoes National Park. Hale Loke was the family vacation cottage from the days when Aunt Nina and her siblings were kids.

I could smell the volcano as we pulled up at the front steps.

"Will we go see the volcano now?" I asked....

... It grew dark. The glow of the volcano reddened the sky.

"Are we going to see the volcano now?"

"After cocktails and dinner." I nearly ached....

... In the dimness of the living room, against a fire in the stove, the cocktail conversation was different. Aunt Nina told about the time Grandpa had picked up a very old lady on the Saddle Road and had driven her to Hilo - only to find that she'd vanished from the back seat.

Of course the woman was Pele.

Aunt Nina told another story about watching an eruption in Puna when the volcano sprang from a cane field. As she stood and watched, she became aware of a beautiful young women with flowing hair, standing all alone, also watching the fountains of fire.

My aunt approached her.

"Where do you live?" asked Aunt Nina.

"Over there," said the beauty, gesturing vaguely....

... Of course it was Pele....

Dinner was served. It was eaten quickly. There was more talk of Pele. And then it was time. Wear your warmest clothes, commanded my aunt. Quite rapidly, we piled into the Pontiac. Minutes later, we were parked at the edge of Halemaumau, peering into the crater....

Hour upon hour, we stared, our faces toasted and warm, our backsides cold. From her bag, Aunt Nina produced a thermos of hot chocolate and cookies. We stared some more....

Finally, the dark crust over one of the large pools of lava began to move and crack. And then, through the smoke and quite unmistakably, there was the face of a beautiful women.

It was Pele. She had waited for us. My Aunt Nina knew she would."

Pele is not the original volcano deity of Hawaii according to legend. She is not responsible for the base volcanic mountains that form the Hawaiian Islands. She came to Hawaii long ago from a distant and mystical land of Kahiki, a name meaning any foreign place (in this instance believed to be from the ancestral homeland of Tahiti; Emerson, 1915). Kahiki is believed to be a free-floating land that shows itself only to mystics, poets and prophets.

It is said that Pele was ambitious as a child, ever staying near her mother's fireplace, where she carefully studied the methods of the firekeeper, Lono-makua (Emerson, 1915). Pele's older sister, Na-maka-o-ka-hai (Namaka), grew suspicious and alarmed of Pele's ambitions. Namaka's fears proved true. On returning from one of her expeditions across the sea, Namaka found that Pele had caused a fierce volcanic eruption that covered a portion of their homeland with lava.

The episode forced Pele to seek refuge with her elder brother, Ka-moho-alii, who was a deity of great power, authority and wickedness. The refuge was only temporary. Soon, Pele vanished from Kahiki in a famed mythical canoe called Honua-i-a-kea. Pele was allegedly accompanied in her canoe trip by such god-like beings as Ka-moho-alii, Kane-apua, Kane-milo-hai, and many other relatives of Pele, including her favorite sister, Hiiaka. Pele and Hiiaka are Hawaii's most spectacular female deities. The canoe trip was an adventurous one and eventually ended at the Big Island of Hawaii.

The proposed geothermal wells and power plant are located in Kilauea Volcano's East Rift Zone, part of Pele's traditional home. Some worshippers of the goddess Pele believe that withdrawing steam from the volcano would desecrate the body of the goddess and destroy her. Consequently, several residents of the area appealed decisions by the State Board of Land and Natural Resources (BLNR) to allow geothermal development in approximately 9,000 acres of the Wao Kele O Puna forest area, about 8 miles up-rift from the project site. The challenge was brought on the grounds that the development would interfere with the plaintiffs' constitutional rights to practice their religion (Pele worship). However, the Hawaii Supreme Court recently ruled that the plaintiffs had not shown that geothermal development would infringe on their religious practices. The Court therefore denied the appeal and upheld the BLNR decision allowing geothermal development.

The PGV project is not anticipated to interfere with access for Hawaiian religious and cultural activities. For security and safety reasons, areas immediately around the PGV power plant, wellfields, and ancillary facilities will be restricted to the public. There will be gates across the two site access roads, but there are no plans for a fence around the perimeter of 500 acres. The land is privately owned; specific activities on the property would be subject to control by the owners.

Section 12

AESTHETICS

12.1 ENVIRONMENTAL SETTING

This section describes the probable and potential aesthetic impacts from the Puna Geothermal Venture (PGV) facility. The primary aesthetic impacts are visual views of the power plant, wellpads, and construction equipment.

REGIONAL VISUAL SETTING

Much of the Puna District is comprised of volcanic uplands, Puus, and craters. Kilauea Volcano, one of the most active volcanoes in the world, lies to the southwest of the project site. Several lava flows have occurred in the District. Puu Kaliu and Puu Honuaula are the largest Puus in the area. The latter, which is within the PGV project area, is slightly smaller and lower than the former. Both are dwarfed by the dramatic Kapoho Crater, approximately 3 miles to the northeast of the proposed power plant site. The new cone from Puu Oo is about 10 miles northwest of the site. The East Rift Zones is manifested at the surface as a linear belt, 1 to 2 miles wide, consisting of vents, faults and other volcano-tectonic related events.

The sea can be seen from several vantage points within the region because the land slopes gently to the Pacific Ocean in three directions. The summit of Kilauea Volcano is another dramatic view that can be seen from the Puna District. Views in the region are limited because of the rainy weather and the amount of tree cover, especially for travelers along the region's main highways (Highway 130, Highway 132, and Highway 137).

The basic land vegetation in the area are low scrub, forest, and agricultural plantings. The bushes and grasses are low where the roads pass through scrub vegetation, and the views are usually wide-angle or panoramic. The view is generally restricted to the road corridor in areas with forest cover. Large

canopy trees overarch the road to create shady tunnels in some areas. Other tree-lined roads have species with a more vertical form, these leave the sky above the road clearly visible.

Large fields northeast and southwest of Pahoa were formerly used primarily for sugarcane. These fields began reverting to scrub after the Puna Sugar Company ceased operation in the area. The most significant agricultural crop cover in Puna is currently papaya. Other crops include macadamia nuts, bananas and anthuriums. Pahoa and the surrounding area are rural and contain older structures, buildings, and landscaping. Public opinion surveys (SMS Research, Inc., 1982a) indicate that local residents find agricultural technology to be familiar and generally acceptable.

The view of the proposed power plant and wellfield from roads and houses within the surrounding subdivisions depends on the amount of development at specific locations and, in undeveloped areas, whether the natural vegetation is low scrub or forest. There are no views of the project site from lots and roads within the Leilani Estates, Nanawale Estates, and Nanawale Farm-Ranch Land subdivisions because of the topography and/or the presence of natural vegetation.

VISUAL SETTING AROUND THE SITE

The most dramatic visual features around the geothermal development site are the volcanic Puus and craters. The site is located immediately adjacent to Puu Honuaula. Puu Honuaula and the unnamed Puu just to the west are the visual focus of the project area for several reasons. All of the land immediately around their bases was cleared of natural vegetation. At one time papayas were actively cultivated in some areas. The contrast between the now fallow orchards and the natural vegetation on the steep sides of the conical hills makes the Puu visually distinct. Puu Honuaula, which rises about 150 feet above the surrounding land to an elevation of 850 feet, is the tallest volcanic feature in the immediate vicinity of the site. About 60 acres in the southwest corner of the PGV project area are covered by a 1955 lava flow. This area includes two fifty-foot high vents formed of nearly barren lava near the Pahoa-Pohoiki Road.

Kahuwai Crater, Puulena Crater, and Pawai Crater, located about 1 mile southwest of Puu Honuaula, are impressive depressions several hundred feet deep. These features are not visible except from the craters' edges. While the topography rises slightly to the rims of the craters, their forms are largely masked by the heavy forest around them.

There is one major stand of trees within the PGV project area, though extensive forested land is nearby. Approximately 1 mile northwest of the proposed power plant site is Lava Tree State Park, which is both an aesthetic and geological resource of the area. Lava molds of trees stand among ohia trees and fern growth, forming an attractive and interesting environment. The north sides of Puu Honuaula and the neighboring Puu are visible from the southeastern corner of the park. The mass of these cinder cones lies between the park and the power plant site.

The local area around the project site contains several geothermal-related facilities. These facilities include the HGP-A well and power plant facility, Puna Research Center, three PGV wells (Kapoho State Well No. 1, No. 1A and No. 2), two wells owned by Barnwell Geothermal, Inc. (Lanipuna 1 and 6), and a drilling rig laid down and stored to the south of the PGV project area at the Lanipuna No. 6 well site. The HGP-A facility is located at a bend in the Pahoa-Pohoiki Road where motorists have an unobstructed view of the facility. No landscaping or solid fencing blocks the view of the power plant, well, related structures, or equipment. The PGV wells and the stored drilling rig are unobtrusive.

12.2 ENVIRONMENTAL IMPACTS OF THE PROPOSED ACTION

Some residents in the neighboring subdivisions and travelers along area roads will be able to see portions of the facility. Most, if not all, of the visual impacts are temporary. Graded areas will be revegetated with trees and plants and landscaped in order to minimize views of the facility. Buildings and structures will be painted or constructed of materials to blend in with the natural environment. After the facility is decommissioned, structures will be removed and additional vegetation will be planted on the site. Native vegetation will be used wherever feasible. Areas will be regraded to near-original contours.

Construction

A limited amount of grading (including some cut and fill for the power plant and one of the wellpads) will be required for the project. A total of about 17 surface acres are required for the project site. This will expose bare earth on the flanks of Puu Honuaula that may be visible from adjacent areas. The graded areas will be comparable in size to those created when homes are constructed in nearby subdivisions, and far smaller than those associated with existing agricultural activities.

The tallest piece of construction equipment on-site during construction will be a 150-foot drill rig. This rig will be used for drilling the geothermal wells which requires approximately 60 days each to drill. Six new geothermal wells are initially needed. The rig will return about a year after initial drilling to drill additional geothermal wells. A drill rig will return periodically to the site to drill makeup wells or perform remedial or maintenance work. Lighting is required at night during drilling for this round-the-clock operation.

Small steam plumes will be produced occasionally during periodic well flow testing periods. The visibility of a plume will depend on weather conditions and viewing position. Viewed from below against a cloudy sky, plumes will not be noticeable. Viewed from a high vantage point against vegetation or earth,

or viewed against blue sky, plumes will be apparent. The tradewinds are fairly constant and the plumes will disperse rapidly.

Operation

None of the structures on the power plant or wellpads will project above Puu Honuaula skyline when seen from adjacent properties. Aboveground pipelines will run between the wellpads and the power plant and will rise no more than 5 feet above the ground except where they cross roadways. They may be routed in a door-frame shape as high as 17 feet at such crossings.

The PGV plant will be built at an elevation of approximately 680 feet. The height of the turbine-generator building is not set yet, but the highest point is in the main turbine bay, where the need for an overhead crane requires at least a 30 foot ceiling. The two cooling towers are currently designed to be 75 feet long by 75 feet wide by 40 feet high.

Steam plumes produced by operation of the proposed facility will occasionally be visible. The only steam plume generated under normal operating conditions will be from the cooling tower. The plume is not expected to be visible on warm days with average humidity; visibility increases as the ambient temperature declines and humidity increases. A visible plume can be expected on cold days with moderate to high humidity, which are rare in the project area. There will be a somewhat more dense plume from the power plant rock muffler on occasions when it is necessary to divert geothermal steam from the power plant. No plumes will normally be visible from the wells during operation. A white plume may be visible from south of the project site because of its contrast with the dark vegetation on Puu Honuaula. Weather conditions will determine whether the plume will be visible from the north as it rises above Puu Honuaula. The plume will rise straighter and higher on a calm day than on the normally windy days in Puna. The range of visibility will be much reduced under the more usual weather conditions (rainy and breezy) in Puna.

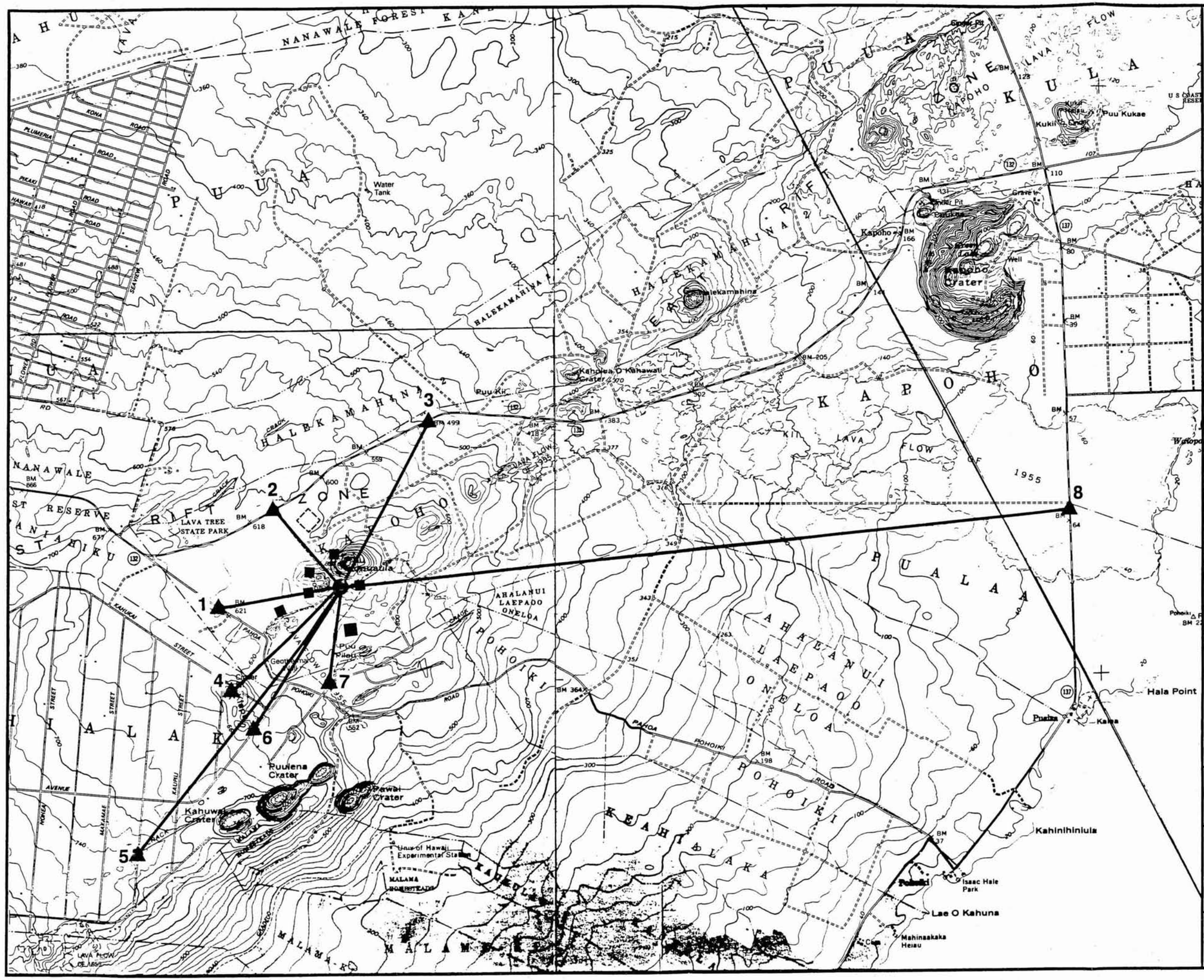
VISUAL IMPACT STUDY

Numerous viewing locations surrounding the power plant and wellfields were examined to determine the PGV facility structures that will be visible. The views were from roads, subdivisions and public parks. Eight specific locations were studied. A cooling tower built at an elevation of 680 feet with a height of 40 feet was assumed for this study. These locations are plotted on Figure 12-1. The eight viewing locations are:

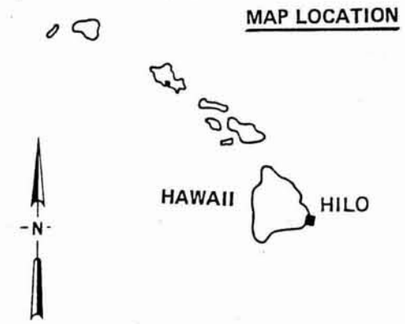
- One view from the west of the power plant along Pahoa-Pohoiki Road
- Two views from the north along Kapoho Road
- Three views from the southwest in Leilani Estates subdivision
- One view from the south in Lanipuna Gardens subdivision
- One view from the east along Highway 137.

Views from the West

Most of the western boundary of this leased land, along the Pahoa-Pohoiki Road, is lined with hedges. The hedges are generally high enough to confine views to the east from most passenger cars, except where a few breaks in the vegetation allow glimpses of Puu Honuaula and the neighboring Puu. Travelers in buses and trucks may be able to see the two Puu over the hedges. There is little or no view of the power plant site because of the vegetation and the Puu west of the site. Figure 12-2 shows the line of sight of an observer standing at location 1 looking towards the plant. A hedge with an average height of 10 feet obstructs the observer's view of the facility at this location. Travelers in buses and trucks may be able to see the cooling tower as they travel this route.



MAP LOCATION



LEGEND:

- ● POWER PLANT
- ■ PRODUCTION WELLPAD
- ⬚ TEMPORARY CONSTRUCTION YARD
- ▲ OBSERVATION POINT

SCALE

CONTOUR INTERVAL 20 FEET

0 — 1 MILE

0 — 2000 — 4000 FEET

0 — 1 KILOMETER

SOURCE: U.S.G.S., 1980, 1981a, 1981b

PUNA
GEOTHERMAL VENTURE PROJECT
HONOLULU, HAWAII

Figure 12-1

VIEWING LOCATIONS OF VISUAL IMPACT STUDY

FLUOR DANIEL	JOB NO.	DRAWING NO.	REV.

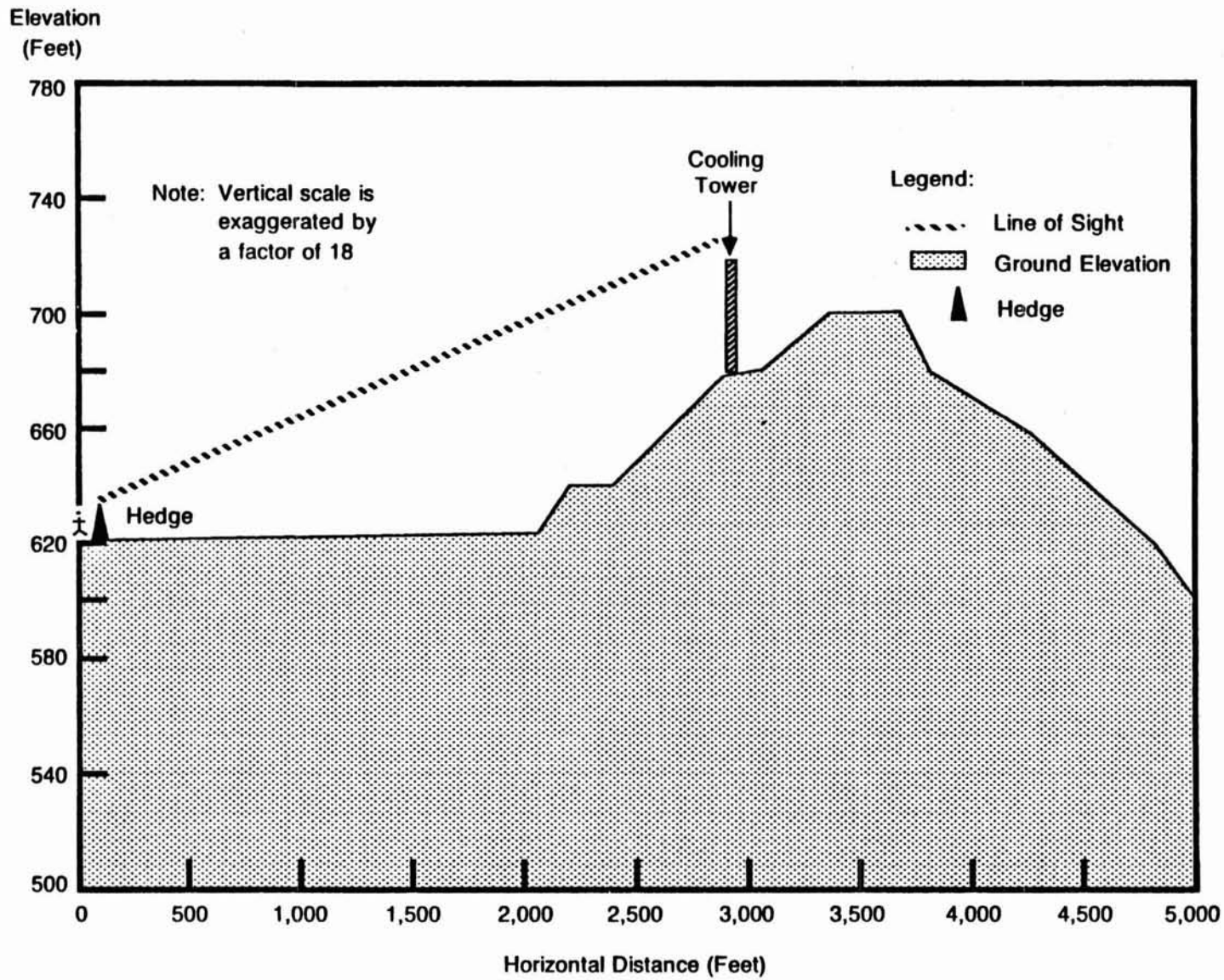


Figure 12-2 OBSERVER'S LINE OF SIGHT FROM LOCATION 1 ON PAHOA-POHOIKI ROAD

The drilling rig will probably be visible from nearby roads because of its height, where vegetation does not confine views to the roadway corridor. There are thick stands of tall canopy trees north and south of the project site, that effectively block views of the proposed plant.

The stands of trees thin out along Pahoa-Pohoiki Road near the HGP-A site, except near the HGP-A visitor center, where some landscaping has been done. It is possible to see the PGV power plant site beyond the HGP-A complex. The HGP-A facility adjacent to the road will be more dominant than the PGV facility structures, which will be about a half-mile away. Views of the wellpad locations are barely possible south of the HGP-A site where the road turns eastward, through breaks in the stands of ohia trees and the roadside embankment. There is a line of trees along the road after Pahoa-Pohoiki Road turns eastward. Glimpses of the proposed PGV facilities at a distance of about 4,000 feet may be possible between the tree trunks. The PGV facilities will not be visible from this highway after the road bends back to the south because of the woodland on each side of the road.

Views from the North

Structures and construction activities at the power plant site will be hidden from the view of travelers along a large part of Kapoho Road by Puu Honuaula. There is very little vegetation to block views of the facility along some segments of Kapoho Road where the view is not blocked by the Puu. Construction activity on some wellpads will be visible from these segments of the highway. The only pieces of equipment that will rise above the fences once landscaping occurs on the outside of the fences around the pads are the moisture separators located on each wellpad. The separators stand about 17 feet tall and are 30 inches in diameter. The separators will hardly be visible because all wellpads are at least 2,000 feet from Kapoho Road. The electrical switchyard, positioned between Wellheads C and D may be visible from segments of Kapoho Road. The drilling rig will be visible when wells are being drilled at Wellpads C and D.

Figure 12-3 shows the line of sight of an observer standing at Location 2 on Kapoho Road and looking towards the geothermal site between Puu Honuaula and its neighboring Puu. This observer may see the upper third of the power plant cooling tower. A new access road may be built from Kapoho Road at Location 2. A temporary 5-acre construction yard will be next to this new road and will be visible from Location 2. The elevated transmission line along the access road and the switchyard between Wellpads C and D will be visible.

Location 3 is also north of the power plant on Kapoho Road, further east of Location 2. Puu Honuaula blocks most of the view of the geothermal site. Figure 12-4 shows the line of sight of an observer standing at Location 3. Wellpads C and D and will be visible from this location.

Lava Tree State Park is located approximately one mile northwest of the power plant. The north side of Puu Honuaula and neighboring puu should block any view of structures on the power plant site. The drilling rigs on several of the wellpads may be visible to park visitors if they walk off the trail to the western boundary of the park. The western boundary of the park has only sparsely scattered trees.

Views from the Southeast

Three subdivisions are southwest of the power plant: Pohoiki-Bay Estates, Kapoho Estates, and Leilani Estates. Leilani Estates is the largest of the three subdivisions. Views of the PGV site from roads in the Leilani Estates subdivision are now blocked by forest. Location 4 on Kahukai Street is at the highest elevation near the project in Leilani Estates. An observer's view of the plant site is screened by trees. Figure 12-5 shows the positions of the observer, trees, and cooling tower.

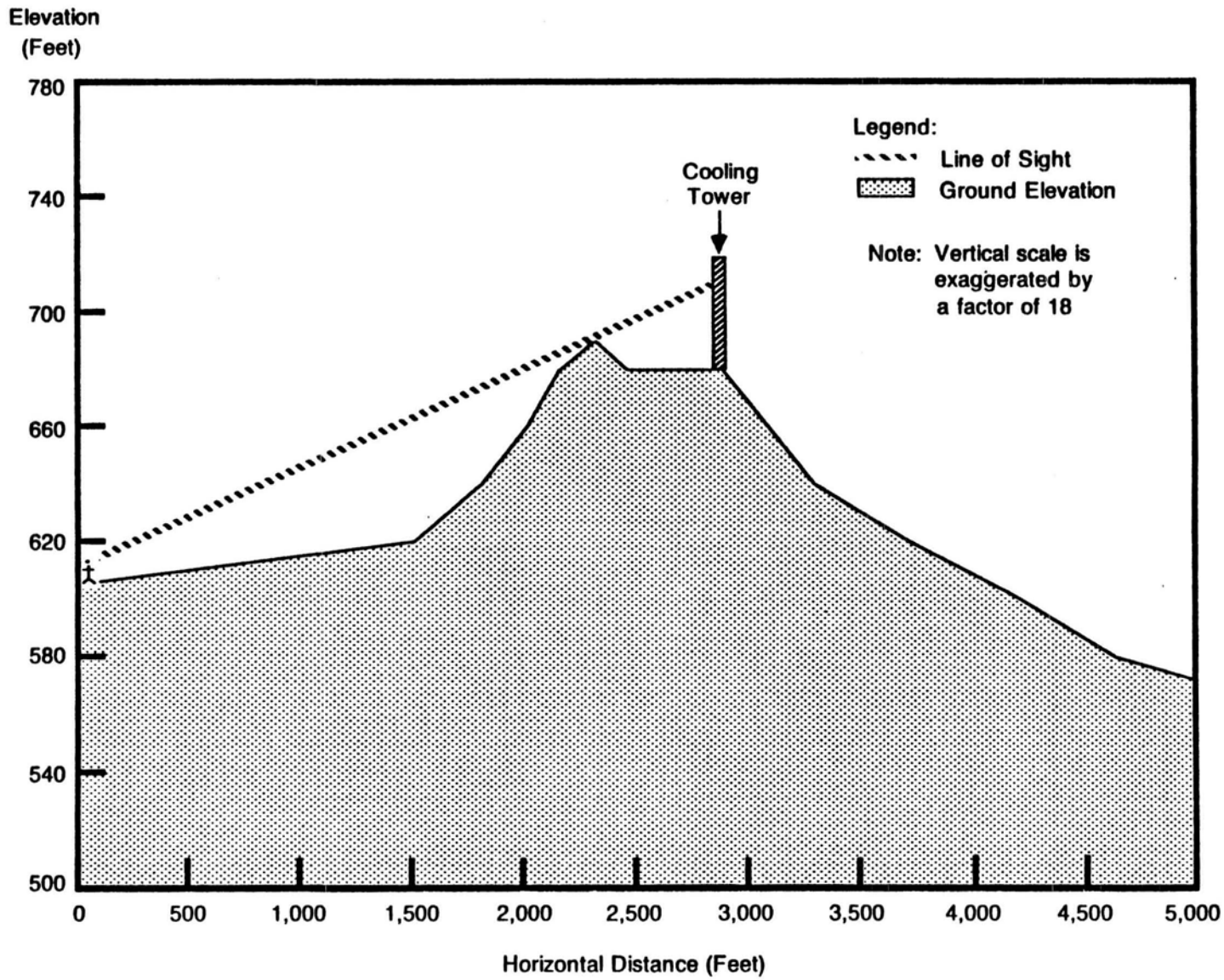


Figure12-3 OBSERVER'S LINE OF SIGHT FROM LOCATION 2 ON HIGHWAY 132

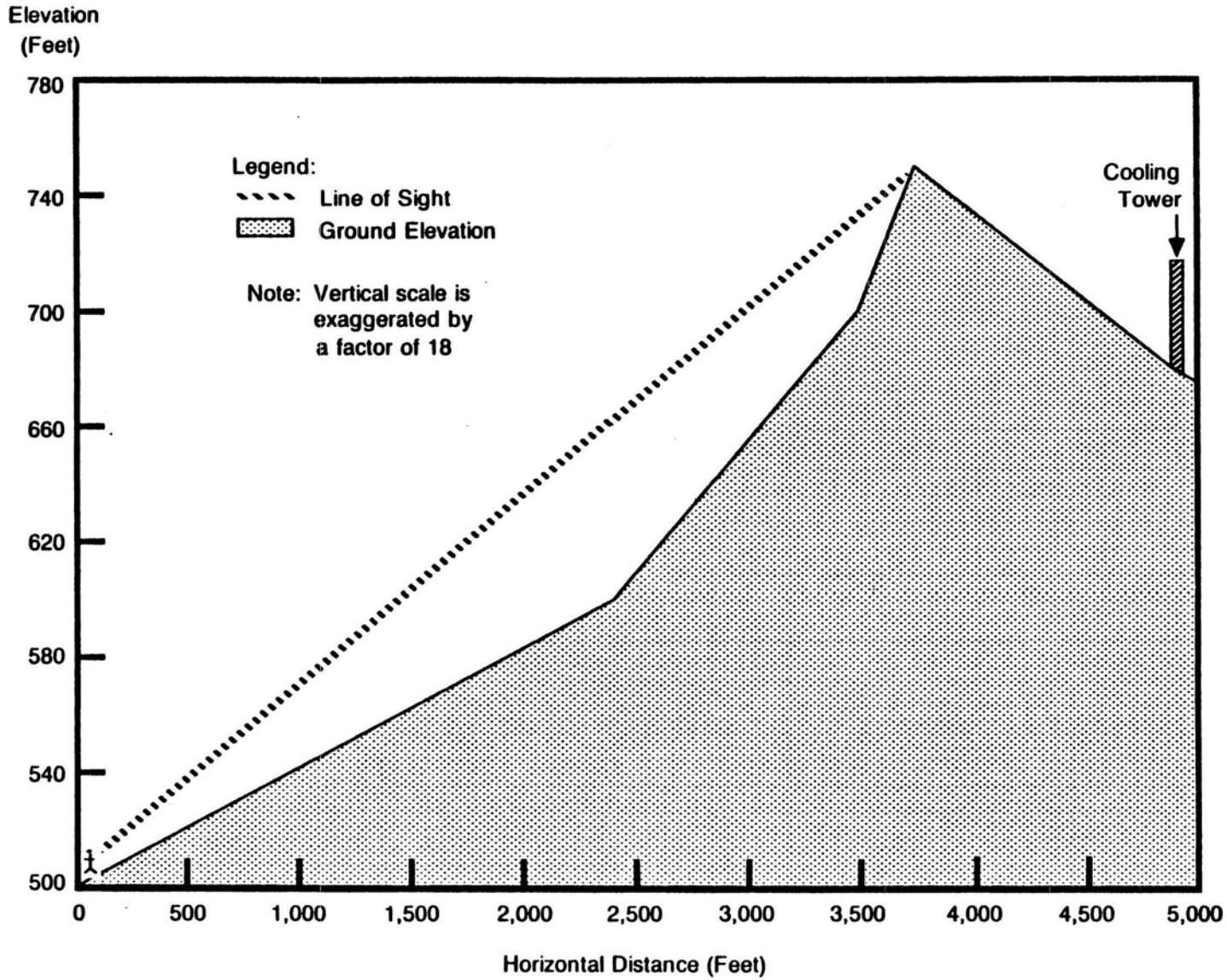


Figure 12-4 OBSERVER'S LINE OF SIGHT FROM LOCATION 3 ON HIGHWAY 132

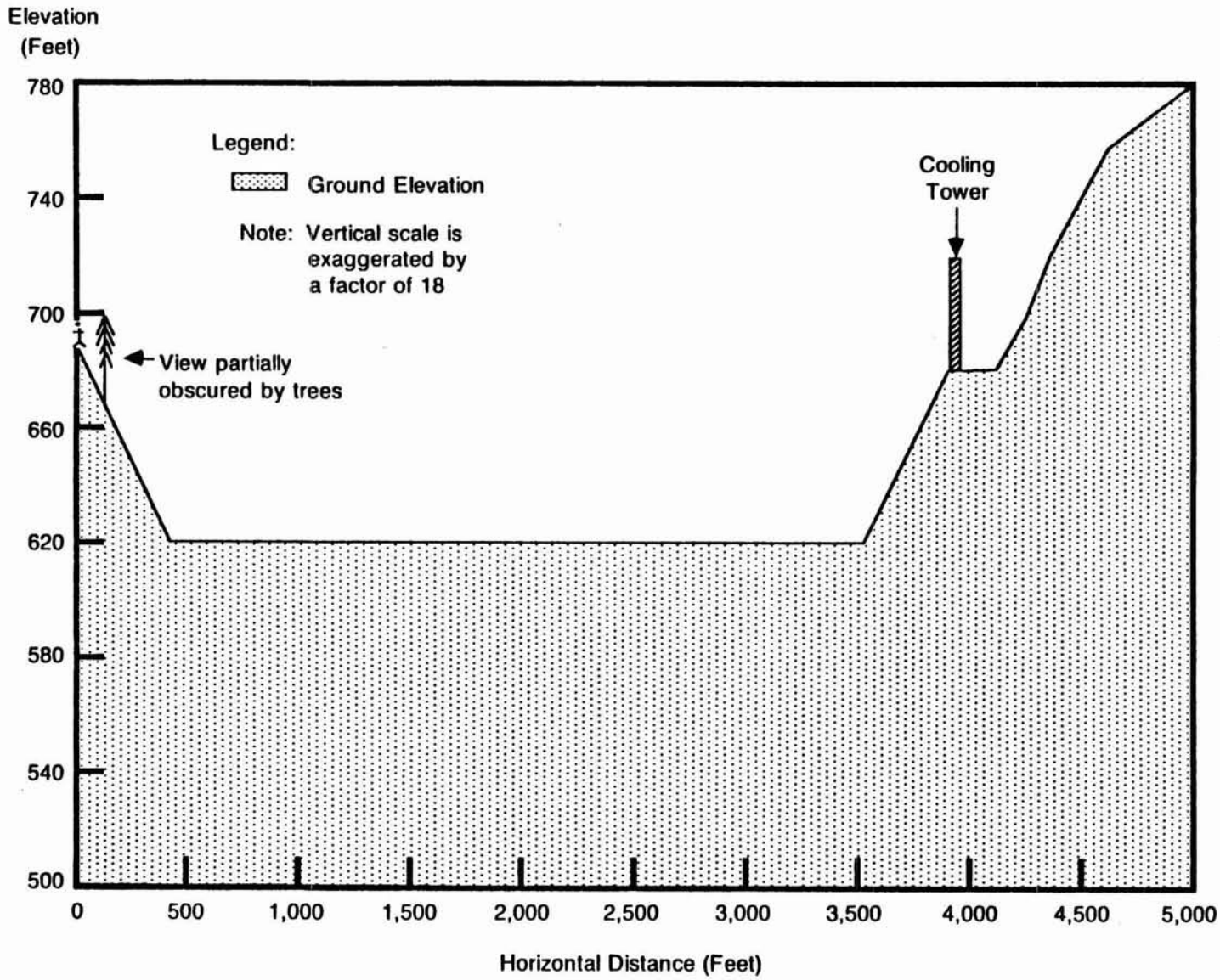


Figure 12-5 OBSERVER'S LINE OF SIGHT FROM LOCATION 4 ON KAHUKAI STREET

Location 5 is another high point in Leilani Estates. Trees obstruct an observer's view of the plant from this location. The positions of the observer, trees, and cooling tower are shown on Figure 12-6. The PGV site may become visible if a large number of the lots at the eastern end of the subdivision are cleared and developed. It is unlikely that many lots will be developed before the major facilities are landscaped considering the tens of thousands of undeveloped lots in the Puna District and the present slow rate of development.

The third view, Location 6, in Leilani Estates was from Leilani Avenue at Mohala Street. Puu Honuaula lies directly in the view of east-bound travelers on Leilani Avenue for approximately 3,000 feet, though there is a dip in the road from which the view is blocked. The view of the power plant site will be very brief at usual speeds. The scenery from this location is not entirely rural and natural. Travelers presently see a cut in Puu Honuaula for Wellpad B and the roof and steam plume from the HGP-A facility. Construction equipment and activities on the power plant site will make the scenery for travelers on this road somewhat more industrial, during PGV project construction. The view of the facility may be blocked and the excavation cut on Puu Honuaula hidden once landscaping is established along the fences. Figure 12-7 shows the partially obscured view of the facility at Location 6. Figure 12-8 shows a photomontage of the view from the crest of Leilani Avenue before landscaping is provided.

Views from the South

South of the power plant is Location 7 in the Lanipuna Gardens subdivision, Figure 12-9. Two short segments of Hinalo Street have wide-angled views that include most of the wellpads and power plant since the street transverses a lava flow that has only short grass coverage. Construction activities such as clearing and grading and erection of structures and equipment will be visible at these segments. Only a few subdivision residents currently use this dead-end street. Landscaping should be installed around the pads before this subdivision road is more heavily traveled. An observer standing at Location 7 will see the geothermal plant site, the top 30 feet of the power plant cooling tower and portions of the turbine building.

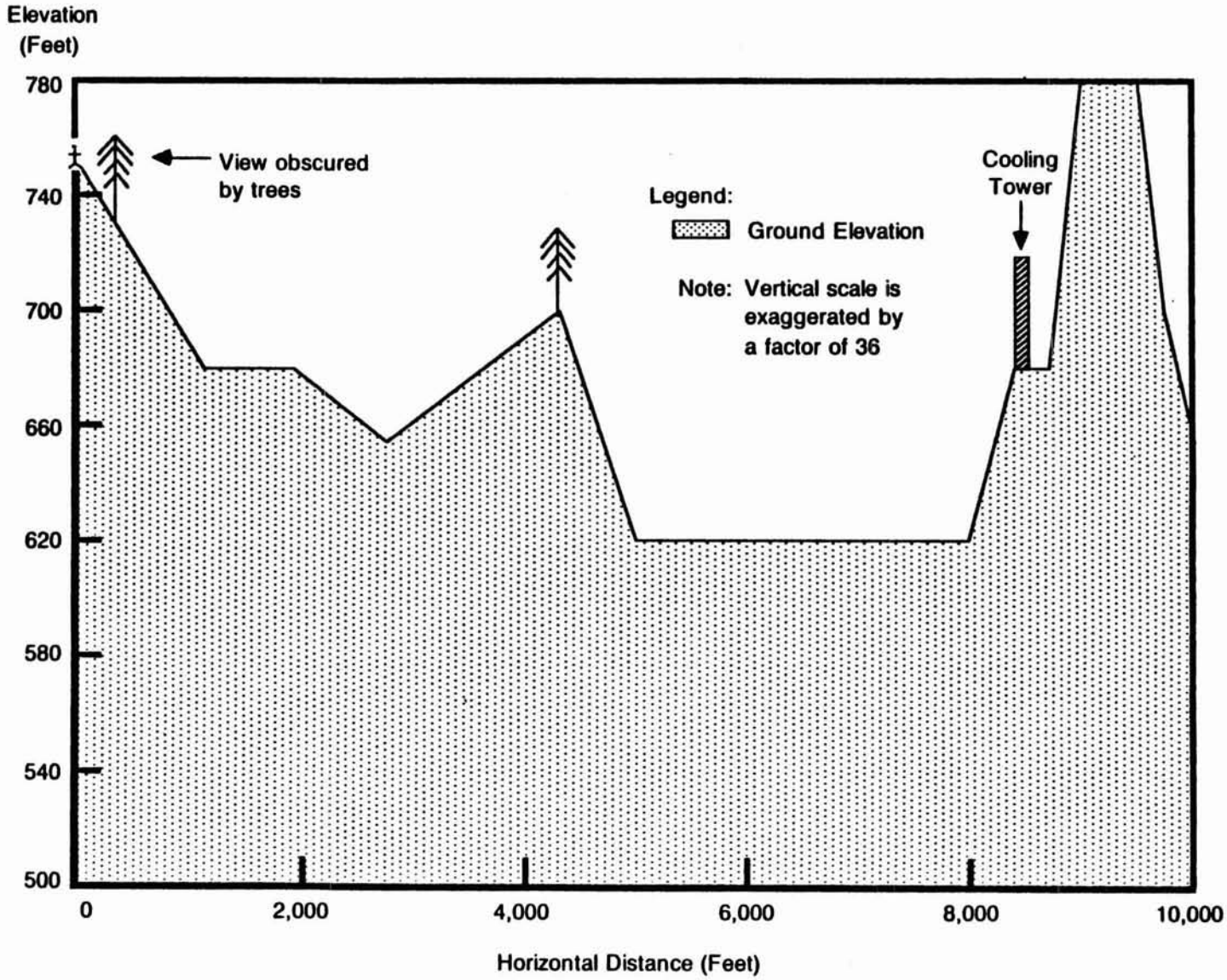


Figure 12–6 OBSERVER'S LINE OF SIGHT FROM LOCATION 5 IN LEILANI ESTATES

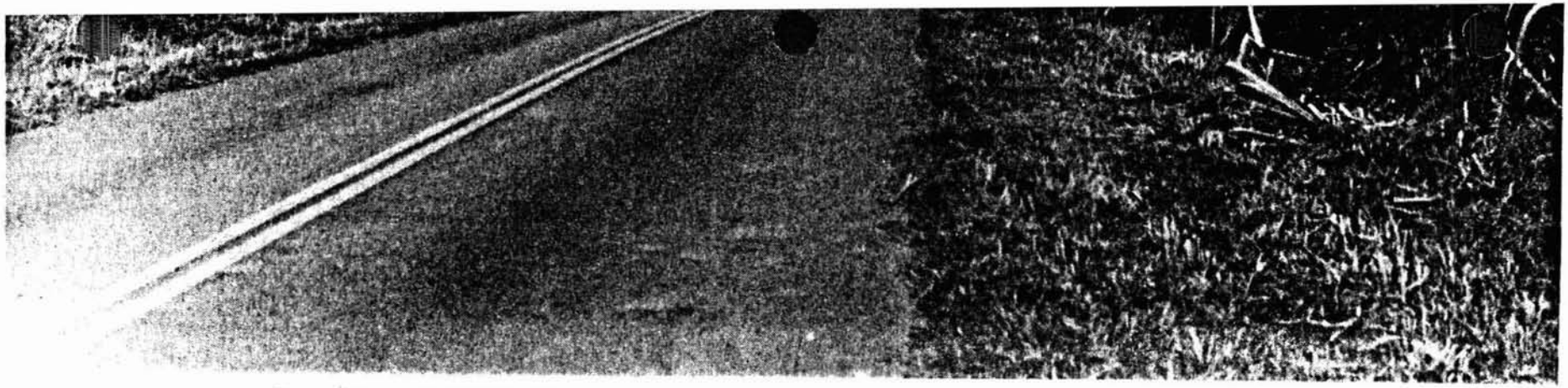


Figure 12-8 PHOTOMONTAGE OF PROPOSED PGV FACILITIES VIEW FROM LEILANI AVENUE

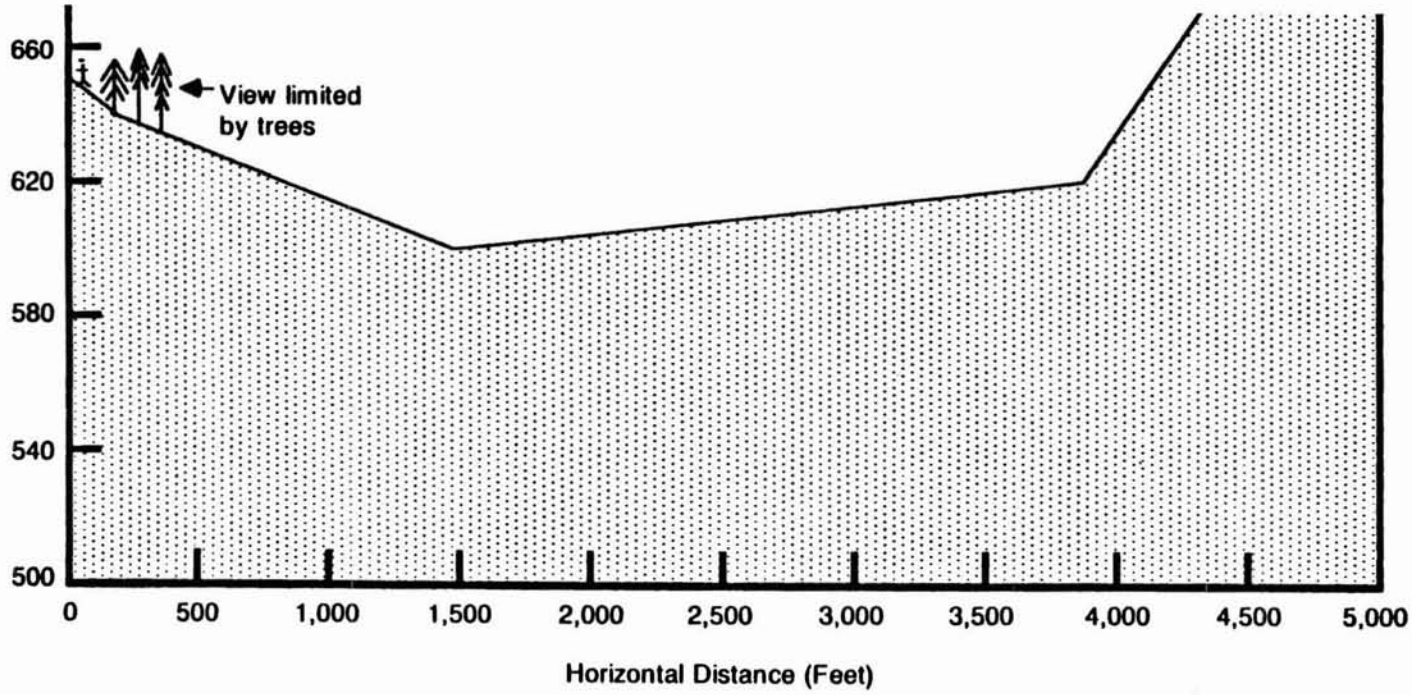


Figure 12-7 OBSERVER'S LINE OF SIGHT FROM LOCATION 6 ON LEILANI AVENUE

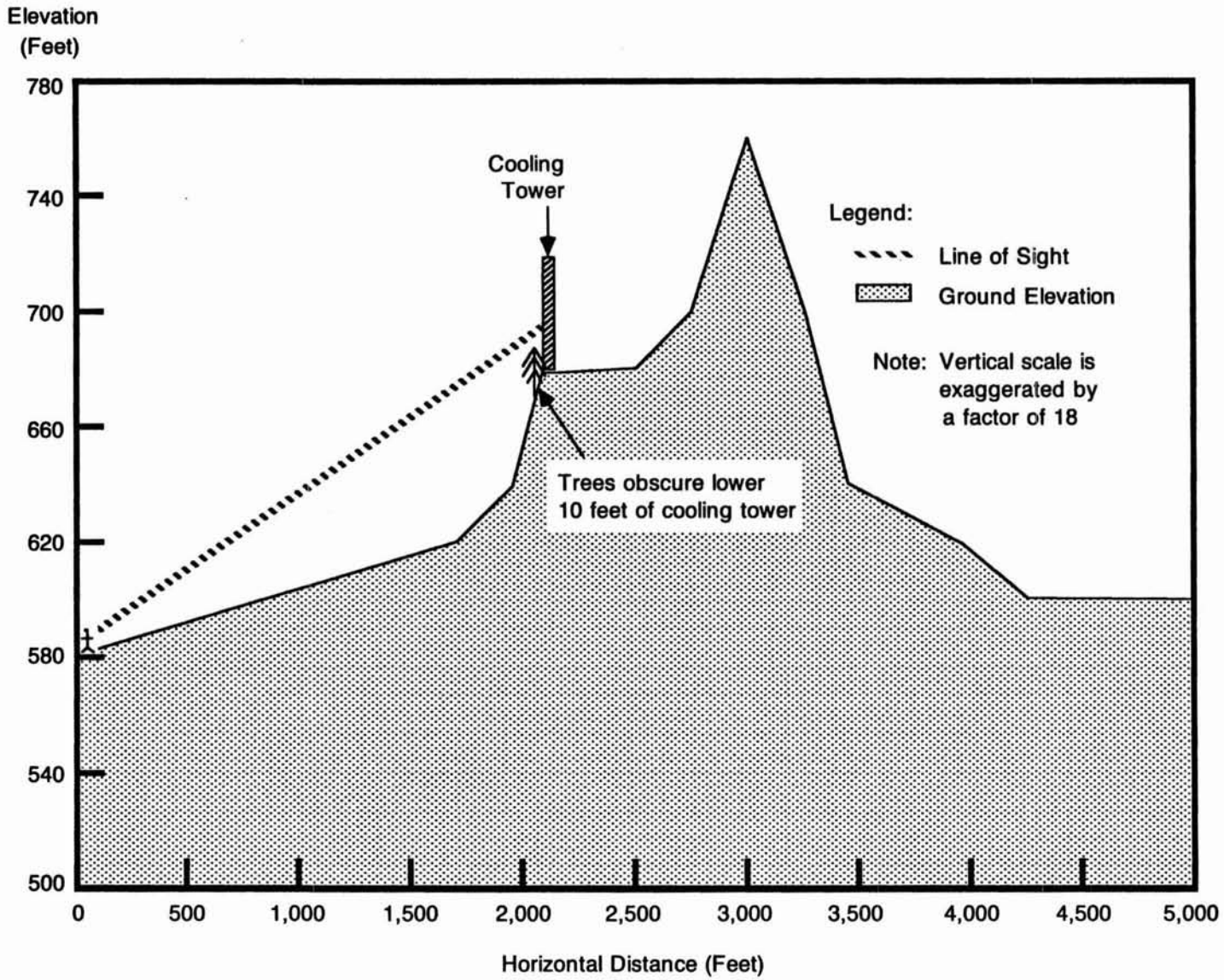


Figure 12–9 OBSERVER'S LINE OF SIGHT FROM LOCATION 7 NEAR PAHOA-POHOIKI ROAD

A few residences will have views of the wells and power plant. The actual number of residents that will be affected will depend on the occupancy of the lots in the surrounding subdivisions. The closest residents to the site are about 1,000 feet southeast of Wellpad F. The power plant may be seen from the back of the house. Vegetation and topography will shield views of the project from other houses in the vicinity.

Approximately four vacant lots bordering the PGV project area in the Lanipuna Gardens subdivision are on a recent lava flow. These four lots are about 2,000 feet from the base of Puu Honuaula and have wide-angle views of the planned PGV site. Development of these lots is not likely until after the geothermal facilities are constructed and landscaped considering the supply of lots and their development rate in Puna.

MacKenzie State Park is located approximately 3 miles south of the PGV facility on the southern Puna Coast. No views of the power plant wellfield or construction equipment are possible because the Malama-Ki Forest Reserve is in between the park and the project site.

Views from the East

Puu Honuaula is visible from the shoreline areas, about 3.5 miles east of the PGV site where there is no high vegetation in the near foreground. Construction activities will hardly be noticeable from the shore, except for the lights used during drilling at night. An observer will see the cooling tower at Location 8, along Route 137 between Kapoho Crater and Pohoiki but it will appear very small because of the distance as Figure 12-10 shows.

12.3 PROPOSED MITIGATION MEASURES

Visual concerns were an important criteria in choosing the location of the power plant and wellpads. Most, if not all, of the visual impacts will be temporary. Visual views of the plant will be insignificant once planted

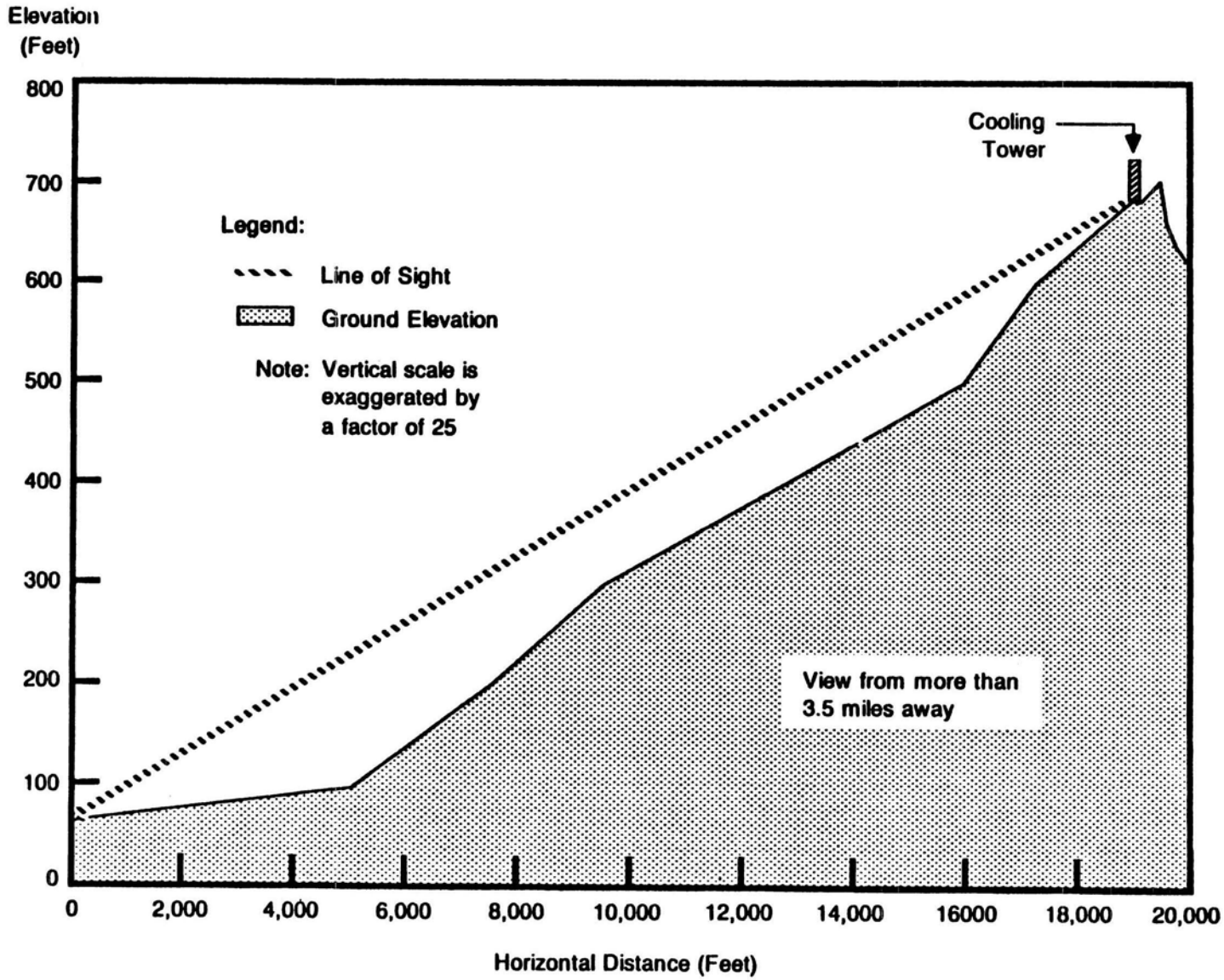


Figure 12–10 OBSERVER'S LINE OF SIGHT FROM LOCATION 8 ON HIGHWAY 137

landscaping matures and effectively blocks the structures. After the geothermal facility is decommissioned visual views will be completely eliminated. All structures and piping will be removed from the site, wells will be plugged with concrete and wellhead equipment, and casing will be removed to below grade. Roadways on the site will be abandoned to the extent agreed upon with the landowner. The site will be regraded to approximate original contours, and seeded or planted with natural vegetation.

The layout of the facility is designed to minimize the amount of land required for clearing. Graded areas will be landscaped promptly. Cut-and-fill slopes will be engineered to minimize the visual impacts created by clearing and grading activities, so that the transition to the surrounding terrain appears more natural.

Landscaping will be installed around the power plant and wellpads to screen the industrial structures and equipment from view. Planting vegetation along the roads, pipeline routes, and the southeast property boundaries that abut the Lanipuna Gardens subdivision are additional mitigation measures under consideration. The choice of vegetation will take into account the species' height and camouflaging ability. Native plants will be used to the extent feasible for compatibility. Almost all of the undeveloped lots in the surrounding subdivisions are densely forested and a vegetation screen can be left when they are developed.

Facility structures, including pipelines, will either be painted to blend into the surrounding environment or constructed of such material that they will blend in with surrounding vegetation since it may take a few years before plants and trees grow tall enough to screen views. Dark greens or grays are the best colors to use, depending on background vegetation. Reflective metal surfaces will be coated or screened with solid fencing.

Site lighting will be mitigated by shielding as needed to conform with all lighting limits. Such mitigation requirements are specified by regulatory agencies in various County and State permits required for the project.

Section 13

RELATIONSHIP OF THE PROPOSED ACTION TO LAND USE PLANS, GOVERNMENT POLICIES, AND REQUIRED PERMITS

This section discusses the project's consistency with State and County land use and energy plans, policies and controls. A list of required permits throughout the life of the project is also included.

13.1 STATE PLANS AND POLICIES

HAWAII STATE PLAN

The State of Hawaii enacted the State Plan in 1978 (Chapter 226, Hawaii Revised Statutes (HRS)). The most recent amendment was in 1986. The purpose of the plan is to improve the State-wide planning process and to articulate goals, objectives and policies that will guide future development in the State. This section reviews the State Plan to determine the project's consistency with the stated goals and objectives.

The plan is divided into several topical areas. The areas that relate to the Puna Geothermal Venture (PGV) project include:

- Economy (Section 226-10, HRS)
- Physical Environment (Section 226-11 through 226-13, HRS)
- Energy (Section 226-18, HRS)
- Public Safety (Section 226-26, HRS)

Economy Objectives

The primary economy objective is to develop and diversify Hawaii's economic base. The PGV project is consistent with this primary objective. The project supports the following policies stated in the economy functional plan:

- Facilitate investment and employment in economic activities that have the potential for growth such as .... energy .... [industry]

- Accelerate research and development of new energy-related industries based on .... underground resources ....

Physical Environment Objectives

One of the policies of the State Plan is protection of rare or endangered plants and animal species and habitats native to Hawaii. One endangered plant (Tetraplasandra hawaiiensis), three rare species of Cyrtanda, and one endangered bird, (Hawaiian hawk) were found on the project site. In addition, one candidate endangered plant (Bobea timonioides) was potentially located on site. However, none of the rare or endangered plants occur and no active Hawaiian hawk nest has been found on the areas that will be disturbed. The hawk uses the project area as part of its feeding ground. No adverse impact on the rare native flora or fauna species is anticipated. The PGV project is consistent with the goal of protecting rare native species.

Another objective of the State Plan in regard to the physical environment is enhancement of the scenic assets, natural beauty, and multi-cultural historic resources. The project's location is not a designated historical, archeological, architectural or unique ecological site. The area is visually appealing and has natural beauty due to its natural state. Aesthetics were taken into account in designing the layout of the site and developing the grading plan. The power plant will be located between two Puus, thereby minimizing the visual impacts. Only 17 acres of the 500-acre site will be graded. Graded areas will be landscaped to avoid bare, vertical cuts. Native plants and trees will be planted to landscape the graded areas and to conceal the wellpads and other equipment.

To achieve the scenic natural beauty and historic resources objective, one of the State's policies is to protect special areas, structures, and elements that are an integral and functional part of Hawaii's ethnic and cultural heritage. The project is located on the Kilauea Lower East Rift Zone, which is part of the traditional home of the volcano goddess Pele. The location has not been designated an integral or functional part of Hawaii's ethnic and cultural heritage. Some Hawaiians have strong cultural and religious feelings about traditions of Pele.

A third objective is maintenance and pursuit of improved quality in Hawaii's land, air and water resources. The primary disposal of the geothermal fluids is reinjection. This technique is an essentially closed-loop process where brines, steam condensate and noncondensable gases that come to the surface with steam are reinjected back into the reservoir. Air, water, and land pollution is virtually eliminated by this reinjection technique.

Energy Objective

A major goal of the State is to increase energy self-sufficiency. A second energy goal is to achieve dependable, efficient, and economical statewide energy systems capable of supporting the needs of the people. To achieve these goals, the following policies have been adopted:

- Support research and development as well as promote the use of renewable energy sources

- Ensure a sufficient supply of energy to enable power systems to support the demands of growth

- Promote prudent use of power and fuel supplies through education, conservation, and energy-efficient practices

- Ensure that the development or expansion of power systems and sources adequately consider environmental, public health, and safety concerns, and resource limitations

The PGV project supports the State's major energy goal of increasing energy self-sufficiency. Simultaneously, it is consistent with developing a new energy source and meeting the energy demands of Hawaii. Although 25 megawatts small percentage of the State's energy needs, it is significant for the Island of Hawaii. Construction of the PGV facility is a step in self-sufficiency for the Island of Hawaii and for the State. The Hawaii Electric Light Company (HELCO) has forecast an increase in energy needs for the near term on the Island of Hawaii. The PGV facility development is scheduled to meet this increase in energy demand.

Public Safety

Ensuring public safety and adequate protection of life and property for all people is a goal of the State. The design and operation of the PGV facility has been carefully planned to minimize all health risks, both for employees and the public.

The most serious potential health risk is from the hydrogen sulfide (H_2S) which naturally occurs in geothermal fluids. During normal operation of the power plant, H_2S emissions are very low at the plant and only in trace amounts at residences in the vicinity. During certain procedures, H_2S emissions are higher than normal. Such conditions are only temporary and ambient H_2S concentrations will not endanger public health.

Economic Priority Guidelines

The State of Hawaii established Priority Directions to address areas of State-wide concern (Section 226-101 through 226-107, HRS). Economic priority guidelines are developed for various industries. The priority guidelines for energy use and development (Section 226-103(f), HRS) fall into two main categories: self-sufficiency through alternative energy forms and energy conservation. The priority guidelines are listed below:

- Encourage the development, demonstration, and commercialization of renewable energy sources

- Initiate, maintain and improve energy conservation programs aimed at reducing energy waste and increasing public awareness of the need to conserve energy

- Provide incentives to encourage the use of energy conserving technology and appliances in residential, industrial, and other buildings

- Encourage the development and use of energy conserving and cost-efficient transportation systems

The PGV geothermal plant furthers the goals of attaining energy self-sufficiency and developing alternate forms of energy. The remaining priority guidelines concern energy conservation measures. They are not directly related to the PGV project. However, the project is not in conflict with the objective of conservation. PGV will develop the wellfield in such a manner as to conserve the geothermal resource.

STATE ENERGY FUNCTIONAL PLAN

In June 1984, the Department of Planning and Economic Development (DPED) issued the Hawaii Energy Functional Plan. Functional plans are mandated by the State Plan. They further define and particularize the State Plan's comprehensive goals, objectives, policies and priority guidelines. They translate the broad goals and objectives of the State Plan into detailed courses of action in order to implement the State Plan.

One of the five areas of concern addressed in the State Energy Functional Plan is alternate energy resource development. The objective is to promote alternate energy technologies through commercialization in order to shift demand from petroleum to indigenous renewable resources. The Functional Plan states:

> "Hawaii's near-total dependence on imported petroleum, spiraling oil prices, the net outflow of dollars for oil payments, and the political unrest of major oil-producing nations threaten local economic stability and

the ability to serve energy needs over time. Support and assistance for private sector activities to develop local energy resources will reduce dependence on the world oil market, improve the State's balance of payments, and thus promote economic development, and increase the number and diversity of employment opportunities."

Four implementing actions are established that directly relate to geothermal energy:

- Support continued implementation of the State Geothermal Commercialization Program to address and mitigate legal and institutional concerns

- Designate, as appropriate, geothermal resource subzones within each of the land use districts to be used for the exploration, development, production and distribution of electrical energy from geothermal sources

- Continue State-wide alternate energy resource assessment studies, as appropriate, to supplement private sector investigations. High priority is given to the completion of resource assessments for geothermal energy on the islands of Hawaii and Maui

- Continue geothermal research activities, as appropriate, to support commercialization efforts

STATE LAND USE LAW

The project is located within the Kapoho Section of the Kilauea Lower East Rift Geothermal Resource Subzone and, therefore, is consistent with Hawaii Land Use Laws. In 1983, the State Legislature passed the Geothermal Resource Subzone Act (Act 296-83), which amended Hawaii's Land Use Laws (Chapter 205, HRS). It mandated the designation of geothermal resource subzones, in which geothermal exploration and development could occur (Section 205-5.1). The Act directs the Board of Land and Natural Resources (BLNR) to designate the subzones. The designated subzones are areas of significant geothermal potential

where the BLNR has determined that the positive economic and social benefits of the development outweigh the potential negative environmental and social impacts.

The project area was designated as a subzone by Hawaiian legislation. Act 151, signed into law on May 25, 1984, established three areas as geothermal resource subzones since the land owners had obtained State geothermal mining leases and developers had been issued County special use permits for geothermal development (DPED, 1986).

13.2 COUNTY PLANS AND POLICIES

THE GENERAL PLAN OF THE COUNTY OF HAWAII

In 1971, the County of Hawaii adopted a General Plan designed to guide the long-range comprehensive development of the Island of Hawaii. The plan sets forth the objectives, standards and courses of action for achieving the goals of a coordinated development of the island. In February 1980, the Plan was amended to give special emphasis on energy self-sufficiency because of the heavy dependence on imported fuel (approximately 60%) and the escalating cost of electricity.

The amended plan contains several goals and policies which relate to the development of alternate energy resources. The PGV project is consistent with these goals and policies. Among those goals and policies relating directly to the PGV project are:

- The County shall strive towards energy self-sufficiency
- The County shall encourage the development of alternative energy resources
- The County shall encourage the expansion of energy research industry
- The County shall ensure a proper balance between the development of alternate energy resources and the preservation of environmental fitness

- The County shall strive to ensure a sufficient supply of energy to support present and future demands

The General Plan is currently being revised and should be implemented by the end of 1987. Work began in 1982 to update the Plan. The County Planning Department released a draft plan in May 1987, which incorporates revisions based on a public review of a previous draft. The review included 17 workshops and numerous meetings with groups and individuals. The Plan's goals relating to energy self-sufficiency and alternative energy resources are not expected to be changed.

13.3 APPLICABLE PERMITS AND APPROVALS

The required permits and approvals for the PGV project are listed in Table 13-1. Permits are needed from the Hawaii Department of Health, State Department of Land and Natural Resources, State Department of Labor and Industrial Relations and from the County. The Authority to Construct application was submitted to the State Department of Health on September 24, 1987. PGV submitted a Geothermal Resource Permit application and a Geothermal Plan of Operations application to the appropriate agencies. However, action on them has been suspended pending completion of the EIS. PGV will submit additional materials needed to update the two permit applications. The other permits are at various stages of preparation and will be submitted when completed.

Table 13-1

APPLICABLE PERMITS, LEGISLATION, AND REGULATIONS

Permits and Approvals	Legislation/Regulation
State Permits	
Department of Health (DOH)	
o Authority to Construct or Modify a Facility; Permit to Operate	o Clean Air Amendments of 1977, Title I, Section 165 o 40 CFR 52.21, PSD Regulations o Hawaii Revised Statutes, Chapter 342 o Administrative Rules of the DOH, Title 11, Chapters 59 and 60
o Underground Injection Control Permit-Approval to Construct; Approval to Operate	o 40 CFR 122 and 146, Regulations and Technical Criteria and Standards; State Underground Injection Control Programs o Hawaii Revised Statutes, Chapter 340E o Administrative Rules of the DOH, Title 11, Chapter 23
Department of Land and Natural Resources (DLNR)	
o Geothermal Exploration Permit	o Hawaii Revised Statutes, Chapters 177, 178, and 182 o Administrative Rules of the DLNR, Title 13, Chapter 183, Subchapter 2
o Geothermal Well Drilling Permit	o Hawaii Revised Statutes, Chapters 177, 178, and 182 o Administrative Rules of the DLNR, Title 13, Chapter 183, Subchapter 8

Table 13-1 (Continued)

Permits and Approvals	Legislation/Regulation
State Permits (Cont'd)	
o Modification of Geothermal Well for Injection Use Permit	o Hawaii Revised Statutes, Chapters 177, 178, and 182 o Administrative Rules of the DLNR, Title 13, Chapter 183, Subchapters 8 and 9
o Abandonment of Geothermal Well Permit	o Hawaii Revised Statutes, Chapters 177, 178, and 182 o Administrative Rules of the DLNR, Title 13, Chapter 183, Subchapters 8 and 11
o Geothermal Mining Lease	o Hawaii Revised Statutes, Chapter 182 o Administrative Rules of the DLNR, Title 13, Chapter 183
o Permit to Drill, Deepen, Redrill, Plug, or Alter a Water Well and to Install, Replace, or Modify a Pump	o Hawaii Revised Statutes, Chapters 177 and 178 o Administrative Rules of the DLNR, Title 13, Chapter 166, Subchapter 8
o Geothermal Plan of Operations	o Hawaii Revised Statutes, Chapters 177, 178, and 182 o Administrative Rules of the DLNR, Title 13, Chapter 183, Subchapter 7
Department of Labor and Industrial Relations (DLIR)	
o Pressure Vessel/Boiler	o Hawaii Revised Statutes, Chapter 397 o Administrative Rules, Title 12, Subtitle 8, Chapters 210, 220-224

Table 13-1 (Concluded)

Permits and Approvals	Legislation/Regulation
County Permits	
o Geothermal Resource Permit	o Hawaii Revised Statutes, Chapter 205 o Hawaii County Charter, Section 5-4.3, Section 13-7 o Hawaii County Planning Commission, Rule 12
o Building Permit	o Hawaii County Code, 1983, Chapter 5 o Hawaii County Code, 1983, Chapter 14, Article 9
o Electrical Permit	o Hawaii County Code, 1983, Chapter 9, Article 5, Division 1
o Plumbing Permit	o Hawaii County Code, 1983, Chapter 17, Article 2
o Grading Permit	o Hawaii County Code, 1983, Chapter 10, Articles 2 and 3
o Grubbing Permit	o Hawaii County Code, 1983, Chapter 10, Articles 2 and 3
o Stockpiling Permit	o Hawaii County Code, 1983, Chapter 10, Articles 2 and 3

Section 14

ALTERNATIVES TO THE PROPOSED ACTION

Alternative energy sources, project sites, and hydrogen sulfide abatement processes are described and discussed in this section relative to their technical feasibilities, costs and potential environmental impacts. The consequences of taking no action or delaying action on the development of a geothermal power source are also considered.

14.1 ALTERNATIVES TO GEOTHERMAL POWER PRODUCTION

Eleven alternative energy sources are considered relative to the unique characteristics and specific power requirements of the Big Island of Hawaii. These sources are:

- Fuel Oil
- Coal
- Nuclear
- Hydroelectric
- Wind
- Biomass
- Municipal Solid Waste
- Solar Thermal
- Photovoltaic
- Ocean Thermal Energy Conversion
- Ocean Wave

The present state of technology for each alternative as well as cost estimated for future years are also presented.

The key factors discussed for each alternative are summarized in comparison with geothermal energy in Table 14-1. All of the alternatives are not technically feasible on a 25 MW scale at the present time. Some alternatives

Table 14-1
SUMMARY OF ENERGY SOURCE CHARACTERISTICS
(on 25 MW basis)

	Technically Feasible	Economically Feasible	Resources Are Indigenous To Island	Baseload Capacity	Potential Environmental Concerns
Fuel Oil	YES	YES	NO	YES	SOx, NOx, CO, CO_2, and HC emissions.
Coal	YES	YES	NO	YES	SOx, NOx, CO, CO_2, HC, and particulate emissions.
Nuclear	YES	NO	NO	YES	High-level radioactive by-products.
Hydroelectric	YES	YES	YES	NO	Land Use.
Wind	YES	YES	YES	NO	System stability; land use.
Biomass	YES	YES	YES	YES	SOx, NOx, CO, CO_2, HC and particulate emissions; land use.
Municipal Solid Waste	YES	YES	YES	NO	SOx, NOx, CO, CO_2, HC and particulate emissions; hazardous waste.
Solar Thermal	YES	NO	YES	NO	
PV	YES	NO	YES	NO	Land use.
OTEC	YES	NO	YES	NO	
Ocean Wave	NO	NO	YES	NO	
Geothermal	YES	YES	YES	YES	H_2S emissions.

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are not economically feasible. Either the size of the plant or technical shortcomings preclude them from being cost-competitive. Resources indigenous to the Island of Hawaii are given special consideration. The intermittent or inadequate nature of some of the alternatives prevents them from having the capacity to produce 25 MW of baseload energy. Environmental impact concerns are outlined as they apply to each alternative.

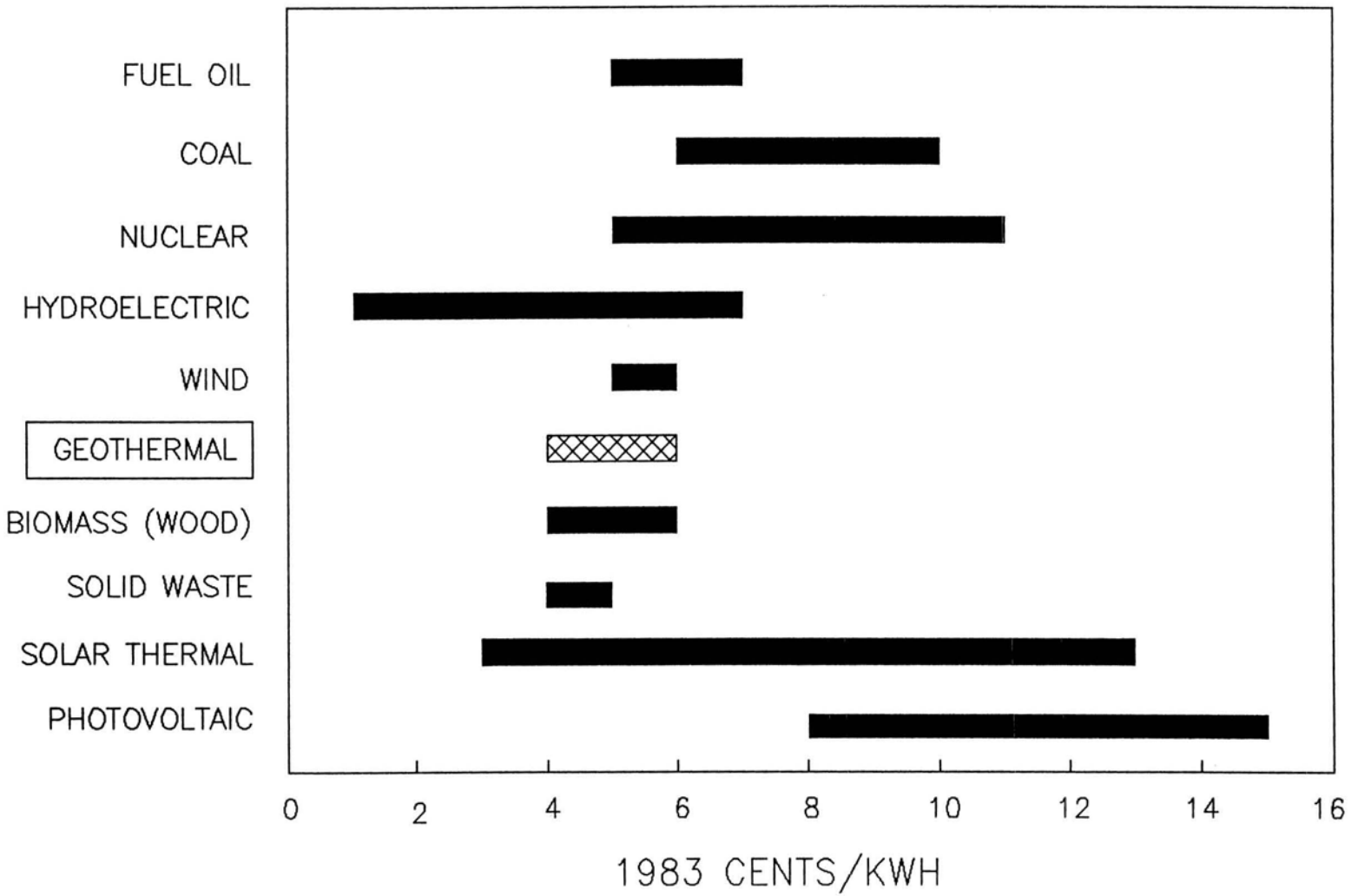
Figure 14-1 presents cost estimate ranges for nine of the 11 alternatives between the years 1997 and 2027. The California Energy Commission (CEC) electrical cost predictions were used for the comparison of alternate technologies. These predictions are presented in the April 1987 "Relative Costs of Electricity Production" (CEC, 1987). All values listed are in 1983 dollars. The production costs for geothermal power ranged from $0.04/KWH to $0.06/KWH. Even though the CEC cost predictions include certain technical and economic assumptions specific to California, the underlying conclusions on cost rankings should remain valid. For this reason, the production costs presented should be used for comparisons and not considered to represent actual costs in either California or Hawaii.

There were several important reasons involved in the decision to use the CEC cost predictions.

- The values are generic, no specific plant or utility was used.
- The alternatives were compared by a single organization, using a consistent set of assumptions and cost basis.
- The CEC has access to a number of different utilities and operating companies to establish the cost data base.
- The CEC is not a special interest group trying to sell a specific technology.
- Comparable data for Hawaii was not readily available.

FIGURE 14-1

COST ESTIMATES FOR 1997 TO 2027



The emission levels of five criteria pollutants are compared in Table 14-2 for fuel oil, coal, geothermal, biomass (wood), and municipal solid waste (MSW) energy sources. The five pollutants presented are particulates, sulfur (represented as SO_2), nitrogen (represented as NO_2), carbon monoxide, and hydrocarbons. The emission levels shown represent an estimate of the quantities that would be allowed for the different fuel sources under the current air emission regulations. Figure 14-2 provides a graphic comparison of geothermal, fuel oil, coal and biomass (wood) baseload energy sources.

FUEL OIL

Diesel oil and industrial fuel oil are currently the primary sources of power for the Island of Hawaii. Two oil-burning steam plants and numerous diesel-driven generation plants are being operated by HELCO. Approximately 60 percent of the Island of Hawaii's annual electrical output has historically been supplied by fuel oil. In 1979, the Island of Hawaii imported over 500,000 barrels of oil for conversion to electricity.

The consumption rate of fuel oil and the dependency on fuel oil has increased over the years, causing concern for future availability. Reducing Hawaii's dependency on imported oil and developing indigenous natural resources is one of the objectives in both State and County plans (Hawaii State Plan, 1978, Chapter 226, HRS; General Plan, County of Hawaii, as amended). Electrical energy produced from the PGV project will allow Hawaii Electric Light Company (HELCO) to reduce its use of imported oil by approximately 250,000 barrels per year.

In addition, the cost of fuel oil in the future is uncertain and subject to rapid increases. The cost of electrical power produced from fuel oil is subject to wide fluctuations because of the price fluctuations of crude oil. For example, from 1970 to 1979 the cost of electricity increased an average of nine percent per year. However, several increases of 15 to 25 percent per year occurred during that period (DPED, 1980). Based on a conservative estimate, the residential rate in Hawaii will increase by 25 percent in five years. Future costs of electrical production, using fuel oil, are conservatively predicted to range from $0.05/KWH to $0.07/KWH (CEC, 1987).

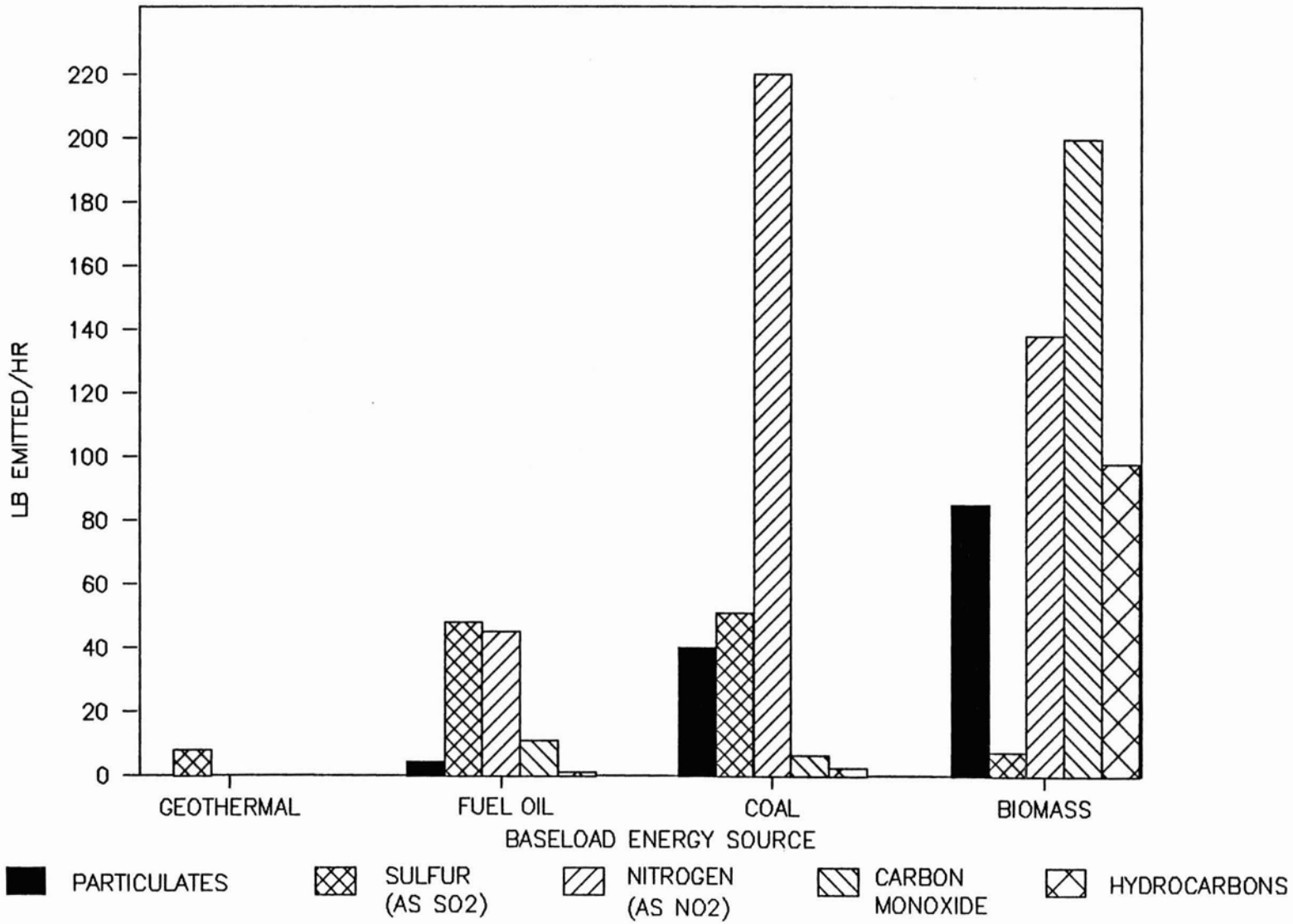
Table 14-2
EMISSION LEVELS

EMISSION LEVELS ON A 30 MW BASIS
(LB EMITTED/HR)

BASELOAD SOURCE	PARTICULATES	SULFUR AS SO2	NITROGEN NO2	CARBON MONOXIDE	HYDRO-CARBONS
FUEL OIL	4.5	48	45	11	1.1
COAL	40	51	220	6.6	2.6
GEOTHERMAL	<1	8	---	---	---
BIOMASS (WOOD)	85	7.4	138	200	98
MSW	70	90	170	1990	85

FIGURE 14-2

EMISSION LEVELS ON A 30 MW BASIS



The combustion of fuel oil causes sulfur dioxide, nitrogen oxides, carbon monoxide, carbon dioxide, and particulates to be emitted into the atmosphere. As a result, environmental costs are an aspect of fuel oil use that must be considered as well as monetary costs.

COAL

The abundance and relatively low cost of coal on a world-wide basis makes its use as a source of fuel for generating electricity an attractive alternative. Coal-to-energy conversion technology is highly developed and well-established. Coal can be directly burned either in a micronized, pulverized, or slurry form to produce energy. It can also be gasified to methanol which can then be used as a direct fuel source.

The environmental costs of using coal, however, are extremely high. Significant amounts of sulfur and nitrogen oxides as well as carbon monoxide are emitted when coal is burned. Control of these emissions is costly and only partially effective. In addition, large amounts of nitrogen and sulfur oxide emissions can cause acid rain which can destroy vegetation, aquatic life, and buildings. It is formed when the nitrogen and sulfur oxides come in contact with water vapor in the air. Low-sulfur coal can be used to reduce these problems, but it is generally more expensive and, thus, the economics are less attractive.

Coal-to-energy conversion can produce serious health effects. Air pollution stemming from the combustion of coal has been connected to premature deaths from lung cancer and other respiratory diseases. Many pollution abatement systems must be utilized to avoid risking the health and welfare of the population. Pollution abatement systems are expensive to install and maintain in proper working order. This condition, in turn, increases the price of electricity that consumers pay.

Coal is not indigenous to Hawaii; therefore, the use of coal as a source of fuel would not make Hawaii more self-sufficient than it is now with fuel oil. Coal is more abundant and available than fuel oil, but it would still have to be imported. In mid-1987 dollars, the cost of producing electricity from coal

is estimated to be between $0.05/KWH and $0.10/KWH. (It should be noted that these values were taken from an April 1987 Fluor study done for HECO, in which conversion of the existing Kahe and Waiau power plants to coal-fired plants was studied. If no plant conversions take place on the Island of Hawaii, the costs would be higher than the above values.) The cost of producing electricity from coal was estimated by CEC to be between $0.06/KWH and $0.10/KWH. (CEC, 1987).

NUCLEAR

Nuclear fuel is a viable source of producing energy. Most practical applications of nuclear energy for electricity production utilize the fission process which consists of splitting the nucleus of a heavy atom (in most cases, uranium) into two fragments, each one making a nucleus of a lighter atom. A considerable amount of energy is then produced along with a chain reaction causing more fission reactions to occur.

Significant environmental and health considerations are associated with the transportation, storage, and disposal of high-level radioactive materials. Currently, State law prohibits the use of nuclear power in Hawaii. Unless the law is changed, the use of nuclear energy is not a possible option.

Price-per-KWH cost estimates for the use of nuclear energy in generating electricity are $0.05/KWH to $0.11/KWH (CEC, 1987). The minimum size at which a nuclear power plant is economically feasible is approximately 500 MW. The required power output of the proposed facility is considerably below that value. Thus, the use of nuclear fuel as a source for generating electricity would not be cost-effective.

HYDROELECTRICITY

Hydroelectricity is a relatively well-established and mature renewable energy source that is used throughout the world. It utilizes water set in perpetual motion by evaporation, rainfall, and the force of gravity. The energy in flowing streams is harnessed and converted to electricity by water wheel and turbine devices.

The Island of Hawaii does not have any water resources that are adequately consistent in flow or potentially powerful enough to serve as the primary source of electric power. Perennial streams and rivers are rare on the Big Island. The unweathered and highly permeable lavas and well-drained soils allow much of the rainfall to percolate to the water table. The surface runoff that does occur fluctuates considerably with the variations in rainfall. The estimated maximum amount of power that could be generated on the entire island is less than 20 MW. In future years, the cost could range from $0.01/KWH to $0.07/KWH (CEC, 1987). Some plans for hydropower development have been examined. However, sites presented in the plans are located primarily in conservation areas and have not been implemented to date.

WIND ENERGY

Wind machines used to generate electricity are becoming more reliable and less expensive as research and development efforts progress. Large-scale wind energy projects are being developed in the United States, Canada, Europe, and the Soviet Union. The machines typically range from 100 KW to over 1000 KW in power output and have blades up to, and exceeding, 300 feet in diameter. A wind farm consisting of several wind machines can have a considerably large power output. Wind farms with 125 MW capacities are being developed. The cost of wind-generated electricity depends on the size and power output of the wind machines as well as average wind speed and variability. Predicted costs are $0.05/KWH to $0.06/KWH for the 1990's and beyond (CEC, 1987).

High winds are a characteristic of the Island of Hawaii. As a result, many potential wind farm sites exist on the Big Island. The Kahua Ranch in North Kohala District provides approximately 4 percent of the Big Island's peak late-afternoon electrical needs. Over 200 wind machines generate up to 4 MW of power daily on the Kahua Ranch.

Wind energy has major disadvantages as an energy source. The intermittent nature of wind precludes total reliance on it as a baseload energy source. Wind power cannot be controlled or matched to load requirements. Electric grid stability, can be affected adversely by the use of wind energy, especially considering the small size of Hawaii's electric grid. To ensure system

stability, wind energy should not comprise more than 20 percent of the total generating capacity, and should be reserved to peak power rather than baseload power generation.

Unresolved safety concerns exist when wind machines operate in high winds. Noise and television interference can be potential problems. A large area of land is needed for the requisite number of wind machines in order to generate any sizeable amount of electricity from wind energy. The aesthetics of the land, once the wind farm is in place, is significantly affected by the placement of numerous wind machines.

BIOMASS FUEL

Biomass fuel technology extracts energy from plant life. Direct combustion of the biomass feedstock provides heat that produces steam to drive electricity-generating turbines. The feedstock can also be converted to gaseous and liquid fuels which can be used as fuel sources. As much as 40 percent of the Island of Hawaii's electricity in the past has been provided by biomass fuel. Most of the biomass fuel used in Hawaii has traditionally come from the direct combustion of bagasse (sugar cane waste).

A decline in the sugar industry was predicted, however, and, in December of 1984, the unprofitable Puna Sugar Company ceased its sugar production operations. Wood chips have since replaced bagasse as a biomass fuel source. Productive forest land is plentiful on the Big Island. Eucalyptus tree farms are being developed specifically for energy purposes.

The continuous use of biomass fuel on a 25 MW scale may not be economically or environmentally sound, however. A major drawback of biomass fuel technology is the opportunity costs associated with the biomass sources. Wood chips, for example, command a market value, as an export commodity in the paper industry, that is considerably higher than the value that would make it cost-competitive as a fuel source. Another disadvantage of biomass fuel technology is the potential for adverse environmental impacts, such as soil erosion and hydraulic

runoff, due to large-scale use of crops and trees. The use of wood as a fuel source may cost an estimated $0.04/KWH to $0.06/KWH in future years (CEC, 1987).

MUNICIPAL SOLID WASTE

The conversion of municipal solid waste to electricity is carried out to a limited extent in waste-to-energy plants throughout the world. Solid waste from city dumps is burned, and the resulting thermal energy is used to generate electricity. Honolulu has begun the construction of a 40 MW waste recovery facility, and Hawaii County has developed plans for a waste-to-energy project.

The contents and nature of the solid waste, however, cause considerable environmental and economic problems. Plastics, metal foils, coatings, and chemicals in the waste may produce harmful gases when they are burned. Heavy metals are released in the residual ash of plants and must be treated as hazardous waste. In Hawaii, the high moisture content of waste, mainly plant materials, causes a reduction in the burning efficiency of the materials.

Facilities that burn solid waste typically work at levels far below capacity when there are no strict municipal solid waste dumping restrictions. When solid waste dumps include items such as household chemicals and old lawn mowers, small chemical explosions and the presence of large metal objects in the municipal waste cause expensive routine repairs on the plant equipment. The expected cost of providing electricity from solid waste is $0.04/KWH to $0.05/KWH.

Solid waste combustion is not a realistic alternative primary source of energy on the Big Island because the scattered communities do not generate the large and consistent amount of solid waste needed to feed a central municipal waste-to-energy plant. The entire Island of Hawaii, assuming a population of 92,000, could provide a maximum of 24 MW of power. (These values were determined assuming a 100 percent conversion efficiency. Actual power output values would be considerably lower.) Costs of collection and transportation to a central plant would be high.

SOLAR ENERGY

Electrical energy can be produced using solar heat which is trapped in solar cell devices. This heat, converted to steam, can be used to operate turbines which generate electricity. Various types of solar collectors are being developed to trap the sun's rays for heating purposes. Flat plate collectors and parabolic trough collectors that track the sun's rays can be used for this purpose.

Extensive research and development has been done on this renewable energy source. Nevertheless efficiencies are still too low and costs too high to make solar-powered energy generation economically feasible on a 25 MW scale. It will cost an estimated $0.03/KWH to $0.13/KWH (CEC, 1987) to produce electricity from solar heat in the future. The cost depends on which type of solar collector is used. Parabolic collectors are at the upper half of the cost scale. The large range of cost values associated with solar energy use indicates the extent to which technological advances could affect electricity production costs.

PHOTOVOLTAIC

Sunlight can be converted to electricity by means of a device known as the photovoltaic cell. These cells consist of two different semi-conductor materials which, by virtue of their opposing properties, set up an internal electric field. If photovoltaic cell technology continues to progress at the rate it has in the last decade, this alternative could be very cost-competitive with conventional energy sources by the mid-to-late 1990's.

The development of new semi-conductor materials has greatly reduced the cost of photovoltaic cells. Amorphous silicon is considerably better at absorbing sunlight than crystalline silicon, the initial material used. As a result, the semi-conductors can now be manufactured in thin-film form (0.5

micrometers thick down from 300 micrometers thick). The new thin-film cell technology amounts to considerable savings due to the smaller amount of material needed. Cell conversion efficiencies currently range from 14 to 22 percent.

Photovoltaic cell technology is approaching large-scale output capabilities; however, the cost/KWH of photovoltaic systems is still considerably higher than that of more conventional systems. The CEC has predicted a $0.08/KWH to $0.15/KWH range within the next ten years. These values assume certain technological advances; however; actual current costs are considerably higher. In addition, land availability is an issue. It has been estimated that approximately 0.5 square miles will be needed for every 25 MW of electricity produced by photovoltaic cells.

OCEAN THERMAL ENERGY CONVERSION

Ocean thermal energy conversion (OTEC) technology utilizes the temperature differential that exists in the ocean between the sun-warmed surface water and cooler water several hundred meters below. Thermal energy can be converted to electricity by means of this method. A low-boiling-point fluid such as ammonia is heated by the warm surface water. The resulting vapor drives a gas turbine which, in turn, powers an electric generator. The ammonia vapor is condensed by cool ocean water.

A significant amount of research has been done on OTEC in Hawaii and other coastal locations throughout the world. The National Energy Laboratory of Hawaii (NELH) laboratory at Keahole is one of the leading research facilities in this technology. However, OTEC is not technically or economically feasible on a large-scale basis at the present time. The relatively small temperature difference that exists in the ocean (40°F) means that the heat transfer area and the volume of seawater needed are quite large relative to more conventional systems. The corrosive capabilities of salt water require that expensive anti-corrosive materials be used for the piping. Maintenance costs are high

due to the necessary removal of algae and barnacle growth on the equipment. Further development is also needed to safeguard the system against tropical storms which have disrupted OTEC research in the past. Insufficient information exists regarding the specific comparative costs of generating electricity from OTEC technology.

OCEAN WAVE ENERGY

Research is being done to study ways in which ocean wave energy could be converted to electricity. Ocean waves are enormously powerful. They contain both kinetic and potential energy. Wave energy generators that could be placed in the ocean to absorb and process wave energy into electrical power are being developed.

The amount of energy present in ocean waves depends on the location of the coastline and the distance of the waves from the shore. The inherent power of wave energy varies considerably around the world. Values typically range from 31 KW/meter to 61 KW/meter (measured along the wave crest). Wave energy increases with distance from the shore. Net efficiencies of the energy conversion process are expected to be 25 percent at a maximum. This relatively low efficiency makes actual wave energy potential in the 8-15 KW/meter range a more realistic value.

It is conceivable that 25 MW of power could be generated from a few kilometers of coastline. However, the process is not technically feasible at the present time. Insufficient information exists on the cost of ocean wave energy to estimate price per KWH.

14.2 ALTERNATIVE SITES

ISLAND OF HAWAII

Other geothermal resource sites may exist on the Big Island, but the proposed project site was selected because it is within a designated geothermal resource subzone and is the only site that has known geothermal resources. Kilauea Volcano is the most attractive of the five volcanoes which make up the

Island of Hawaii, for geothermal purposes because it is the most active. Two exploration geothermal wells attempted in the Hualalai region of Kona were not successful in locating a geothermal reservoir.

Figure 14-3 depicts the rift zones for the Island of Hawaii. Two rift zones, the East and the Southwest Rift Zones, emanate from Kilauea. When eruptions or magma swelling take place at Kilauea Crater, molten rock often moves below the surface along these rift zones. It is the existence of this magma that supplies the heat to the geothermal resource.

The East Rift Zone is the only area on the Big Island where proven geothermal resources have been discovered. Seven deep geothermal borings have been carried out in the East Rift Zone, and four of them have confirmed the existence of a geothermal reservoir in a small area including the proposed project site. Three wells are specifically within the project site area.

KILAUEA EAST RIFT ZONE

The specific site within the Kilauea Lower East Rift Zone was chosen for a combination of reasons. The site selected is the one most suitable for making maximum use of the known geothermal resources. Environmental impact concerns also played a role in the decision-making process. The factors that contributed to the site selection are outlined below.

Land Use Constraints

The area considered for potential plant sites was limited to property within the designated 816-acre leasehold area and within the State-designated geothermal resource subzone. It was assumed that five acres of land would be needed for the power plant. The area was also limited to within about 0.5 miles of the three existing PGV geothermal wells since proven geothermal resources were identified at these locations. The PGV project may utilize one or all of these wells in its operations.

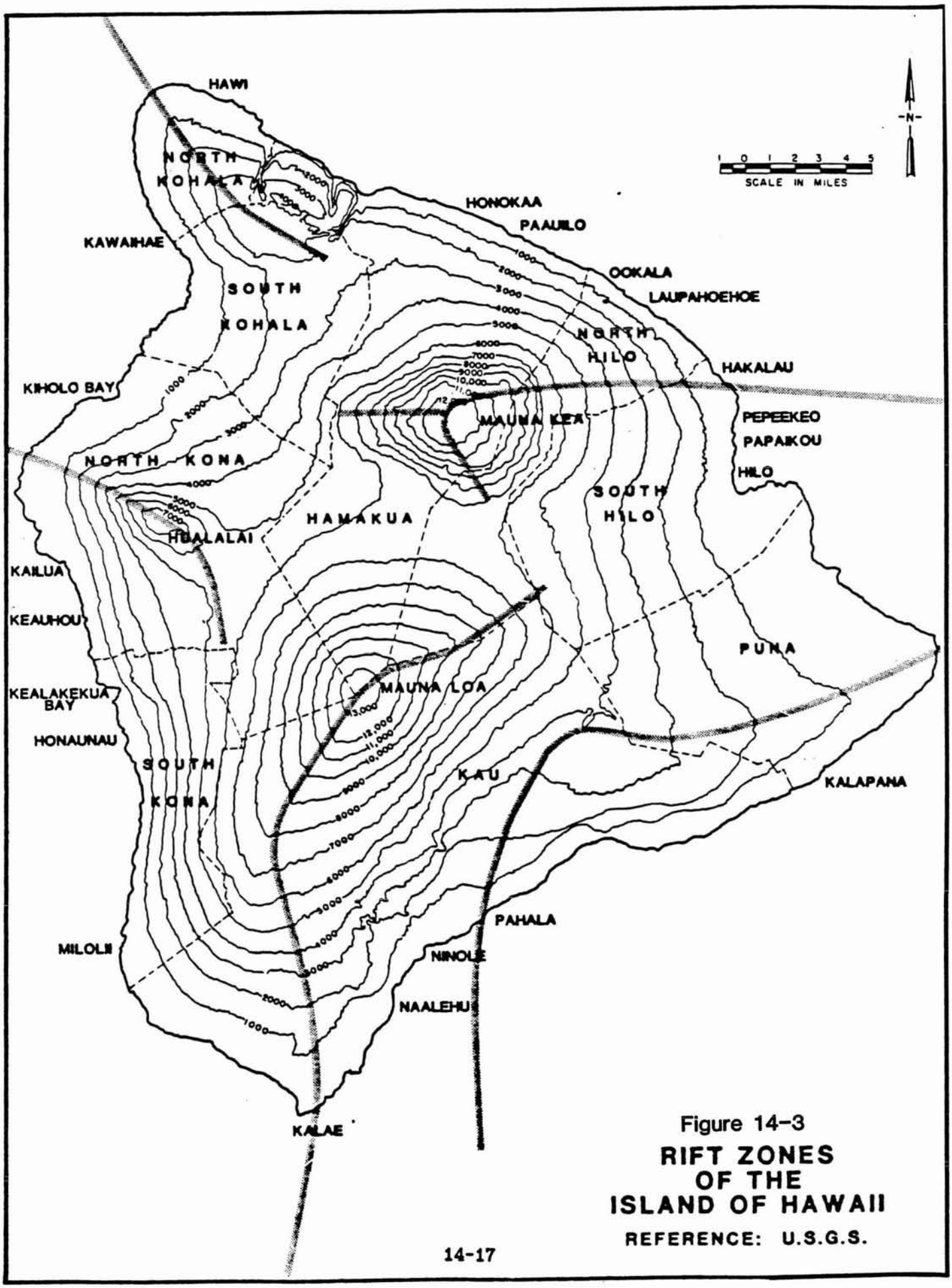


Figure 14-3

RIFT ZONES OF THE ISLAND OF HAWAII

REFERENCE: U.S.G.S.

Compatibility with land use was a criteria in the site selection process. Unproductive soils (e.g., lava cover) and noncultivated areas were preferred. The selected site is located on aa lava flows, Pahoehoe lava flows, or cinder land which have a lower productive capability than nearby soils (Keaukaha, Opihikao, and Malama Series).

Topography

Land in the study area requiring extensive earthwork was excluded. The two cinder cones at Puu Honuaula were excluded because the steep and erratic topography would result in higher construction costs, design constraints, additional grading and site preparation, increased safety risks, and unnecessary impacts on the aesthetics of the area. Areas with flat or minimum sloping terrain (0-5 percent slope) were preferred.

Compatibility with Soils, Geology, and Seismology

Preference was given to sites that were covered with aa lava rather than Pahoehoe lava which has an increased probability of flow tubes, cavities, etc., such openings would cause the foundation to be unstable. Areas most susceptible to lava flow (as determined by a 1981 report by Slemmons, et. al.) were excluded. Available information on fissures and faults was examined, but it did not differentiate between potential sites in the study area.

Visual and Noise Impacts

Potential visual and noise impacts were taken into account in choosing the location of the power plant and wellfield. The area of greatest visual and noise sensitivity is in the housing developments southwest and southeast of the study area. Preference was given to sites that would be located between the Puu Honuaula cinder cones due to the shielding effect of the cones.

Potential Air Quality and Ecosystem Impacts

Prevailing daytime winds are from the northeast, and prevailing nighttime winds are from the west and northwest. Preference was given to areas south and southeast of the Puu Honuaula cinder cones to avoid any potential plume effects from the facility.

14.3 ALTERNATIVES WITHIN THE PROPOSED ACTION

Thermal Power Company evaluated several alternative power plant H_2S abatement processes and designs prior to selecting the proposed alternative. The alternative that provided the Best Available Control Technology (BACT) for H_2S abatement was selected.

A proposed air quality rule (issued by the Hawaii Department of Health in March 1987) defines BACT as:

> "an emissions limitation based upon the maximum degree of reduction for a pollutant which would be emitted from any proposed stationary source or modification which the director on a case-by-case basis, taking into account energy, environmental, and economic impacts and other costs, determines is achievable for that source or modification through application of production, processes or available methods, systems and techniques, including techniques for control of each such pollutant. In no event shall BACT result in emissions which would exceed the emissions allowed by applicable Standards of Performance for New Stationary Sources and National Emission Standards for Hazardous Air Pollutants."

The proposed rule further specifies that the BACT shall not cause H_2S emissions to exceed 8.5 lb/hr or 0.33 lb/gross megawatt, whichever is greater. This regulation, when applied to the PGV power plant, limits H_2S emissions to 9.9 lb/hr or the calculated maximum allowable concentration at ground level (see Section 5), whichever is less. Dispersion modeling studies have indicated that H_2S emissions which meet 9.9 lb/hr will satisfy the ground level limit criteria.

This section discusses the seven alternative H_2S control technologies that were examined, including the selected alternative of reinjection. A full discussion of each control technology can be found in the Authority to Construct permit application.

The seven alternatives that were examined to determine the BACT were:

- Burner/Scrubber system
- Stretford Process
- LO-CAT Process
- Claus-SCOT Process (with tail gas treating)
- Selectox/CI
- Clinsulf Process
- Reinjection system (selected alternative)

A summary of the BACT analyses is presented in Table 14-3. (Further information on the BACT analyses may be found in the Authority to Construct Permit). The selected alternative is Reinjection. The Reinjection system alternative includes the Burner/Scrubber system as a backup abatement system. All of the processes evaluated in this study are capable of reducing H_2S emissions to below 9.9 lb/hr. The abatement system having the lowest overall emissions and the lowest primary abatement cost per ton of H_2S handled is Reinjection.

A further advantage of the reinjection process not reflected in Table 14-3 is the cost of disposing of cooling tower blowdown. This water would have to be reinjected into the geothermal reservoir, probably through a separate well in all alternatives. The reinjection system makes use of the cooling tower blowdown to dissolve the NCG; therefore, no additional costs are incurred. Similarly, the cost of disposing of any sulfur or other by-product of the process is not reflected in Table 14-3. Reinjection and the Burner/Scrubber alternative are the only alternatives that would not incur transportation costs for disposing of large amounts of sulfur. Sulfur could be sold as a product if the quality were high and a market existed. The market is very volatile, however, and the remote location of the project probably precludes, recovering more than transportation costs.

Table 14-3
SUMMARY OF BACT ANALYSIS

	Burner/Scrubber	Stretford	Selectox	LO-CAT	Claus-SCOT	Clinsulf	Reinjection
Emissions: H_2S	0.2 lb/hr	1.0 lb/hr	-	<0.5 lb/hr	-	-	<0.5 lb/hr
SO_2	2.0 lb/hr	-	2.0 lb/hr	-	<6 lb/hr	9 lb/hr	-
Capital Costs	$1,509,600	7,198,200	5,344,000	3,483,900	4,702,700	3,282,000	4,212,600
Annual Operating Costs (94% onstream)	$6,885,000	4,086,600	748,000	948,000	485,600	241,800	183,400
Normalized Costs[1] (Annual)	$7,187,000	5,527,000	1,817,000	1,645,000	1,426,000	898,200	1,026,000
Solid Waste (tons/year)	None	Sulfur-4,320	Sulfur-4320 Spent Cat-5[5]	Sulfur-4,320	Sulfur-4,311 Spent Cat-9[5]	Sulfur-4,305	None
Liquid Waste[2] (tons/year)	19760 (reinjected)	3,320		396		None	4320 (re-injected)
Makeup Chemical	NaOH	Catalyst,[3] ADA, Citric Acid	NaOH Catalyst	ARI[4] solutions NaOH	Catalyst & Scot Chemicals	Catalyst	None
Quantity (tons/year)	19760	1065	520 5 tons/5 yrs[5]	396	9 tons/5 yrs[5]	NA	
$/ton H_2S Removed	$1,664	$1,280	$420	$381	$330	$208	$238

(1) The normalized costs include 20 percent factor of the capital investment, (covers debt service, depreciation, insurance, and taxes) plus annual operating costs.
(2) Liquid waste quantity does not include 486,000 tons per year of cooling tower blowdown. Only Reinjection includes the cost of blowdown disposal.
(3) ADA = Anthroquinone disulfonic acid, vanadium = catalyst.
(4) ARI = ARI Technologies, Inc.
(5) Catalyst replacement occurs once approximately every 5 years.

Its higher overall reliability is still another advantage to the selected alternative. While all of the processes evaluated are reliable, Reinjection is the only alternative that provides a full backup system (i.e., Burner/Scrubber). A shutdown of both the Reinjection and Burner/Scrubber systems would require a shutdown of the power plant as is the case with all the other alternatives.

The only other process which is cost-competitive with Reinjection is a Clinsulf unit. Although all of the technological elements of the process have been used separately, the combination contemplated for this application has not been used commercially. Therefore, the process is not considered practical from either an environmental or economic aspect. The Burner-Scrubber process is not favored for primary abatement because of the large consumption of chemicals. The Stretford process is not favored for primary abatement because of the large consumption of chemicals and the need to dispose of hazardous waste. In addition, the Stretford Unit requires the largest amount of capital, and the unit's normalized costs are the second highest of the six control technologies. The Claus-SCOT unit is not favored for primary abatement because it emits the largest amount of air emissions of all the alternatives and generates large amounts of solid sulfur requiring disposal.

DESIGN CRITERIA AND ASSUMPTIONS

Five decision criteria were used to evaluate the alternative control technologies. They are:

- Emission limitations
- Estimated capital and operating costs
- Disposal of by-products and wastes
- Chemical makeup requirements
- Expected reliability and availability.

The following assumptions were used in evaluating the alternative H_2S abatement technologies:

- Power production is 30 MW (Gross).

- 18,000 lb/hr/MW (540,000 lb/hr total) of geothermal steam travels to the turbines.

- All fluids are reinjected back into the geothermal reservoir.

- The revenues from selling or costs for disposing of any sulfur product are not considered. (Even the largest quantity of sulfur product generated by the alternatives is not considered a marketable quantity.)

- The concentration of all noncondensable gases in the geothermal steam is 3,500 ppm(w) before abatement.

- Noncondensable gas composition is as follows:

GAS	MOL. WT.	RATE (lb/hr)	COMPOSITION (Mol %)	PPM (w)
CO_2	44.01	514.30	20.55	956
H_2S	34.08	1,049.10	54.13	1950
NH_3	17.03	0.08	0.008	0.1
N_2	28.01	313.10	19.65	582
H_2	2.02	6.50	5.66	12
Total		1,883.08	100.00	3500

- The calculated partitioning in the condenser is based on a pressure of 3 inches mercury absolute.

- The quantity of cooling tower blowdown water is 118,000 lb/hr.

BURNER/SCRUBBER SYSTEM

Process Description

Noncondensable gases from the condenser are removed and sent to the combustor. The noncondensables are incinerated in the combustor, at 2000°F with an excess of air to convert the H_2S to SO_2.

The hot gas is quenched by direct contact with water. Quenching cools the gas to approximately 180°F. The gas is then contacted with an aqueous sodium hydroxide solution in a scrubber. The SO_2 reacts with the sodium hydroxide to produce a mixture of sodium sulfite (Na_2SO_3) and sodium bisulfite ($NaHSO_3$). Figure 14-4 shows a simplified process flow diagram for the Burner/Scrubber system.

Anticipated Emissions

Approximately 2.2 lb/hr of sulfur is emitted by the Burner/Scrubber system. Of this amount, approximately 0.2 lb/hr is H_2S and the remainder is in the form of SO_2.

Estimated Costs

Capital costs are expected to be $1,509,600 and annual operating costs are estimated at $6,885,000. The annual normalized costs of the process are $7,187,000. Normalized cost is the sum of the annualized capital investment and the annual operating costs. The annualized capital (capital recovery) costs are taken as 20 percent of the capital investment, a figure which covers depreciation, debt service, taxes and insurance. Emission control costs amount to $1,664 per ton of H_2S processed.

Products/By-Products

The Burner/Scrubber system does not generate any saleable products. The sodium sulfite and sodium bisulfite that are produced in the system are dissolved in blowdown water and reinjected back into the reservoir. No solid

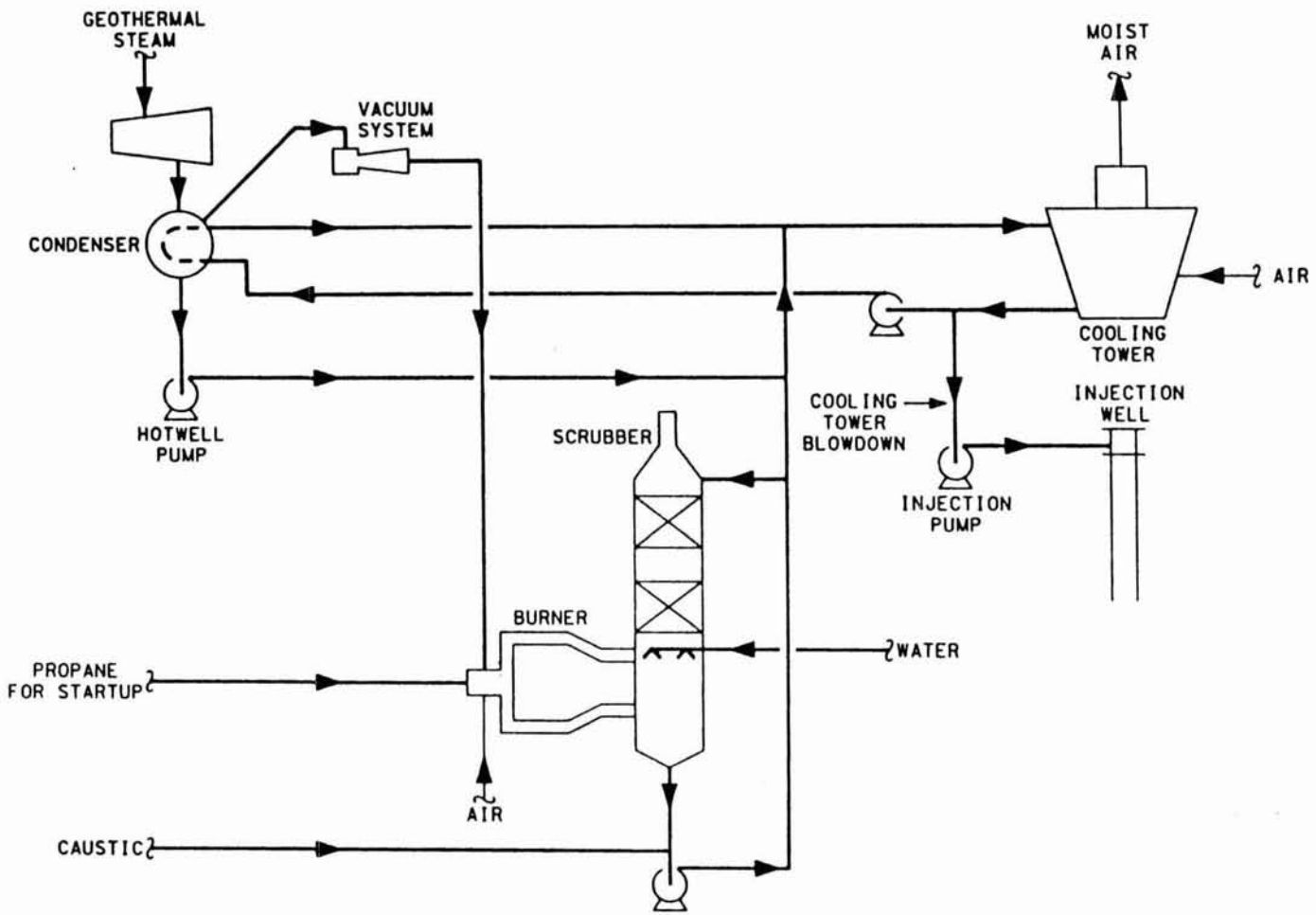


Figure 14-4
BURNER SCRUBBER SYSTEM

wastes are generated by the process. The annual liquid waste is 505,560 tons per year (including the 486,000 tons per year of blowdown), all of which is reinjected.

STRETFORD PROCESS

Process Description

A Stretford unit converts H_2S to elemental sulfur. H_2S is essentially oxidized by air to sulfur and water with vanadium as a catalyst. Figure 14-5 shows a simplified process flow diagram of the process. The chemistry involved in the Stretford process is complex. The Stretford solution composition must be carefully controlled to the licensor's specifications or the resulting sulfur will not be marketable. For example, if the vanadium catalyst used in the Stretford solution enters the sulfur product, the vanadium makes it unsuitable for fertilizer use.

Noncondensable gases are fed to large vertical scrubbers. In these scrubbers, the H_2S is selectively absorbed into the alkaline solution. The absorbed H_2S forms a hydrosulfide which reacts with anthroquinone disulfonic acid (ADA) dissolved in the Stretford solution. The reaction of ADA and hydrosulfide is slow; therefore, a vanadium catalyst is added. The Stretford solution then flows into the bottom of an oxidizer tank where air is bubbled through the solution. Oxygen in the air reacts with the ADA-hydrosulfide to separate the sulfur from the ADA.

The bubbling air also serves to form a sulfur froth which the froth rises to the top of the oxidizer tank where it is removed. The regenerated Stretford solution is removed from below the froth layer and returned to the scrubber. The air leaves the top of the oxidizer tank, passes through the power plant cooling tower, and vents to the atmosphere.

The sulfur froth consists of both sulfur and Stretford solution in a slurry form. The slurry is filtered and washed to separate the sulfur from the solution which is returned to the process. The sulfur is then melted to drive off any water, forming the finished product.

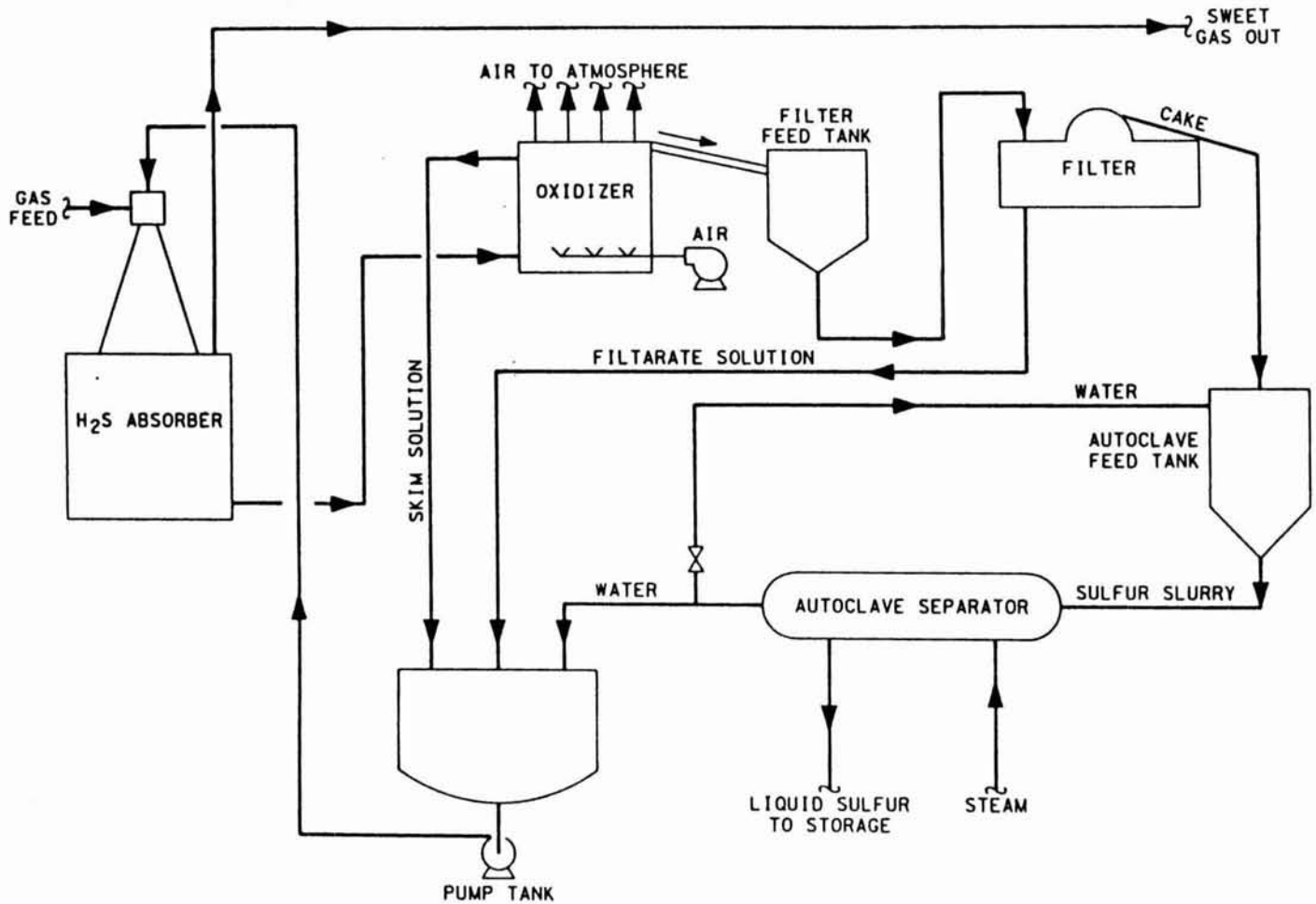


Figure 14-5
STRETFORD PROCESS

The operation of the Stretford unit is affected by high levels of gases which can change the solution's pH. For example, high levels of CO_2 lower the pH of the sulfur solution and reduce H_2S abatement. High levels of ammonia raise the pH of the steam and increase the solubility of H_2S in the steam condensate, thereby decreasing the H_2S abatement.

Anticipated Emissions

The Stretford process emits approximately 1 lb/hr of H_2S. The H_2S is contained in the gas which leaves the scrubbers and is vented through the cooling towers. H_2S emissions are expected to be 8,235 lb/yr.

Estimated Costs

The capital and operating costs for the Stretford unit were calculated by Fluor Daniel using data supplied by the licensor (Peabody Holmes). Capital costs for the Stretford unit are $7,198,200. Annual operating costs for the Stretford unit are estimated to be $4,086,600. Cooling tower blowdown is not involved with the sulfur abatement. Capital costs do not include injection equipment for disposal of the blowdown. The normalized costs of the Stretford process are $5,527,000 per year. Emission control costs amount to $1,280 per ton of H_2S processed.

Products/By-Products

The Stretford process is sometimes capable of producing a saleable yellow sulfur with an ash content in the range of 100 to 200 ppm. The sulfur may be sold as a liquid, or cooled and cast into blocks. The blocks may be shipped directly or converted to flake or prills prior to shipping. The sulfur is more often off-color and contaminated with the vanadium catalyst or other impurities that make it difficult to sell. The presence of the vanadium makes the sulfur unsuitable for fertilizer use and classifies it as toxic. Other impurities which may be present include sodium sulfate and sodium thiosulfate.

Approximately 3,320 tons per year of liquid waste and 4,320 tons per year of solid sulfur will be generated by the Stretford process. The solid sulfur will have to be disposed of in an acceptable manner if it is not saleable. Liquid waste contaminated with vanadium will have to be disposed of at a hazardous waste facility. Disposal costs are not included in the estimated costs; however, because Hawaii has no hazardous waste disposal facility (and is not expected to have one), these costs could be significant.

LO-CAT PROCESS

Process Description

The LO-CAT Hydrogen Sulfide Oxidation Process is licensed by ARI Technologies, Inc. Figure 14-6 shows a simplified process flow diagram for the LO-CAT process. Noncondensable gases are removed from the condenser and sent to the LO-CAT unit. The gas is bubbled into the bottom of one of the absorber chambers in the LO-CAT absorber/oxidizer. Specially designed gas spreaders are used to contact the gas and the LO-CAT solution without plugging. As the gas bubbles up through the slightly alkaline solution, the H_2S is absorbed, ionized and finally oxidized to sulfur by the ferric (Fe^{+++}) ions.

Small, solid sulfur particles precipitate from the solution and circulate down and through the absorber section. As the sulfur circulates, the particles grow to the 10-20 micrometer range. Larger particles settle out of the bulk solution in the bottom of the absorber/oxidizer. The particles are flushed out of the cone-bottomed settling area as a slurry containing 10 to 20 percent sulfur by weight.

The sulfur slurry is pumped by a positive displacement pump through a heat exchanger where it is heated with steam to approximately 270°F. The slurry, now consisting of aqueous catalyst solution and molten sulfur, passes through a 100 psig separator vessel. Molten sulfur is separated from the catalyst solution and sent to storage. The catalyst solution is returned to the absorber/oxidizer.

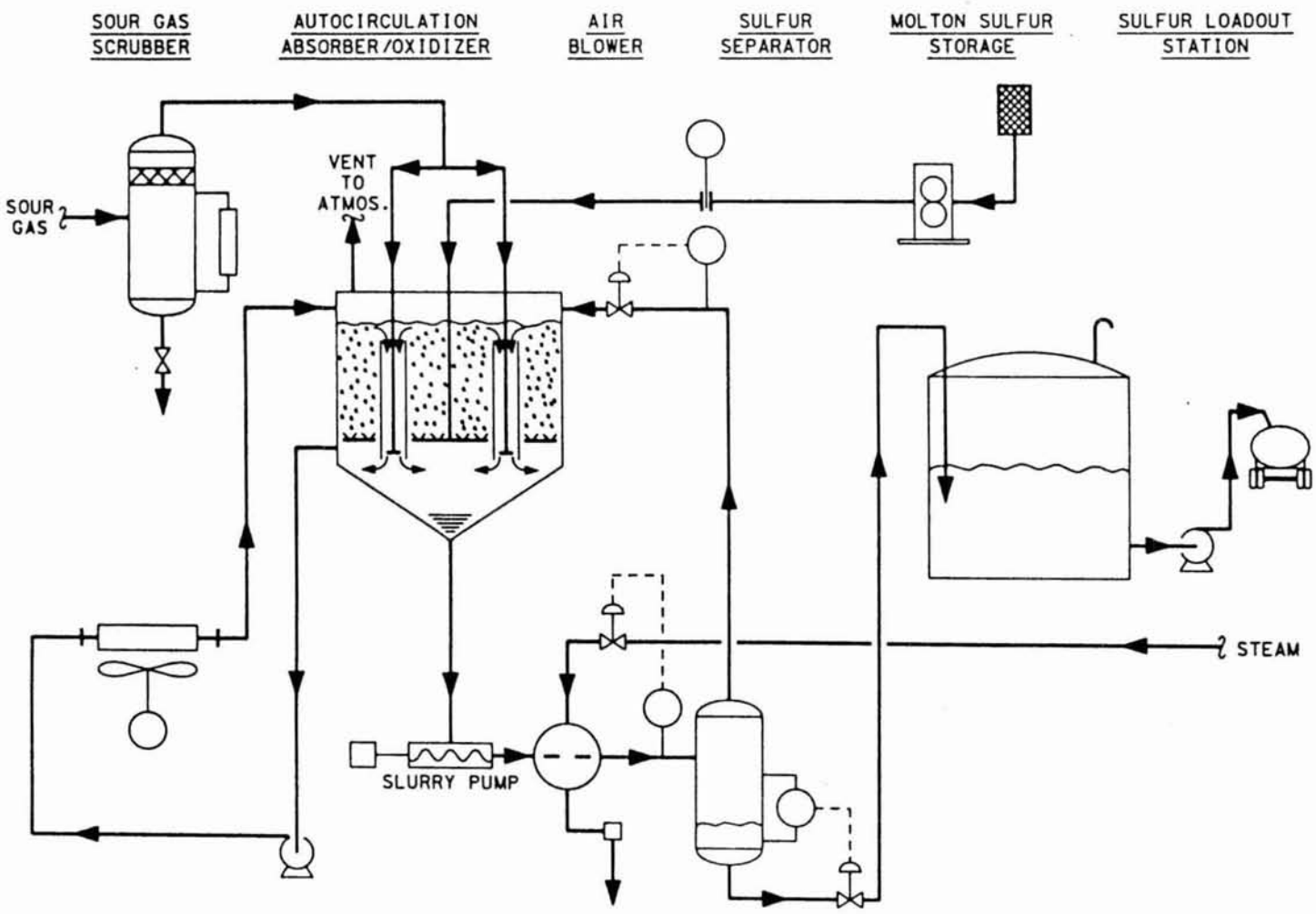


Figure 14-6
LO-CAT PROCESS

The spent LO-CAT solution, with most of the iron converted to the ferrous (Fe^{++}) form, flows upward through the oxidizer portion of the absorber/oxidizer. Compressed air is bubbled through the LO-CAT solution and the iron regenerated to Fe^{+++} with the oxygen. The spent air, mixed with the noncondensable gases (minus H_2S), leaves the top of the oxidizer section of the absorber/oxidizer and discharges to the atmosphere.

In the oxidation of H_2S to sulfur, a side reaction that reduces the pH of the scrubbing solution takes place. Alkaline salts (e.g., Na_2CO_3, KOH, etc.) must be added to maintain the pH of the solution in the 8-8.5 pH range. A gradual buildup of water-soluble sulfur-containing salts occurs in the solution. These salts may cause foaming or salt precipitation at concentrations above 30 percent by weight. For this reason, it may be necessary to purge some solution from the system after it has been operating for several months.

The LO-CAT solution composition is maintained at a stable level by continuous additions of various chemicals and buffers. Addition rates are determined by daily or weekly analytical tests.

Anticipated Emissions

The LO-CAT process will vent less than 0.5 lb/hr of H_2S, or less than 4,120 lb/yr.

Expected Costs

The capital and operating costs for the LO-CAT unit were obtained from the licensor, ARI Technologies, Inc. Capital costs are $3,483,900 and annual operating costs will be $948,000 per year. The normalized costs are $1,645,000 per year. Emission control costs are expected to be $381 per ton of H_2S processed. No costs are included for cooling tower blowdown and liquid waste injection equipment.

Products/By-Products

The sulfur produced by the LO-CAT H_2S Oxidation Process is available in either a liquid or solid form. The product sulfur may be suitable for sulfuric acid or agricultural sulfur production or the 10 to 20 percent sulfur slurry may be used directly (in small quantities) as a fertilizer. Approximately 4,321 tons/yr of sulfur must be disposed of, either as a product or as a waste. Disposal costs are not reflected in the expected costs.

The cooling tower blowdown and a small purge stream from the LO-CAT unit will be injected. The cooling tower blowdown is not included in the sulfur abatement; therefore, the expected capital costs do not include the costs of injection equipment.

CLAUS-SCOT PROCESS

Process Description

The Claus-SCOT process consists of two processes in series. The SCOT unit (i.e., Shell Claus Offgas Treating) removes sulfur from the gas stream exiting the Claus unit. The Claus process is now available from a number of process licensors, but the SCOT unit is licensed by the Shell Oil Company.

Noncondensable gases from the steam condenser are fed to the Claus unit. This gas is fed to a furnace where one-third of the H_2S is burned to SO_2. The unreacted H_2S reacts with the SO_2 to form elemental sulfur and water.

The gas leaving the furnace is cooled to condense any sulfur that has formed. The heat removed from the gas stream is used to generate steam that is added to the geothermal steam.

The cooled gas flows to the first reheater where the gas is heated to reaction temperature and then it flows to the first catalytic reactor. From the reactor, the gas is cooled to condense the sulfur. The reheating, reactor and gas cooldown proceeds through three catalytic reactors.

The gas is routed to the tail gas treatment unit after the third reactor effluent gas has been cooled to condense sulfur.

The Claus tail gas, containing H_2S, SO_2, nitrogen and sulfur, is first catalytically reduced (hydrogenated) to convert SO_2 to H_2S in the SCOT hydrogenation reactor. The hydrogen gas required is supplied by the reducing gas generator. The hydrogenation reactor effluent is cooled in a waste heat boiler where steam is generated. It is further cooled by direct contact with circulating water in a water wash cooling tower. The circulating water is cooled using cooling water. A small stream of water is removed from the tower to maintain water balance in the unit.

The cold gas then enters a typical amine absorber system where H_2S is absorbed by an amine solution and then desorbed in a stripper. The treated gas then flows to a catalytic incinerator prior to venting to the atmosphere. The gas stripped from the amine solution, containing H_2S and CO_2, is recycled back to the Claus sulfur furnace for processing. Figure 14-7 shows a simplified process flow diagram for the Claus Unit, and Figure 14-8 shows a simplified process flow diagram for the SCOT unit.

Anticipated Emissions

The combined Claus-SCOT process does not emit any measurable amount of H_2S. All sulfur that is emitted is in the form of SO_2. The quantity of SO_2 emitted will be less than 6 lb/hr (49,500 lb/yr).

Estimated Costs

The capital and annual operating costs for the combination Claus-SCOT process is $4,702,700 and $485,600, respectively. The normalized cost for the Claus/SCOT process is $1,426,000 per year. Emission control costs amount to $330 per ton of H_2S processed.

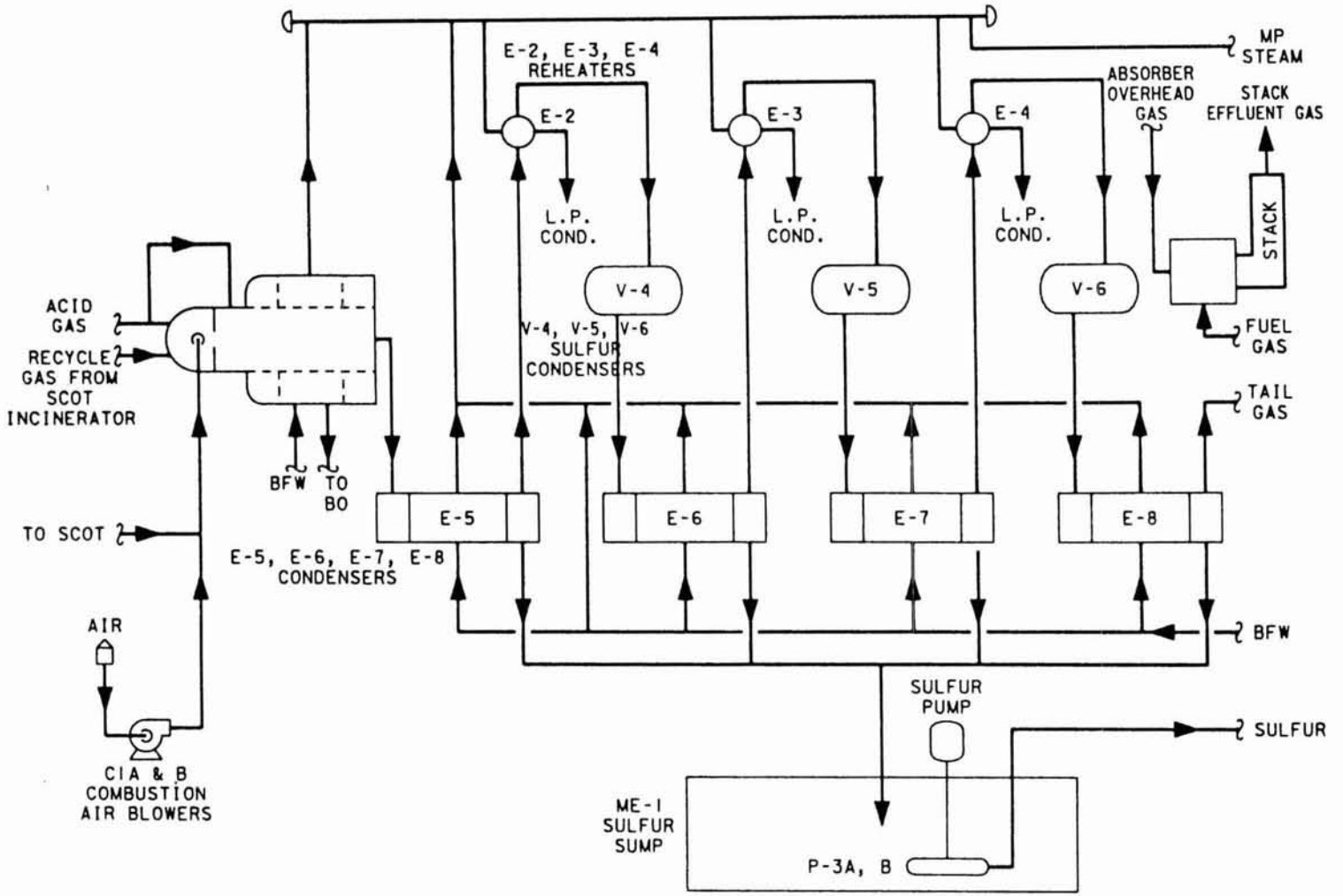


Figure 14-7

CLAUS UNIT

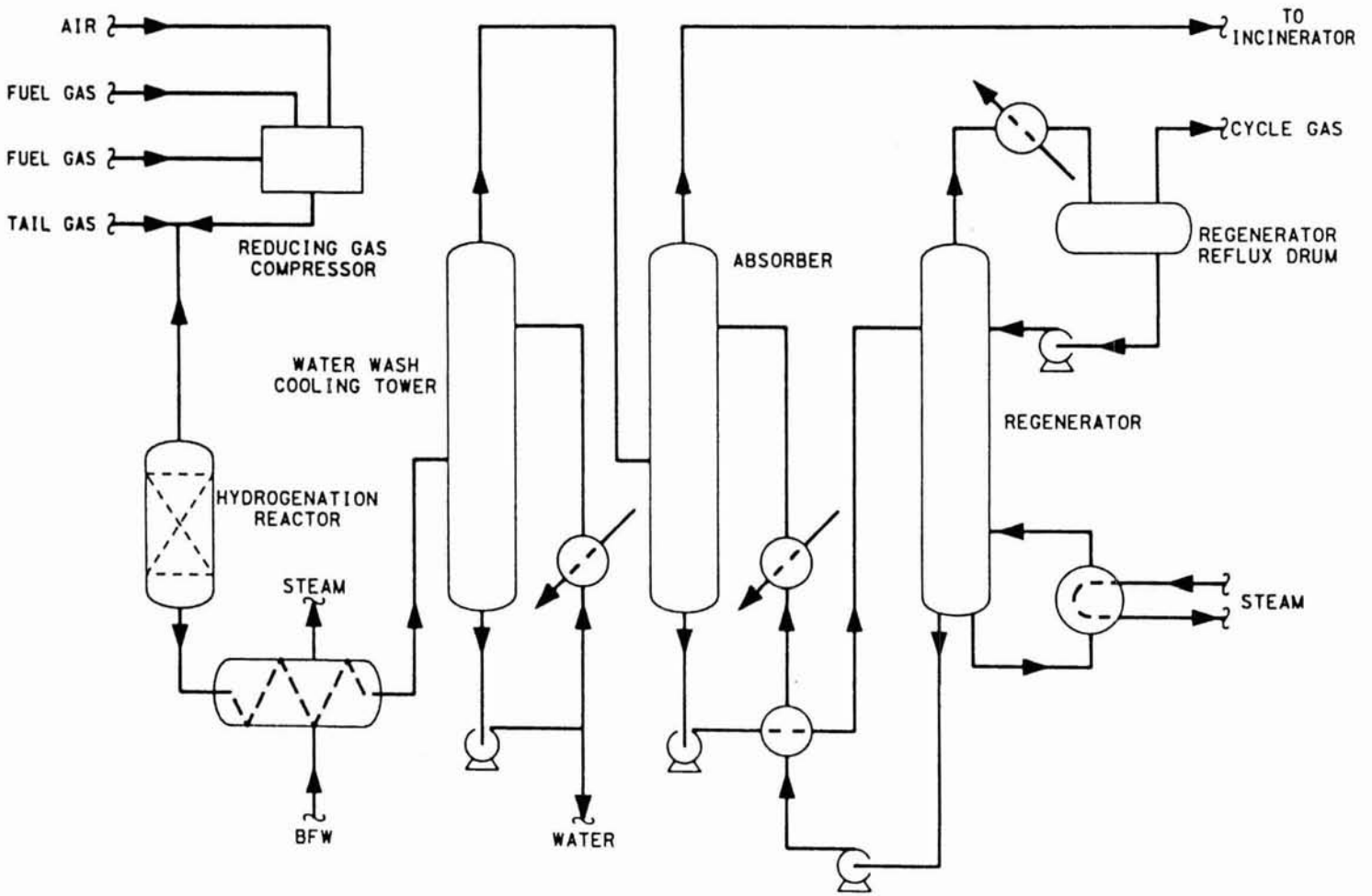


Figure 14-8
SCOT UNIT

Products/By-Products

The Claus/SCOT process produces a sulfur which is saleable. The total production is approximately 4,311 tons/yr of solid sulfur. In addition to the disposal of the solid sulfur, the catalyst must be replaced every five years, resulting in a solid waste of about 9 tons. Liquid process wastes amount to approximately 2 tons/yr which is mixed with the cooling tower blowdown and reinjected. Spillage of the absorbant amine may require collection and disposal offsite.

RECYCLE SELECTOX/CI PROCESS

Process Description

This process is similar to the Claus process but differs in the first stage combustion process. The Claus process burns a portion of the H_2S with air to form SO_2 which is then reacted with the remaining H_2S to form elemental sulfur. The Selectox process accomplishes the combustion step catalytically, which allows a lower temperature to be used. The Selectox process is capable of processing gases containing from 0.3 percent to as high as 65 percent H_2S by weight. The high concentration requires the recycling of the first stage reactor gas to reduce the inlet concentration of H_2S.

The Selectox catalysts are selective for the formation of SO_2 and can operate at temperatures in the 300° to 700°F range compared to 2000°F for the Claus process. The Recycle Selectox process is licensed by Unocal.

The noncondensable gases from the steam condenser are fed to the first stage reactor along with a measured amount of air. A recycle blower is used to return a portion of the clean gas leaving the sulfur condenser to the inlet of the first reactor. It is the use of this recycle gas which limits the temperature in the reactor to 700°F. Some of the H_2S is bypassed around the reactor and combined with the reactor effluent. The SO_2 from the reactor combines with the H_2S to form elemental sulfur which is then removed by cooling in the sulfur condenser.

The gases remaining after the sulfur condenser are processed in two stages of Claus reactors to remove the remaining H_2S. A catalytic incinerator, using Selectox catalyst, converts any H_2S remaining after the reactors to SO_2. The effluent from the incinerator is then scrubbed with sodium hydroxide to further reduce the emission of H_2S and SO_2. Figure 14-9 shows a simplified process flow diagram for the Recycle Selectox/CI process.

Anticipated Emissions

The Recycle Selectox/CI process does not emit any measurable amount of H_2S. All sulfur emissions are in the form of SO_2. The SO_2 emitted will be less than 2 lb/hr (16,500 lb/yr).

Estimated Costs

The capital and annual operating costs for the Recycle Selectox/CI process are $5,344,000 and $748,000, respectively. The normalized cost for the process is $1,187,000 per year. Emission control costs amount to $420 per ton of H_2S processed.

Products/By-products

The Recycle Selectox/CI process produces a sulfur which is saleable. The total production is approximately 4,320 tons/yr of solid sulfur. The Selectox catalyst must be replaced every five years, resulting in a solid waste of approximately 5 tons. Liquid process wastes from the caustic scrubber will amount to approximately 540 tons/yr, which is mixed with the cooling tower blowdown and reinjected.

CLINSULF PROCESS

Process Description

This process is an adaptation of the Claus process. The principle of the Clinsulf process is to operate reactors both above and below the sulfur dew

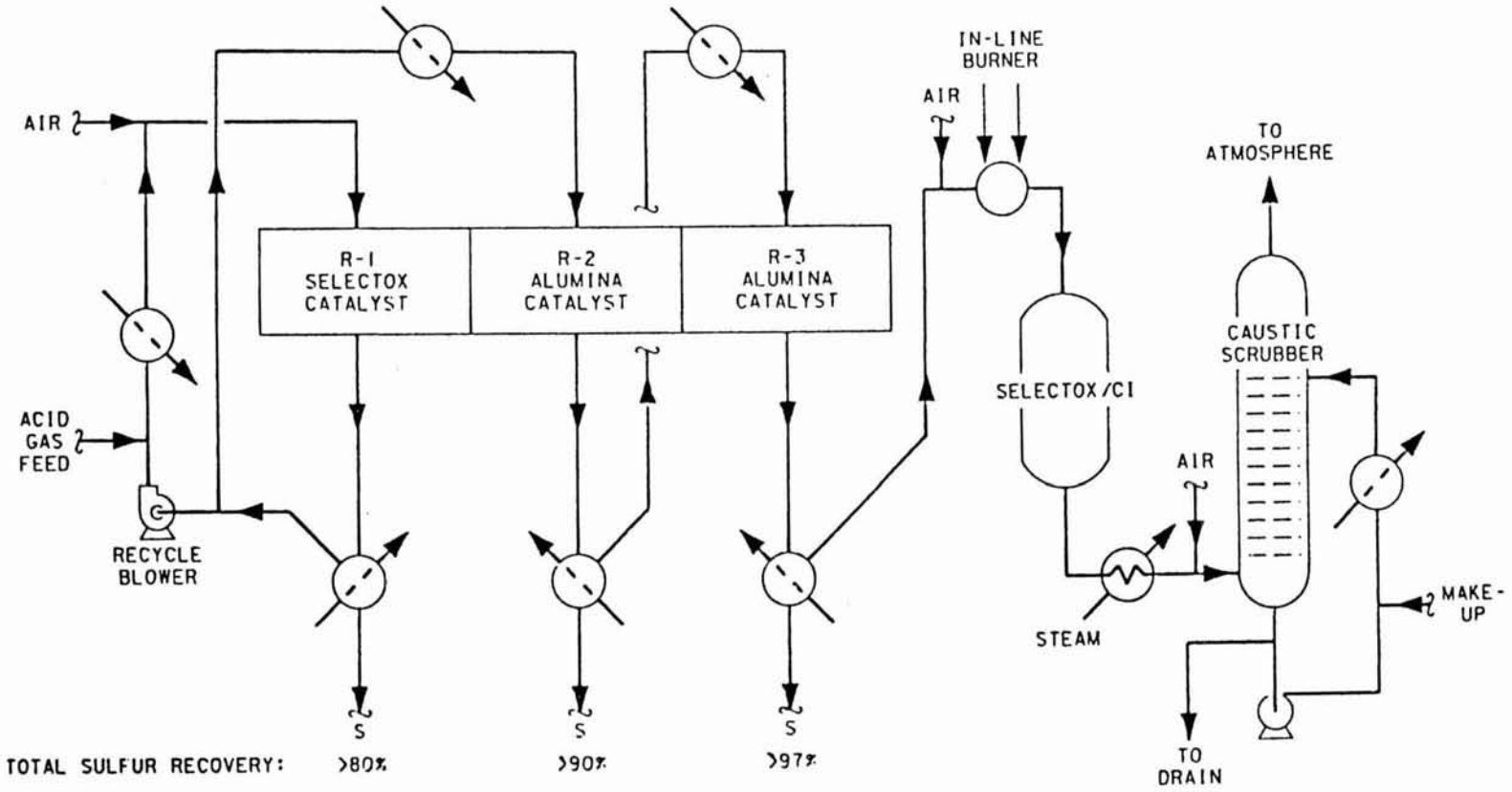


Figure 14-9

RECYCLE SELECTOX/CI PROCESS

point. Operation below the dew point causes the sulfur to adsorb onto the surface of the catalyst. The adsorption removes elemental sulfur from the reaction causing more sulfur to be formed. The catalyst is then heated to remove the sulfur product. Figure 14-10 shows a simplified process flow diagram of the Clinsulf process.

Approximately one-third of the H_2S is combusted in a special furnace with a stoichiometric amount of air to produce SO_2. The remaining two-thirds of the H_2S (which is not combusted) is heated and then combined with the combusted portion. The combustion of H_2S to SO_2 and subsequent recombination of H_2S and SO_2 to produce sulfur are referred to as Claus reactions. At this point, the entire stream is cooled to condense the sulfur that has formed. The sulfur flows to storage and the gas enters the first of two catalytic reactors.

The first reactor operates adiabatically above the sulfur dew point, converting more of the sulfur compounds to elemental sulfur through the Claus reactions. The hot gases then enter a condenser which liquifies the sulfur. Liquid sulfur is sent to storage and the unreacted gas is sent to the second reactor.

The second reactor operates below the sulfur dew point of 260°F. The sulfur formed in this reactor deposits on the catalyst surface, causing a gradual catalyst deactivation. The two reactors are reversed at a predetermined catalyst deactivation level.

The second reactor is now heated. The sulfur deposited on the catalyst is vaporized and sent to the condenser, thereby reactivating the catalyst. The hot, first reactor must be cooled below the dew point to adsorb the sulfur. Sulfur recovery is reduced during the reactor reversal and cooldown period. Unreacted gas from the second reactor is incinerated to convert any residual H_2S to the less toxic SO_2.

This concept has been used in a number of commercial gas cleanup processes such as Sulfreen (by SNEA and Lurgi), the Amoco Cold Bed Adsorption (CBA) process and the MCRC process.

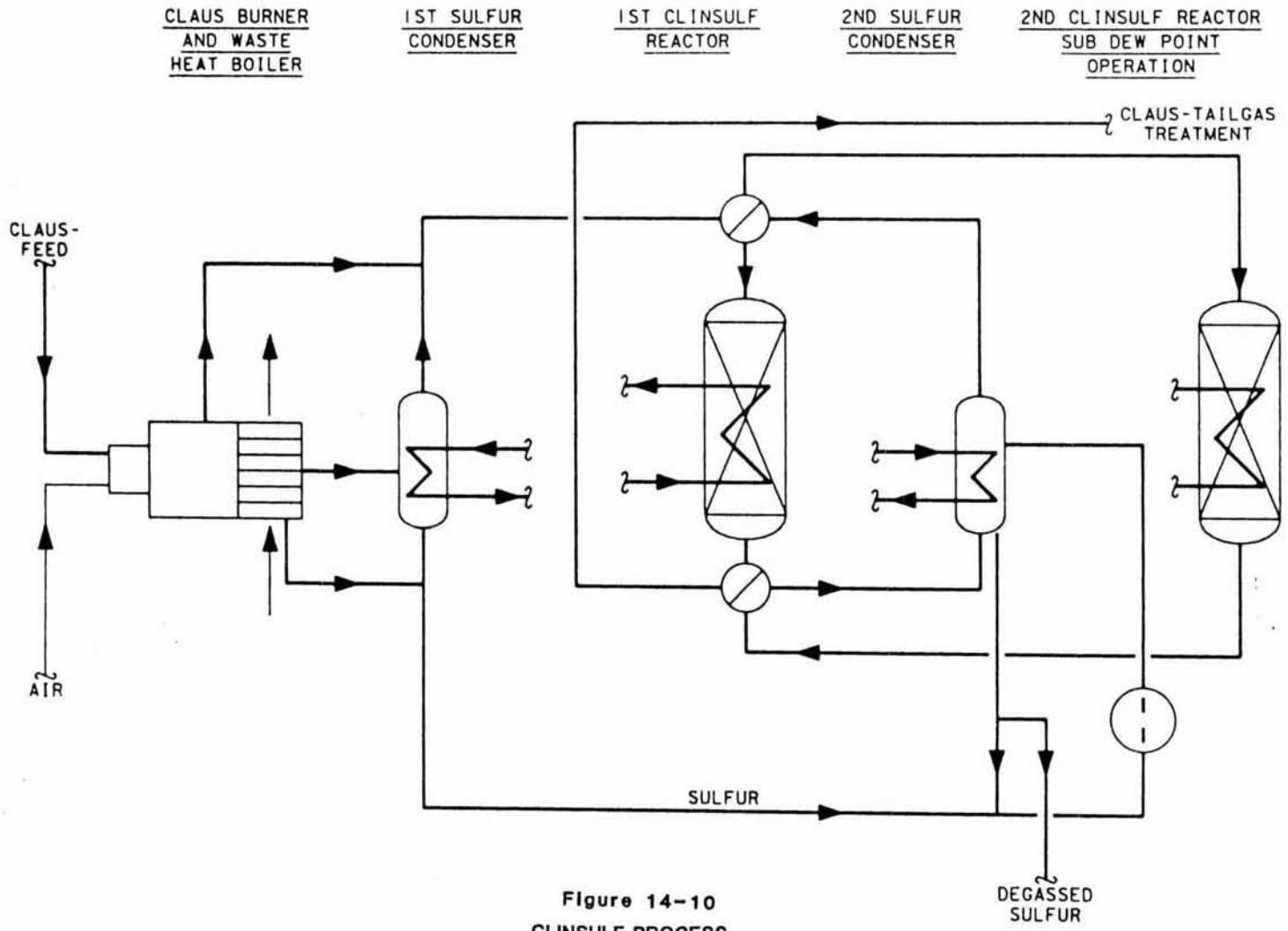


Figure 14-10
CLINSULF PROCESS

Anticipated Emissions

The Clinsulf process emits approximately 9 lb/hr of SO_2 (74,110 lb/yr) and a trace amount of H_2S.

Estimated Costs

The capital expenses of a Clinsulf unit are $3,282,000. Annual operating costs are estimated to be $241,800. The normalized costs of the Clinsulf process are $898,200 per year. Emission control costs amount to $208 per ton of H_2S processed. No capital costs are included for injection equipment to dispose of cooling tower blowdown.

Products/By-Products

The Clinsulf process produces a sulfur which is saleable. The total production is approximately 4,305 tons/yr of solid sulfur. Liquid process wastes include only the cooling tower blowdown (not associated with sulfur abatement) which amounts to 486,000 tons/yr.

REINJECTION SYSTEM (Selected Alternative)

Process Description

The noncondensable gases are removed from the condenser, compressed to approximately 200 pounds per square inch gauge (psig) and sent to an absorber. The absorber contacts the noncondensable gases with the blowdown water from the cooling tower. The H_2S and CO_2 in the noncondensable gas stream dissolve in the water while the other components (nitrogen and hydrogen) do not dissolve in the water. The gaseous components which do not dissolve in the water pass through the absorber and are vented.

The water containing the H_2S and CO_2 is pumped from the absorber into an injection well for disposal. Figure 14-11 shows the simplified process flow diagram for the Reinjection system.

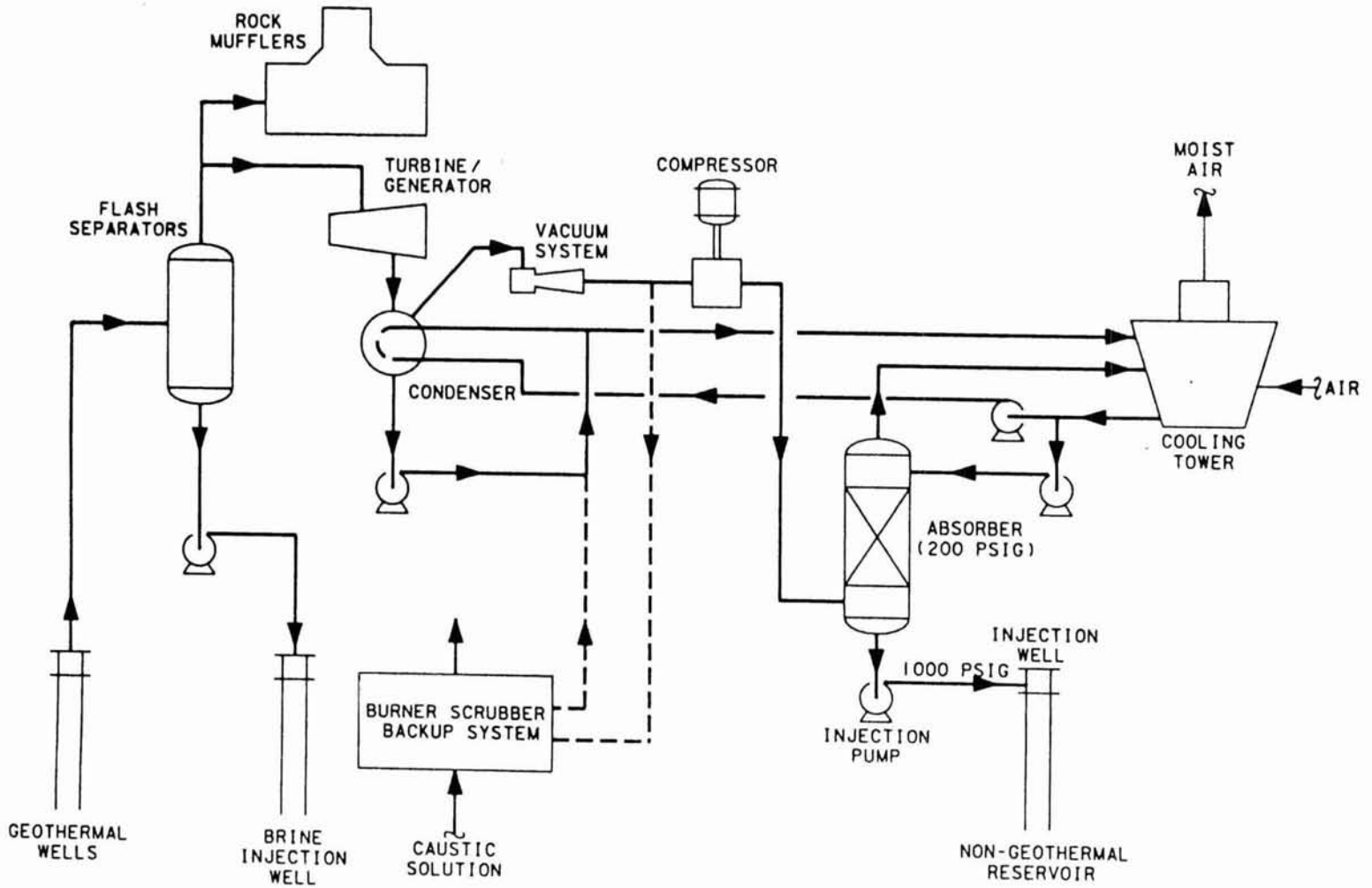


Figure 14-11
REINJECTION SYSTEM

A backup system is provided for the Reinjection system. The selected backup system is the Burner/Scrubber system and is described in detail in an earlier subsection. The Burner/Scrubber system would be used in the event of a malfunction in the Reinjection system.

Anticipated Emissions.

Essentially no emissions result from the reinjection of process fluids. The amount of H_2S which does not dissolve in the absorber is less than 0.5 pounds per hour (less than 4,120 lb/yr). This H_2S is directed to the cooling tower and most, if not all, is oxidized in sulfites. Therefore, H_2S air emissions from the cooling tower are not detectable.

Estimated Costs.

The capital and annual operating costs of a Reinjection system are $4,212,600 and $183,400, respectively. The operating costs are the lowest of the alternative control technologies. The normalized costs of the process are $1,026,000 per year. The emission control costs amount to $238 per ton of H_2S processed. These costs include the costs of the backup Burner/Scrubber system that will be employed if the Reinjection system temporarily malfunctions.

Products/Byproducts

Absorption of the H_2S into the cooling tower blowdown and the subsequent reinjection of the process fluids produced no solid waste. Approximately 4320 tons/yr of liquid wastes (dissolved H_2S) and the cooling tower blowdown (486,000 tons/yr) are reinjected into the reservoir.

14.4 NO ACTION/DELAYED ACTION ALTERNATIVES

NO ACTION

The "no action" alternative is defined as no geothermal development on this leasehold. The "no action" alternative requires that the electrical power needs forecast by HELCO will be met by fossil fuel power plants. This

alternative is counter to the goal of replacing imported oil with indigenous renewable resources contained in both the State and County plans (Hawaii State Plan, 1978, Chapter 226, HRS; General Plan, County of Hawaii as amended).

The reliance on imported oil and petroleum products as the primary energy source on the Island of Hawaii will continue under this alternative. Currently, the Island of Hawaii obtains approximately 60 percent of its electrical energy supply from imported petroleum. Hawaii's dependence on imported oil is disproportionate compared with that of other states. This dependency on imported oil costs Hawaiians an excess of $1 billion each year.

The State of Hawaii is rich in alternative renewable energy sources that are becoming increasingly available through new or improved technologies. Accordingly, the State and County plans direct the attainment of greater energy self-sufficiency through replacement of imported petroleum with power generated from renewable resources. The PGV geothermal power plant's use of an indigenous energy source would displace approximately 250,000 barrels of oil per year and would be in accord with the State and County goals of increased energy self-sufficiency. The "no action" alternative -- continued reliance on imported petroleum -- is clearly in conflict with the stated energy goals of the County and the State.

Positive economic impacts associated with the PGV are eliminated by the "no action" alternative. These impacts include capital expenditures on goods and services, increased employment during construction and operations, County revenue (e.g., property taxes), and State royalties.

The "no action" alternative eliminates all the potential environmental impacts associated with the proposed project. The impacts that would be avoided include:

- Controlled air emissions during well testing and well venting

- Discharges to geothermal and nonreservoir groundwater (within regulatory limits)

- Alterations of site topography and vegetation resulting from excavation and grading

- Temporary noise nuisance

- Alteration of the aesthetic character of the area resulting from visual and controlled noise impacts.

Costs and environmental impacts of abandonment of the current project would be high and would not be recoverable if another alternative were pursued.

It should be noted, however, that the "no action" alternative is not a "no energy" alternative, but one that derives electrical power from other energy sources, probably fossil fuel. The "no action" alternative has environmental impacts such as air and water quality deterioration from the combustion of fossil fuels. Even if these impacts occur elsewhere (i.e., around other power plants), they must still be considered.

DELAYED ACTION

This project has been designed to accommodate increases in local energy needs as forecast by HELCO. The consequences of delaying the proposed project depend on changes in local power needs and the future cost and availability of fuel oil.

Conservation offers an economically and environmentally compatible opportunity for reducing the demand for power and delaying the need for new power plants. An active conservation program helps individuals and companies act in a responsible manner to reduce the amount of energy wasted. The State currently devotes a significant portion of the annual budget of the Department of Business and Economic Development (DBED) to conservation related activities. A significant part of the energy consumption is related to the large number of tourists who visit the island each year. This makes conservation difficult because persons on vacation tend to be less conscious of the energy used since they never see the utility bills.

Conservation also requires that the baseload electricity is available. The projected increase in population (residents and visitors) from 1985 to the year 2000 is approximately 40 percent. (DBED, 1987). This increase and increases in the Island's industrial base may exceed the potential savings from conservation, requiring additional baseload power generation.

The power needs for the Island of Hawaii have been established by HELCO, based upon the demonstrated need for more power on the Island. The resulting question for electrical consumers is how to obtain this needed power in the most economical and environmentally sound manner. The PGV project meets the needs for power in an economical and environmentally responsible manner.

The actual construction time has been designated as 18 months for each 12.5 MW unit. Including permitting time, wellfield development, equipment fabrication, and construction, the project will take a total of three years to complete. The first 12.5 MW unit is scheduled to be in commercial operation by the end of 1989; the second unit will be operating by the end of 1991, depending on the needs of HELCO's system.

HELCO has forecast a significant increased need for electric energy within the next three years. In a relatively short period of time, fossil fuels could become considerably more expensive and considerably less available, as occurred during the 1973 Middle East oil embargo. The combination of these two factors and the time lag of construction could delay the operation of the geothermal facility, possibly resulting in a power shortage for the Big Island at some point in the near future.

Section 15

IRREVERSIBLE AND IRRETRIEVABLE COMMITMENT OF RESOURCES, PROBABLE UNAVOIDABLE ADVERSE IMPACTS, AND RELATIONSHIP BETWEEN SHORT-TERM USE OF THE ENVIRONMENT AND MAINTENANCE OF LONG-TERM PRODUCTIVITY

The Puna Geothermal Venture (PGV) project requires the commitment of land, geothermal fluids, building materials, labor and private capital. Some of the building materials, all the labor, and the private capital are considered irreversible and irretrievable commitments of resources.

15.1 IRREVERSIBLE AND IRRETRIEVABLE COMMITMENT OF RESOURCES

LAND

Approximately 17 acres of land are utilized for the project. No actively cultivated land is disturbed. At the end of the project's life, the site will be returned to its natural state. Structures and piping will be removed; wells will be plugged; roadways will be abandoned to the extent agreed upon with the land owner; the site will be regraded to the approximate original contours; and the land will be revegetated with native plants. The commitment of land for the project's duration does not irreversibly curtail the potential future uses of the land because of the planned restoration.

GEOTHERMAL RESOURCE

The performance of geothermal reservoirs over time and the possible depletion or cooling of the resource are major uncertainties in geothermal development. It is unknown at this time whether tapping the geothermal reservoir for steam production is an irreversible or irretrievable commitment of the resource. Although temperature fluctuations have been observed in geothermal production wells throughout the world, the variations are attributed largely to cooler water recharging the reservoir and not to a change in the heating potential of the reservoir. Cool water recharge can, at least

temporarily, lower the temperature of a reservoir to the point of being uneconomical for geothermal power production. However, the PGV project is located in one of the most active volcanic centers in the world. This high level of volcanic activity has helped to perpetuate a very high heat regime within the geothermal reservoir, one of the hottest geothermal systems in the world. Therefore, it is extremely improbable that removing the relatively small amount of heat energy needed to meet the requirements of the power plant will produce a significant cooling effect on the geologic process.

The primary recharge source of the geothermal reservoir is largely unknown. It is unknown at this time whether the extraction of reservoir fluid will irreversibly diminish the total volume of fluids contained within the reservoir. Due to the highly dynamic nature of the reservoir environment, there is almost certainly some substantial source(s) of reservoir fluid recharge at depth. Therefore, it is expected that insignificant depletion of the volume of reservoir fluid will occur as a result of power plant operations.

BUILDING MATERIAL

The facility consists of a power plant and a wellfield. The primary equipment in the power plant is the generator, turbine, and cooling tower. The wellfield is comprised of six wellpads and up to 20 wells.

The generator and the turbine are not irreversibly committed to the project. Both the generator and turbine could be reused in another power plant at the end of the project's life (or before, if desired), with only minor alterations.

The building materials used in the cooling tower, piping, wellpads and wells are considered primarily irreversible and irretrievable commitments of resources other than the potential reuse of the metal and piping as scrap material. The geothermal wells are considered irretrievable commitments since they are not planned to be reused after the project's decommission. The wells will be properly plugged with cement in accordance with regulatory standards.

LABOR

The estimated number of full-time employees required for normal operation and maintenance of the facility is 19. Construction of the wellfield and power plant employs approximately 23 people, with a peak employment of 100 people for temporary periods of time. The labor cannot be committed elsewhere since the labor that is necessary to build and operate the facility is committed to the project. Hours that have been worked are irretrievable.

PRIVATE CAPITAL

The capital costs needed to build the facility are estimated at $60 million. The investment is irretrievable during the life of the project. Annual operating and maintenance costs are calculated to be $3.3 million. Additional capital investments throughout the life of the project will amount to $2.2 million per year. These costs are irretrievable and irreversible.

15.2 PROBABLE UNAVOIDABLE ADVERSE ENVIRONMENTAL IMPACTS

Most of the potential adverse environmental impacts of the project are mitigated throughout the life of the project. Planned mitigation measures are discussed at the end of each section. Some impacts cannot be completely mitigated or avoided. Most of the unavoidable impacts occur only throughout the 35-year life of the project. These impacts include:

- Minimal alterations to topography
- Controlled quantities (within regulatory limits) of air emissions during well drilling, well flow testing, steam stacking, well venting, construction, and power plant operation
- Controlled discharges (within regulatory limits) to subsurface zones during well drilling
- Commitment of 17 acres of land for the power plant and associated wellfield

- Temporary visual changes in the immediate area of the project

- Controlled noise (within regulatory guidelines) during construction, well drilling, well testing, steam stacking, well venting, plant operation, and decommissioning

- Increased traffic during construction/decommissioning

Air emissions, water discharge and noise generation cease when plant operations cease. The impacts are not completely reversed. Water quality, air quality and noise impacts during the project are not significant. After project decommissioning, buildings and piping will be removed, wells will be sealed, and the land will be regraded to approximate original contours and planted with native vegetation.

15.3 RELATIONSHIP BETWEEN LOCAL SHORT-TERM USES OF THE ENVIRONMENT AND MAINTENANCE OF LONG-TERM PRODUCTIVITY

This section addresses the relationship between local short-term uses of humanity's environment and the maintenance and enhancement of long-term productivity; the extent to which the proposed action involves trade-offs between short-term losses and long-term losses, or vice versa; and the extent to which the proposed action forecloses future options, narrows the range of beneficial uses of the environment, or poses long-term risks to health or safety.

LAND USE

The site is located on fallow fields, scrub vegetation, and abandoned papaya orchards. There is no actively cultivated land on the site of the power plant and wellpads. Thus, no short-term agricultural production is foregone. After decommissioning, structures on the project will be removed and natural vegetation will be planted. Consequently, there will be no adverse effects on the long-term productivity of the land.

The project is located on approximately 500 acres of the Kapoho Section of the Kilauea Lower East Rift Geothermal Resource Subzone. The project area was

designated a subzone by a 1984 Hawaiian law (Act 151). Geothermal development and production are encouraged in designated subzones.

BIOLOGICAL RESOURCES

One candidate endangered plant species was found during the survey - Tetraplasandra hawaiiensis. A single plant of the Bobea species was also found. The identity of the species was inconclusive, but could have been Bobea timonioides because the Bobea species lacked flowers or fruit. Bobea timonioides is considered a candidate endangered species by the U.S. Fish and Wildlife Service. Three rare species of Cyrtandra were located in the study area: Cyrtandra paludosa var. integrifolia, Cyrtandra paludosa var. irrostrata, and Cyrtandra sp., (as yet undescribed). None of these species occurred on the well or power plant sites. According to Char and Stemmermann (1984) those native species which did occur on the well and power plant sites were not considered rare, threatened or endangered. No short-term effects on plant productivity are anticipated. No long-term effects are anticipated, since the site will be landscaped with natural vegetation both during the life of the project and after decommissioning.

One endangered fauna, the Hawaiian hawk, has been sighted in the vicinity of the PGV facility. The bird uses the area as foraging ground. No active nest has been found on the project site during numerous surveys. Therefore, no adverse short-term or long-term effect on the reproduction of the Hawaiian hawk is expected.

AESTHETICS

Visual impacts are short-term losses associated with the project. People living in some residences and vehicle travelers will be able to see construction activities, wellpads, the power plant and occasional steam plumes. Trees and other vegetation will be planted around the facility's structure and in the graded areas. The structures will be much less visible once this vegetation grows. Steam plumes from wells will be visible periodically. The visibility of the plumes depends on weather conditions and viewing position. Strong trade winds will normally disperse the plumes. The PGV project's pollution abatement

technology is substantially improved over that of the HGP-A facility. There are no permanent brine ponds at the PGV facility and the visual impacts are significantly smaller than at the HGP-A location. There are no long-term aesthetic impacts, since all structures will be removed at the end of the expected 35-year project life, and vegetation will be planted on the site.

HEALTH AND SAFETY

There are some risks associated with any development project. The major public health concern associated with geothermal power is hydrogen sulfide (H_2S). Health and safety risks at the PGV facility include exposure to low levels of H_2S released from the cooling tower and temporary exposure to higher levels of H_2S, resulting from planned venting of wells and upset conditions. The PGV facility will meet Hawaii's proposed H_2S air emission standards as well as occupational exposure limits recommended by the American Conference of Governmental Industrial Hygienists (ACGIH). No adverse long-term health risks from H_2S are expected.

SECTION 16

SUMMARY OF UNRESOLVED ISSUES

This section presents a summary of the unresolved issues for the Puna Geothermal Venture (PGV) project. Unresolved issues are those for which information is currently pending or unavailable. Issues identified as unresolved include the geothermal reservoir characteristics, regulatory requirements and permits, noise impacts, and the electrical transmission line issues.

The following paragraphs provide a brief description of the unresolved issue and the means by which the issue may be resolved or the overriding Oreasons for proceeding without fully resolving the issue.

GEOTHERMAL RESERVOIR CHARACTERISTICS

The geothermal reservoir which lies underneath the plant site has a proven capability as demonstrated by the HGP-A facility. Data presently available indicate that the reservoir has the potential for providing 30 megawatts of electricity for the PGV project. However, only development of the reservoir will answer such questions as:

- The structure and physical dimensions of the reservoir
- The total production capability of the reservoir
- The average production rate of wells
- The effect of the decline rate on production
- Long-term chemistry of the reservoir

Most of these points will be resolved with further development. Sufficient data exist to predict the capability of the reservoir to sustain the proposed project, but only long-term operation of the project will resolve the remaining details.

REGULATORY REQUIREMENTS AND PERMITS

The PGV project, the first commercial geothermal power generation facility in Hawaii, is establishing the precedents for the geothermal permitting process. In some cases, controlling regulations are only in the proposed state. In others, the procedure for approving a geothermal facility is still being established. There are areas where regulatory responsibility of agencies overlaps, and the controlling agency has not been clearly identified. The exact conditions and requirements governing the development of geothermal facilities in Hawaii are unknown and will be unresolved until this project has received all necessary approvals to proceed with development.

The three key areas of unresolved regulatory issues include:

- Air Pollution Control
- Underground Injection Control
- Geothermal Resource Permit Procedures

Hawaii Administrative Rules for Ambient Air Quality Standards (Chapter 59, Title 11) and Air Pollution Control (Chapter 60, Title 11) as proposed, contain substantive changes specifically addressing geothermal development and setting emission standards, including:

- Adoption of a hydrogen sulfide (H_2S) standard
- Limits on time-averaged concentration of H_2S
- Establishment of emission limitations from geothermal wells, geothermal power plants, and other geothermal facilities
- Requirements for administrative review of geothermal rules before July 1, 1992.

Thermal Power Company has worked closely with the Hawaii State Department of Health to participate in the development and promulgation of these rules and to assure the PGV facility is designed for compliance with proposed standards. The facility design was modified (changed to a closed-loop reinjection) to assure that H_2S emissions will be well below the proposed

emission limit. This primary H_2S abatement system and a backup H_2S abatement system (burner/scrubber) were selected based on a Best Available Control Technology analysis. Thermal Power Company has submitted the application for an Authority to Construct permit based on estimated H_2S emission compliance, although permit standard conditions have not been established.

Underground Injection Control (UIC) rules (Title II, Chapter 23) have been approved by the State of Hawaii and are currently in review by the U.S. Environmental Protection Agency. The PGV reinjection wells (Class V) are currently mauka of the UIC boundary line; therefore, by definition, the wells could impinge upon non-exempt aquifers.

Thermal Power Company has submitted a petition to modify the Lower East Rift Zone UIC Line, which would relocate the UIC line such that the PGV site would be makai of the UIC line. The petition was based on chemical characterization of the aquifer beneath the PGV site, which indicates significant geothermal water intrusion into the upper aquifer.

The County of Hawaii Planning Commission adopted administrative rules (Rule 12) in 1986 covering the issuance of Geothermal Resource Permits, pursuant to the authority conferred to the Planning Commission by Section 205-5.1 of the Hawaii Revised Statutes. The County rules had a provision for a contested case hearing on the application, but Act 378, passed by the Legislature in 1987, specifically excludes such a hearing. Thermal Power Company has submitted a petition to the County for an amendment to Rule 12, making it conform to the State regulation. Planning Commission hearings are in process and a decision is expected early next year.

NOISE IMPACTS

Two activities are identified which are unresolved in terms of compliance with noise guidelines. The County noise guidelines are not regulations, but have been successfully applied to previous geothermal well drilling on the project site. The identified activities are well drilling and well workover from 7:00 p.m. to 7:00 a.m.

Short duration activities, such as well venting, are exempted from the noise guidelines.

Well drilling is a 24-hour activity. Noise predictions for well drilling present a worst case and do not account for the probable reductions resulting from terrain and vegetation. Even under these worst-case conditions, predicted drilling noise at only three wellpads will slightly exceed the nighttime noise level guidelines. In addition, drilling noise at all wellpads will not exceed the daytime guidelines. Extensive mitigation measures have been taken during the previous drilling of exploratory wells to reduce the noise generated by this activity. These measures have resulted in a minimal number of complaints being made about drilling noise.

Well workover activities will not occur for approximately five years after a well is operational. The well workover operation will last only five days, 24 hours per day, for each well. Noise predictions for well workover present a worst-case and do not account for terrain and vegetation noise attenuation. Not all workover noise will exceed the nighttime guidelines, and well workover noise will not exceed the daytime guidelines. Extensive mitigation measures, similar to well drilling, will be taken to reduce the noise generated by well workover activities.

ELECTRICAL TRANSMISSION LINE

The transmission line connecting the PGV facility to the Hawaii Electric Light Company (HELCO) grid is vital to the PGV project. This line is a separate project, and is not covered by this EIS. The transmission line project will have its own permits and a separate environmental review.

Section 17

ORGANIZATIONS AND PERSONS CONSULTED

A listing of persons, organizations and public agencies commenting on the draft EIS is attached in Table 17-1. Table 17-1 lists the date of each letter and whether the letter had any comments.

NAME OF PERSON OR ORGANIZATION COMMENTING ON DRAFT EIS	LETTERS/COMMENT WITH	LETTERS/COMMENT WITHOUT
U.S. AGENCIES		
DEPT. OF AGRICULTURE, SOIL CONSERVATION SERVICE		
Mr. Richard N. Duncan		02SEP87
DEPT. OF THE ARMY, U.S. ARMY ENGINEERING DISTRICT		
Mr Kisuk Cheung	19AUG87	
DEPT. OF THE INTERIOR, FISH AND WILDLIFE SERVICE		
Mr. Ernest Kosaka	22SEP87	
DEPT. OF THE INTERIOR, U.S. GEOLOGICAL SURVEY		
Mr. William Meyer		25AUG87
DEPT. OF THE NAVY		
Captain T.L. Ferrier		18AUG87
STATE AGENCIES		
BOARD OF LAND & NATURAL RESOURCES		
Mr. William W. Paty	09OCT87	
DEPT. OF AGRICULTURE		
Ms. Suzanne D. Peterson	21SEP87	
DEPT. OF BUSINESS AND ECONOMIC DEVEL.		
Mr. Roger A. Ulveling	17SEP87	
DEPT. OF BUSINESS AND ECONOMIC DEVEL., HOUSING FINANCE & DEVELOPMENT CORP.		
Mr. Russell N. Fukumoto		13AUG87
DEPT. OF DEFENSE, OFFICE OF THE ADJUTANT GENERAL		
Major Jerry M. Matsuda		17AUG87
DEPT. OF EDUCATION		
Mr. Charles T. Toguchi		17AUG87
DEPT. OF LAND AND NATURAL RESOURCES		
Mr. Ralston H. Nagata	11SEP87	
DEPT. OF PUBLIC WORKS		
Teuane Tominaga		12AUG87
DEPT. OF TRANSPORTATION		
Mr. Edward Y. Hirata		18SEP87

NAME OF PERSON OR ORGANIZATION COMMENTING ON DRAFT EIS	LETTERS/COMMENT WITH	LETTERS/COMMENT WITHOUT
OFFICE OF ENVIRONMENTAL QUALITY CONTROL		
Mr. Marvin T. Miura		
Ms. Faith Miyamoto	22SEP87	
COUNTY AGENCIES		
COUNTY COUNCIL		
Mr. Russell S. Kokubun	18SEP87	
COUNTY COUNCIL		
S.K. Yamashiro		19AUG87
DEPT. OF PARKS & RECREATION		
Ms. Patricia Engelhard		17SEP87
DEPT. OF PUBLIC WORKS		
Mr. Hugh Y. Ono	19AUG87	
DEPT. OF WATER SUPPLY		
Mr. H. William Sewake	26AUG87	
PLANNING DEPARTMENT		
Mr. Albert Lono Lyman	22SEP87	
ORGANIZATIONS/INDIVIDUALS/OTHER		
AMERICAN LUNG ASSOCIATION		
Mr. James W. Morrow	22SEP87	
CITIZENS FOR RESPONSIBLE ENERGY DEVELOP. WITH ALOHA AINA		
Mr. Earl A. Dunn, Jr.	21SEP87	
CITIZENS FOR RESPONSIBLE ENERGY DEVELOP. WITH ALOHA AINA		
Mr. J.T. (Stuart) Marks	20SEP87	
HAWAII AUDUBON SOCIETY		
Ms. Mae E. Mull	20SEP87	
PARADISE PARK HUI HANALIKE		
Ms. Doborah Hay	16SEP87	
PELE DEFENSE FUND		
Ms. Lehua Lopez	20SEP87	
SIERRA CLUB-MOKU LOA GROUP		
Mr. Nelson Ho	19SEP87	
UNIVERSITY OF HAWAII AT MANOA, ENVIRONMENTAL CENTER		
Mr. John T. Harrison	21SEP87	

Reply #4

Your comment is appreciated. Mr. Phillips has been contacted with a request that he provide the information mentioned so that engineering evaluation can occur.

Comment

All brine holding ponds and well pad sumps for solid waste should be lined to prevent seepage of geothermal effluent into the groundwater, and to prevent on-site accumulation of toxins in the substrate. Such considerations are necessary for land use reclamation following decommissioning of the plant.

Reply #5

Toxicity tests of drilling fluids previously placed in the Wellpad A sump show no Environmental Protection Agency (EPA) established toxicity levels. Arsenic, lead, and mercury were among the metals measured in these 1985 tests. Neither wellbore fluid losses while drilling nor drilling sump residues are indicated to approach toxic levels or to impact the existing non potable groundwater in the project area.

Wellpad sumps for solid wastes will be utilized for disposal of cooling tower sludge which has been shown to be nontoxic in analyses performed on sludges taken from the HGP-A facility. The main constituents of this sludge are iron, sulfur, and biological materials. None of the solid wastes that will eminate from the new facility will be toxic. Repeated testing will be performed to ensure that nontoxic conditions are maintained.

Brine ponds are only intended for injection system upsets and maintenance activities. The volumes discharged to the ponds, therefore, will be limited and infrequent. The constituents in the brine are not toxic and the quality of the underlying groundwater is already contaminated with naturally leaking geothermal fluids. As the temperature of the brine decreases, silica precipitation makes handling of contained fluids very difficult posing many problems for disposal.

The contents of drilling mud, cooling tower sludge, and brine are not expected to be toxic, and their disposal in unlined sumps or ponds will, therefore, not cause a significant impact to the environment. Land use reclamation following decommissioning of the facility can be accomplished without the use of linings.

We thank you for your interest in our project.

Sincerely,

Ralph A. Patterson

Ralph A. Patterson, Jr.
Hawaii Project Manager

RAP:os
044/02355M

THE PELE DEFENSE FUND
POST OFFICE BOX 404 • VOLCANO, HAWAII 96785

RECEIVED
SEP 24 1987

September 20, 1987

Mr. Ralph A. Patterson, Jr.
Hawaii Project Manager
Thermal Power Company
Central Pacific Plaza
220 South King Street, Suite 1750
Honolulu, Hawai'i 96813

Dear Mr. Patterson,

The following are comments on your Draft Environmental Impact Statement:

Having carefully reviewed the eight-page section on Cultural Resources, including the subsections on Historical Survey, Archeological Resources and Native Hawaiian Religious Beliefs and Practices, we find this section woefully inadequate in addressing the issues and concerns we are most interested in.

To wit:

1. There is no acknowledgment, recognition, research or discussion of Pele as a goddess in her body forms of lava, magma, heat, and STEAM.

2. There is no acknowledgment, research or discussion of the importance of Pele and the hula in the Puna District, nor any discussion of the importance of Pele and the Puna District and Hawai'i Island in Hawaiian chants (mele and oli).

3. There is almost no acknowledgment, research or discussion of the numerous places (particularly those places visited by Pele) important to Pele and Hawaiian beliefs and customs throughout the Puna District contained in Pele stories, chants and legends.

4. There is no mention of access or denial of access for Hawaiian religious and cultural purposes in accordance with our beliefs and traditions.

The paucity of acknowledgment and discussion of the above concerns in your DEIS are only part of the many issues of importance to Pele Practitioners. We are gratified that you have at least recognized Kilauea's East Rift Zone as part of Pele's

traditional home and that "Some worshippers of the Goddess Pele believe that withdrawing steam from the volcano would desecrate the body of the goddess and destroy her." But we are deeply disturbed by the superficiality and shallowness of research contained in your section on Cultural Resources.

Me ka 'oia 'i'o,

Lehua Lopez

Lehua Lopez,
Pele Defense Fund

Diamond Shamrock
Thermal Power Company

Ralph A. Patterson, Jr.
Hawaii Project Manager

November 16, 1987

Ms. Lehua Lopez
The Pele Defense Fund
Post Office Box 404
Volcano, Hawaii 96785

Dear Ms. Lopez:

Thank you for your letter of September 20, 1987 expressing comments on the Puna Geothermal Venture Project's Draft Environmental Impact Statement.

Your concerns are addressed below:

Comment

Having carefully reviewed the eight-page section on Cultural Resources, including the subsections on Historical Survey, Archeological Resources and Native Hawaiian Religious Beliefs and Practices, we find this section woefully inadequate in addressing the issues and concerns we are most interested in.

To wit:

1. There is no acknowledgment, recognition, research or discussion of Pele as a goddess in her body forms of lava, magma, heat and steam.

2. There is no acknowledgment, research or discussion of the importance of Pele and the hula in the Puna District, nor any discussion of the importance of Pele and the Puna District and Hawaii's Island in Hawaiian chants (mele and oli).

3. There is almost no acknowledgment, research or discussion of the numerous places (particularly those places visited by Pele) important to Pele and Hawaiian beliefs and customs throughout the Puna District contained in Pele stories, chants and legends.

4. There is no mention of access or denial of access for Hawaiian religious and cultural purposes in accordance with our beliefs and traditions.

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Central Pacific Plaza 220 South King Street Suite 1750 Honolulu Hawaii 96813 Phone 808 524-8940

Reply #1

The Cultural Resources section has been expanded to more fully discuss your comments by adding information presented at the Board of Land and Natural Resources hearings on the Middle East Rift Zone and Campbell Estate/True/Mid-Pacific Development hearings. This information is closely related to the issue of geothermal development and native Hawaiian concerns.

We thank you for your interest in our project.

Sincerely,

Ralph A. Patterson

Ralph A. Patterson, Jr.
Hawaii Project Manager

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MOKU·LOA·GROUP
SIERRA CLUB • HAWAI'I CHAPTER

Ralph Patterson
Thermal Power Company
220 South King Street, Suite # 1750
Honolulu, Hawaii 96813

September 19, 1987

DRAFT EIS COMMENTS ON THERMAL POWER'S 25 MEGAWATT
GEOTHERMAL PROJECT ADJACENT TO THE EXISTING HGP-A FACILITY

Dear Mr. Patterson:

Sierra Club is impressed with the great improvements made to the project that result in much lower releases of the putrid smelling hydrogen sulfide gas during normal operations of the geothermal power plant.

However, despite the bulk of this two inch draft EIS, relevant issues raised at the preparation notice stage remain unanswered, and potentially significant environmental impact and geologic hazard concerns are inadequately discussed.

In addition, there are assertions made which are unsupported by textual discussion or appended reports.

It is our belief that it is the time to begin discussion on partial or full industry funding for a county "Environmental Compliance Officer" as is the case in Lake County, California.

HYDROGEN SULFIDE/AIR POLLUTION CONCERNS

1) PGV's decision to attempt a "closed loop" hydrogen sulfide abatement system during normal plant operations should be applauded. We are concerned however, because the reinjection method is novel in Hawaii, and our understanding of the Geysers' reinjection experience is that it is done more for reservoir recharge than hydrogen sulfide abatement reasons.

We would like this experiment to proceed with caution and insist that responsible monitoring be a condition to prove this technique.

2) FAILURE TO DISCLOSE LOCATION OF AIR POLLUTION IMPACTS - No maps or visual aids identify where the highest concentrations of H2S would be under various conditions nor who would be affected.

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3) Table 9-3 H2S AND NOISE EMISSION SUMMARY is very important and should have a map equivalent. ESTIMATED DURATION OF EVENT for a well blowout could have been 36 hours, which was the length of time it took PGV to control the October 1982 blowout incident.

4) Table 9-2 ESTIMATED PERMISSIBLE CONCENTRATION (EPC) VALUES FOR H2S is averaged over 8 hours. One hour averages is the standard measurement used in the proposed State H2S regulations. Table should be revised.

5) NEED TO CLARIFY AMBIENT BACKGROUND LEVELS OF H2S - The DEIS still distorts the data and incorrectly asserts that background ambient conditions reach 48 ppb. The Dames and Moore 1984 report, which this section's data was taken from states:

> "..at the Schroeder site, the maximum concentration after March 1982 was 7 parts per billion which occurred in June, 1983. This is about one-third the maximum concentration for the year (48ppb) which occurred in March. THE SOURCE OF THESE CONCENTRATIONS COULD NOT BE DETERMINED WITH AVAILABLE DATA. [Emphasis added] However, CONCENTRATIONS MEASURED IN 1983 ARE AT THE LOW END OF THE PERCEPTIBILITY RANGE INDICATING THERE DOES NOT APPEAR TO BE AN H2S RELATED ODOR PROBLEM AT THESE SITES [Emphasis added]." Page 8-5.

6) Table 9-2 Est. Permiss. Concen. Values For H2S continues to assert misleading information as to what constitutes background levels of H2S. Footnote "c" references ambient measurements, defined in Section 6. Section 6 refers to Noise pollution.

7) Page 14-39 vs. Page 2-31 - 0.5 lbs. H2S per hour normally is emitted from the cooling tower. WHAT IS THE WORST CASE CONDITION THAT WILL CAUSE THE TOWER TO EMIT 4 lbs. PER HOUR?

8) "RESIDENTS WITHIN A 1 MILE RADIUS OF THE SITE WOULD BE EXPOSED TO H2S EMISSIONS UP TO 24 HOURS A DAY, 7 DAYS A WEEK." PAGE 9-7. This is an unacceptable subsidy that the people around industrial geothermal development should not have to be burdened with. Puna Geothermal Ventures should be prepared in the future to buy out some of the property owners that are adversely affected by the air pollution.

9) PERMIT CONDITIONS RELATED TO AIR POLLUTION - A continuous monitoring station, including radon, should be placed at the site identified as the worst case location.

10) Remotely controlled valves (RCV) at the steam release facility are a good idea. Page 2-41. RCV VALVES SHOULD BE REQUIRED AT THE WELL HEADS PRODUCING STEAM for the power plant as well.

11) The Dames and Moore 1984 Report on Hydrogen Sulfide Best Available Control Technologies states on Page 4-5 that the caustic soda injection abatement method achieves only 90% - 95% abatement. Where is there evidence that PGV's caustic soda abatement gets 98% efficiencies?

12) LAVA TREE STATE PARK H2S CONTAMINATION INADEQUATELY DISCLOSED - DEIS states that during normal operations the air contamination of Lava Tree Park would be less than 25 ppb. There is INADEQUATE DISCLOSURE OF POLLUTION LEVELS AT LESS THAN IDEAL SITUATIONS. Could it be as high as 534 ppb?

13) Page 2-25 Rock muffler used 3% of year or 263 hours . Will this result in 263 hours of greater than 25ppb ambient conditions?. Add on time for unscheduled start-up problems and outages. We urge that the neighborhood alert system be implemented for those potentially putrid times.

14) Why is it that full turbine bypass flow can only be handled for 24 hours? Is it an economic consideration or a mechanical/design problem?

15) "A relief well can be drilled to penetrate the fluid source and terminate the blowout...". Letter from Patterson to Dorn - 7/20/87. DEIS states that a normal production well would take 60 days to drill. How fast could a relief well be drilled and would PGV be venting unabated during those days?

16) INADEQUATE DISCUSSION, DISCLOSURE ON RADON - Page 5-28 states radon at maximum in brine at 749 to 3,010 pico curies per liter. California officialsexpressed concern when ambient air levels were at 1.4 pico curies per liter at Geysers power plants. June 16, 1985 Press Democrat, "State Mulls Probe of Geysers Toxic Gas".

17) Pg. 5-28 states that 0.17 pico curies per liter will be released at the cooling tower, but nowhere is there an acknowledgment of 3,010 pico curies per liter being released during open venting, unscheduled ventings and events using rock muffler ("steam release facility"). WHAT WILL BE THE AMBIENT CONCENTRATIONS OF RADON THEN AND WHERE WILL THE MAXIMUM CONCENTRATIONS FALL?

18) Table 2-2 does not list radon or its volume. Why?

19) The continuous ambient measurements of Radon-222 should be conducted at the site most likely to be downwind (and instream) of the project's pollution plume, not upwind. Page 5-32.

GEOLOGICAL HAZARDS CONCERNS

20) DEIS STATES THAT LOCATIONS OF WELL PADS AND SITES ARE NOT FIXED Pg. 2-7. 6 well pads in 35 year life of project could be drilled anywhere, including closer to residences and public highways thus producing even greater impacts than disclosed in this DEIS.

21) Closest residence to well pad F is 1,000 feet southeast. Pg. 12-18. Well pad E may not be allowed if this project was being reviewed in Lake County. In Lake County's Zoning Code, Article XXV, Section 21-73.6 states:

> 1. No geothermal well shall be drilled within one-half mile of any populated area (defined as more than ten dwelling units established within a quarter-mile diameter area) or within one-half mile of any recorded subdivision, without the written consent of at least 75% of the owners.

22) ACTUAL FINDINGS OF SEISMIC AND VOLCANIC RISK ASSESSMENT STUDY HIDDEN FROM PUBLIC - What are the actual recommendations and findings of the study done for TP? "Full citations" were not provided in the DEIS. There is incomplete disclosure of geologic hazards to the Project as delineated in DEIS.

23) INCOMPLETE DISCLOSURE ON PIPELINE VULNERABILITY - Page 3-10 discloses that there is a 5% probability of damage to primary structures within a 40 year period based on average width of fissures, the width of zone liable to fissuring, frequency of occurrence and dimensions of engineered structure. PIPELINES ARE VERY IMPORTANT , yet lacking in this discussion is the numerical probability of linear structures subject to surface damage.

24) Also lacking is the description of the width of zone liable to fissuring and number used for frequency of occurrence. DECISION MAKERS DON'T KNOW IF ITS 6% OR 60% AND THEREFORE CAN NOT CONDITION THE PERMIT PROPERLY WITHOUT THIS INFORMATION. THEY MAY WANT TO HAVE AUTOMATIC SHUT-OFF VALVES AT THE WELLHEAD IF THE PROBABILITIES ARE VERY HIGH.

25) Figure 3-4 incomplete in that it does not have primary and linear structures depicted on it. Is it accurate to surmise that lava flows could cut both access roads and isolate project?

26) LAVA FLOW VULNERABILITY - We note that lava flows could inundate Well pads E and A, and that fissuring or graben formation could sever brine and steam lines to Well pads F and D.

27) What is the thickness of lava flows in the area? There is data from all 4 previous drillings.

HYDROLOGICAL CONCERNS

28) MUD DISCARDED ON SURFACE OF PROPERTY - Mud drilling can last up to two months per well, 24 hours a day. What is the quantity of spent drilling muds that is being proposed to dump at the PGV site? Page 4-13.

29) Circulating mud in the wellhole entrains contaminants like arsenic and heavy metals in Geysers, along with mud additives, these contaminants cause it to be classified a toxic waste at Geysers, with special disposal requirements, including lined sumps to keep it from leaching into the water table.

What additives are there for Hawaii's muds? Of specific concern in California were Magcobar Foam #44, Magcogel, bentonite clay, tannithin, and lignite. Geyser documents state that Magcogel was found toxic to trout at concentrations of 10 ppm, and the other contaminants proved to also be toxic to fishlife.

30) What kind of testing will be done to show that gas and brine reinjection is physically and economically feasible for the PGV project?

31) CONTROVERSY WHETHER THERE IS CONTAMINATION OF EXISTING GROUNDWATER - EIS presents an "upwelling" model invoking existing pollution of groundwater, therefore not needing monitoring wells, and at the same time saying that there is an "impenetrable seal of caprock" that will keep injected gases and brines from working there way back up into the water table. Page 4-19.

32) At what depth is PGV getting "contaminated" water of 2,000 tds? Are there viable potable water aquifers above this "contaminated" water?

33) COOLING TOWER SLUDGE ON-SITE DISPOSAL - SC is concerned about this concentrated sludge being put in the well pad sump for evaporation and percolation (with the solids being covered over with soil). There is potential for pollution plume in the 120 inches of rainfall a year area.

34) PGV OVERLOOKS CONTAMINATION POSSIBILITIES FROM REINJECTION WELLS - Are there absolutely no scenarios of reinejction well casing breakage or leakage? SC feels there should be monitoring and concurs with Dept. of Health (Letter from Lewin to Patterson 4/3/87) stating that there should be a minimum of 3 monitoring wells per liquid or gas injection well. In consultation with DOH, PGV should decide on factors involved in locating monitoring wells.

35) SC concurs with DOH that "a geothermal signature to groundwate: does not necessarily render the water unfit for human consumption." Ibid. Also it could be used for agriculture or livestock.

36) Water quality monitoring after decommissioning is important. We suggest an escrow account be created so that monitoring can be funded for five or ten years after decommissioning.

NOISE POLLUTION CONCERNS

37) While PGV should be commended for its noise abatement program developed during its exploration phase, the DEIS indicates that lon term industrial noise pollution will accompany this industrial project.

38) Table 9-4 SUMMARY OF NOISE LEVELS IS INCOMPLETE. Rupture disk events and pipeline cleaning events are missing. Worse yet, the text on Page 9-11 indicate that "Operations which are conducted 24-hours per day such as well drilling or well workovers may sometimes slightly exceed the nigh time levels as shown in Table 9-4. THE TRU IMPACTS OF NOISE ARE BEING CONCEALED FROM THE PUBLIC AND THE DECISION MAKERS. THIS DEFICIENCY SHOULD BE CORRECTED IN THE Revise EIS.

39) THE SERIES OF FIGURES FROM 6-3 TO 6-14 SHOULD BE REVISED TO INCLUDE SHORT TERM NOISES. They are intrusive impacts and people d hear them.

40) INCOMPLETE NOISE DISCLOSURES - Well Pad E is especially troublesome because of its noise impacts on the highway and the closest residences. It was disappointing to see that Figures 6-3 t 14 do NOT disclose the true noise impacts on the surrounding residents and environment. Page 6-43 states that no short term nois sources were included for any of the above figures.

41) INCOMPLETE NOISE IMPACT DISCLOSURES - Lava Tree State Park normal impacts and worst case is given at 38-42 dba at southern boundary of Park, but also say that pipe impact noises will be higher, how much higher?

42) Permit conditions should include phone person (not a answering machine) to contact for noise complaints. Could work with County compliance officer.

SOCIOECONOMIC CONCERNS

43) NATIVE HAWAIIAN VALUES - the phone poll discussed on page 10-3 included data that Hawaiians were twice as inclined to be "strongly unfavorable" to the undersea transmission cable as any other ethnic group. This may reflect the controversy surrounding geothermal development and the Pele practitioner's legal efforts to stop the desecration of their religion.

44) Figure 8-3 Location of Residences is misleading. DEIS indicates that noise and air pollution impacts can be felt one mile and more away. Scale of 1/2 mile is insufficient; it should include a one mile radius and possibly a one and 1/2 mile radius ring.

45) TRAFFIC CONGESTION - We feel PGV underestimates the amount of traffic congestion that already exists on the overcrowded Pahoa Highway and also underestimates the hazards generated by more industrial traffic.

46) WORKERS TRAINING NEEDED - only a crew of 36 will be needed to drill wellfield, and up to 100 construction jobs. How many are estimated to be filled by imported labor?

47) Page 2-41 states that only 19 employees will be needed for operation and maintenance of facility. We call for ways to start and fund a training program for local people to get some of these jobs.

48) PAGE 16-3 - TRANSMISSION LINE CONCERNS - The DHM Consultants corridor recommendations were unsatisfactory to subdivision communities. What effect will a delayed/contested corridor decision have on project?

49) Project security lights should be shielded to prevent glare from bothering neighbors, a major sore point with residents of Cobb, a small town in Lake County, Ca.

BIOLOGICAL IMPACT CONCERNS

50) The bleak picture presented in the noise impacts sections suggests that the Hawaiian I'o will not stay in the vicinity of industrial noises that persist over 35 years.

51) We are relieved that this project is not occurring in the unique Hawaiian rainforests of Puna. The disruption to native habitats and species would have been far greater.

52) We are concerned that the nesting and hunting hawks will relocate due to the constant industrial noises that will occur during the 35 year life of the project.

53) There is need for independent verification of industrial impacts upon bird behavior. Are the assurances stated on Pg. 7-20 enforceable now by County or State personnel?

54) Missing from Section 14 is any discussion of "ENERGY CONSERVATION" as a clean alternative to building new generating capacity. Every geothermal developer should discuss this environmentally benign alternative.

AESTHET ICS

55) SECTION 12 AESTHETHICS ANALYZES VISUAL IMPACT BUT DOES NOT GIVE HEIGHTS OR ELEVATIONS OF TOWERS, BUILDINGS. Height of building turbine is not yet set but must accommodate 30 foot interior ceiling Pg. 2-36.

56) While the DEIS states that there will be 40 foot high cooling towers (Pg. 2-37) near the top of Puu Honuaula (which stands 150 feet above the surrounding land), DEIS DOES NOT DISCLOSE THAT STEAM PLUMES CAN OFTEN REACH 200 FEET ABOVE THE COOLING TOWERS. (Contested Case Testimony Kahauale'a Geothermal Project.

Thank you for providing us a copy of the DEIS. We look forward to reviewing the Final EIS.

Nelson Ho

Nelson Ho
for the Conservation Committee
Sierra Club

Diamond Shamrock
Thermal Power Company

Ralph A. Patterson, Jr.
Hawaii Project Manager

November 16, 1987

Mr. Nelson Ho
Moku Loa Group
Sierra Club Hawaii Chapter
Post Office Box 1137
Hilo, Hawaii 96721

Dear Mr. Ho:

Thank you for your letter of September 19, 1987, expressing comments on the Puna Geothermal Venture Project's Draft Environmental Impact Statement.

Your concerns are addressed below:

Comment

We are concerned however, because the reinjection method is novel in Hawaii, and our understanding of the Geysers' reinjection experience is that it is done more for reservoir recharge than hydrogen sulfide abatement reasons. We would like this experiment to proceed with caution and insist that responsible monitoring be a condition to prove this technique.

Reply #1

Reinjection procedures to be used at the Puna Geothermal Venture (PGV) site are to serve two purposes: to aid in the recharge and thereby extend the life of the reservior; and to abate potentially harmful H_2S emissions. Reinjection of liquids is routinely performed at the Geysers and other geothermal areas throughout the world with the primary purpose of reservoir recharge. In the concept proposed by PGV for hydrogen sulfide (H_2S) abatement, the H_2S and carbon dioxide (CO_2) are dissolved in the cooling tower blowdown water prior to reinjection so that a liquid, and not a gas, is returned to the reservoir. Pressure conditions within the reservoir are such that if a gas is dissolved at the surface, it should not come out of solution within the reservoir. Additionally all fluids are being returned to the environment from which they originated. This concept is not unproven. At Coso Hot Springs geothermal facility in California, a similar system is employed for noncondensable gas abatement (including H_2S); tests have also been conducted at the Geysers that demonstrate injection of liquids containing gases is feasible.

Injection wells will be monitored for operating parameters including pressure, temperature, flow rate, annulus pressure, and density of injectate. This

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monitoring procedure will provide information on the efficiency of the injection process as well as early warning in the event of a malfunction or change in reservoir parameters.

Comment

Failure to disclose location of air pollution impacts - No maps or visual aids identify where the highest concentrations of H_2S would be under various conditions, nor who would be affected.

Reply #2

Locations of maximum air pollutant ground level impacts have been included in the final Environmental Impact Statement (EIS).

Comment

Table 9-3 H_2S and noise emission summary is very important and should have a map equivalent. Estimated duration of event for a well blowout could have been 36 hours, which was the length of time it took PGV to control the October 1982 blowout incident.

Reply #3

Table 9-3 represents the maximum anticipated emissions for a variety of events. It is not possible to present this information on a map. Details regarding the H_2S and noise emissions are presented in Sections 5 and 6 of the EIS, respectively. A duration is not included for the well blowout event because the nature of this unlikely event will cause the response time to vary. Section 9 outlines the mitigation measures taken to avoid well blowouts. The likelihood of a failure is considered to be very remote due to these measures.

Comment

Table 9-2 estimated permissible concentration (EPC) values for H_2S is averaged over 8 hours. One hour averages is the standard measurement used in the proposed state H_2S regulations. Table should be revised.

Reply #4

Normal operations emit a continuous, low level amount of H_2S. The 1-hour limit [0.10 parts per million-volume (ppmv)] is used for these operations because of the long term exposure to residents in the area. Short duration events do not pose the same risk to residents. These events are more closely related to occupational exposures than the residential exposures. Concentration limits have been determined for workers who are exposed for 8 hours per day, 5 days per week. These limits are the maximum concentration workers may be repeatedly exposed to without adverse effect. The EPC for short term exposure is therefore based on the American Conference of Governmental Industrial Hygenists' Threshold Limit Value, 10 ppmv for an 8 hour average. Table 9-2 has been revised to indicate appropriate 1 hour and 8 hour EPC and Ground Level Concentration (GLC) values.

Comment

Need to clarify ambient background levels of H_2S - The DEIS still distorts the data and incorrectly asserts that background ambient conditions reach 48 ppb.

Reply #5

The Draft EIS (DEIS) did not attempt to distort data or assert a misleading or inaccurate figure for the background concentration of H_2S. Table 5-4 in the EIS presents a summary of the data collected at the four monitoring stations. A background concentration of 0.048 ppmv was used as a maximum in calculating the maximum GLCs because this yields the highest anticipated GLC for the facility - a more conservative approach. The EIS notes that the background concentrations are below 0.010 ppmv about 98 percent of the time.

Comment

Table 9-2 Est. Permiss. Concen. Values for H_2S continues to assert misleading information as to what constitutes background levels of H_2S. Footnote "c" references ambient measurements, defined in Section 6. Section 6 refers to noise pollution.

Reply #6

Background levels of H_2S have been deleted from Table 9-2 to avoid confusion. Thank you for your comment on footnote "c". The deletion of the background levels eliminated the need for this footnote, which should have read "Section 5" in the DEIS.

Comment

Page 14-39 vs. Page 2-31 - 0.5 lbs. H_2S per hour normally is emitted from the cooling tower. What is the worst case condition that will cause the tower to emit 4 lbs. per hour?

Reply #7

There is no "worst case" when the H_2S concentration changes from 0.5 to 4.0 pounds per hour (lb/hr) of H_2S. The 0.5 lb/hr figure refers to the estimated amount of H_2S which might pass through the absorber along with the insoluble nitrogen and hydrogen gases. These gases makeup one component of the gases which are vented through the cooling tower. The maximum cooling tower emissions during all normal operations is 4.0 lb/hr of H_2S. Section 2 of the EIS identifies some of the other sources which are vented through the cooling tower.

Comment

"Residents within a 1 mile radius of the site would be exposed to H_2S emissions up to 24 hours a day, 7 days a week." Page 9-7. This is an unacceptable subsidy that the people around industrial geothermal development should not have to be burdened with. Puna Geothermal Ventures should be prepared in the

future to buy out some of the property owners that are adversely affected by the air pollution.

Reply #8

Section 8 of the draft EIS describes the land value study that was undertaken to determine the potential effects of the project on housing values. The conclusion was that no significant effect is anticipated since the facility will use injection technology. There are no plans to buy out property owners in the area.

Comment

Permit conditions related to air pollution - A continuous monitoring station, including radon, should be placed at the site identified as the worst case location.

Reply #9

Meteorological and ambient air quality monitoring will be conducted continuously during the life of the project. The details of the air monitoring program will be established by the Department of Health (DOH). It would be inappropriate to speculate on the plan of DOH to monitor air quality from geothermal facilities at this time.

Comment

Remotely controlled valves (RCV) at the steam release facility are a good idea. Page 2-41. RCV valves should be required at the wellheads producing steam for the power plant as well.

Reply #10

Remotely controlled valves were considered for the wellheads, but a decision was made not to include them in the design. During normal operation, flow from the wells is relatively constant and requires minimal flow control adjustment. Steam flow is automatically diverted to the steam release facility during plant upsets. Flow control at the wellhead is not required for this situation. Initiating or discontinuing well flow is the only circumstance where major adjustments are made to wellhead control valves. These operations are very rare and more safely performed at the wellpad where well response can be directly monitored.

Comment

The Dames and Moore 1984 Report on Hydrogen Sulfide Best Available Control Technologies states on Page 4-5 that the caustic soda injection abatement method achieves only 90%-95% abatement. Where is there evidence that PGV's caustic soda abatement gets 98% efficiencies?

Reply #11

Dames and Moore identifies that a state-of-the-art rock muffler, incorporating both hydrogen peroxide and caustic, is designed to remove 98% of the H_2S emissions. (Page 6-41.) This information is supported by observations made on operating abatement systems.

Comment

Lava Tree State Part H_2S contamination inadequately disclosed - DEIS states that during normal operations, the air contamination of Lava Tree Park would be less than 25 ppb. There is inadequate disclosure of pollution levels at less than ideal situations. Could it be as high as 534 ppb?

Reply #12

Maximum H_2S concentrations and associated locations during normal operation have been included in the final EIS. Maximum GLCs typically occur south to southwest of the PGV site. Lava Tree State Park is located west-northwest of the site; therefore, the park will not experience significant concentrations of H_2S from the PGV project. H_2S concentrations will not reach as high as 534 parts per billion (ppb) in the vicinity of the site.

Comment

Page 2-25 Rock muffler used 3% of year or 263 hours. Will this result in 263 hours of greater than 25 ppb ambient conditions? Add on time for unscheduled start-up problems and outages. We urge that the neighborhood alert system be implemented for those potentially putrid times.

Reply #13

The emissions from the rock muffler are identified in Section 5 of the EIS. Recent Air dispersion modeling indicates that these emissions will not exceed 0.013 ppmv (13 ppb). A very slight odor may be detected at the location of the maximum ground level concentration; however, most locations will be at or below the odor threshold.

Comment

Why is it that full turbine bypass flow can only be handled for 24 hours? Is it an economic consideration or a mechanical/design problem?

Reply #14

The length of full turbine bypass is determined by the water requirement for the cooling system. The stored water supply is intended to provide at least 24-hours of bypass from both turbines. This is a very unlikely situation since most bypass operations will only last a few hours.

Comment

"A relief well can be drilled to penetrate the fluid source and terminate the blowout ...." Letter from Patterson to Dorn - 7/20/87. DEIS states that a normal production well would take 60 days to drill. How fast could a relief well be drilled and would PGV be venting unabated during those days?

Reply #15

Well blowouts are considered to be very unlikely due to the many conservative factors included in the design. As was discussed in the letter to Ms. Dorn, there are a number of techniques such as weighted mud injection and cementing which may be used to control a well in the event of a blowout. The cause of the blowout will greatly influence the length of time to shutoff the flow, and the amount of H_2S emission mitigation which may be achieved. In the extremely unlikely event that a relief well was required, it could be drilled in approximately 40 days. The extent of H_2S abatement which could be achieved during this time is dependent upon the nature of the incident.

Comment

Inadequate discussion, disclosure on radon - Page 5-28 states radon at maximum in brine at 749 to 3,010 picocuries per liter. California officials expressed concern when ambient air levels were at 1.4 picocuries per liter at Geysers power plants. June 16, 1985 Press Democrat, "State Mulls Probe of Geysers Toxic Gas."

Reply #16

All parameters used to calculate the radon-222 concentration at the cooling tower plume were not included in Section 5 of the DEIS. This has been corrected and the complete bases for the calculation is included in the final EIS. The estimated quantities of radon-222 in the geothermal fluids range from 749 to 3,010 picocuries per liter (pCi/l) of steam condensate (liquid). The radon-222 concentration in the air leaving the cooling tower is 0.17 pCi/l of air. This value is further reduced when the cooling tower plume is dispersed into the surrounding air. Environmental Protection Agency (EPA) guidelines consider levels below 4 pCi/l to be insignificant.

Comment

Page 5-28 states that 0.17 picocuries per liter will be released at the cooling tower, but nowhere is there an acknowledgment of 3,010 picocuries per liter being released during open venting, unscheduled ventings and events using rock muffler ("steam release facility"). What will be the ambient concentrations of radon then and where will the maximum concentrations fall?

Reply #17

An estimate of maximum GLC of radon-222 for emissions from the steam release facility has been included in the final EIS. Modeling results indicate that the maximum GLC of radon-222 during steam stacking will be less than

0.003 pCi/l of air. The location of the maximum GLC has been included in the final EIS.

Comment

Table 2-2 does not list radon or its volume. Why?

Reply #18

The EIS treats radon separately from the noncondensable gases (Table 2-2) because the testing, measurement and reporting for radon is substantially different from nonradioactive elements. A paragraph explaining the radon concentration has been added to Section 2 of the final EIS.

Comment

The continuous ambient measurements of Radon-222 would be conducted at the site most likely to be downwind (and instream) of the project's pollution plume, not upwind. Page 5-32.

Reply #19

The location of the radon monitor was incorrectly identified in the DEIS. It is located at the Schroeder Site and there are no plans to move it at this time.

Comment

DEIS states that locations of wellpads and sites are not fixed Page 2-7. Six wellpads in 35 year life of project could be drilled anywhere, including closer to residences and public highways, thus production even greater impacts than disclosed in this DEIS.

Reply #20

Two wellpads exist now and are fixed. Four possible new wellpads, proposed at specific sites as shown on Site Plan, Figure 1-2, are based upon current knowledge of reservoir extent, expected reach of directional drilling and higher ground elevation to protect against lava flows. Actual results of future drilling and production may force minor relocations in the proposed C, D, E, and F Wellpads. In no event would Wellpads E and F be moved closer to lease boundaries or existing residences because the topography at these proposed wellpads is favorable to reductions of noise and visual impacts.

Comment

Closest residence to Wellpad F is 1,000 feet southeast. Page 12-18. Wellpad E may not be allowed if this project was being reviewed in Lake County.

Reply #21

See Reply #20. Hawaii does not have a similar regulation.

Comment

Actual findings of seismic and volcanic risk assessment study hidden from public - What are the actual recommendations and findings of the study done for TP? "Full citations" were not provided in the DEIS. There is incomplete disclosure of geologic hazards to the Project as delineated in DEIS.

Reply #22

Pertinent conclusions and findings of the seismic and volcanic risk assessment performed by Slemmons, et al., (1981) were provided in the DEIS and will be somewhat expounded upon in the EIS. The report can be reviewed in detail by interested parties at the County Planning Department or the Office of Environmental Quality Control. The full citation follows:

Slemmons, D.B., Bergantz, G.W., Whitney, R.A., McBirney, A.R., Baker, B.H., 1981, Seismic Volcanic Risk Assessment, Puna Geothermal Project Area, Hawaii, Prepared for Thermal Power Company, Dillingham, AMFAC, 104 p.

The main conclusions of the report are that seismic and volcanic risks are high and diverse, but the risk to engineered structures and installations can be mitigated through proper procedures, siting, and design. The study recommended methods and factors that should be considered to mitigate risks: Avoid installation in low areas, utilize diversion barriers, orient buildings such that their longest dimensions are not normal to the rift trend, and coordinate with Hawaii Volcano Observatory and Hawaii Institute of Geophysics.

Comment

Incomplete disclosure on pipeline vulnerability - Page 3-10 discloses that there is a 5% probability of damage to primary structures within a 40 year period based on average width of fissures, the width of zone liable to fissuring, frequency of occurrence and dimensions of engineered structure. Pipelines are very important, yet lacking in this discussion is the numerical probability of linear structures subject to surface damage.

Reply #23

According to the Risk Study of Slemmons, et. al., (1981), there is an approximately 60 percent probability of a linear fissure of average width 1 meter intersecting a 2,000-foot length of pipeline trending normal to the rift zone within a 40-year period. Several factors combine to mitigate any threat of damage to pipelines: Pipelines are built to withstand a wide range of thermal expansion resulting in a large element of built-in flex; pipelines and other structures will be built to strict seismic standards of safety; pipelines will be designed to accommodate projected average fissure widths as defined by Slemmons et al. (1981) with no damage. Should any sudden seismic event exceed piping design resulting in damage, emergency response procedures would include shutdown and depressurization of pipelines within one hour. Repairs will be conducted in a timely and efficient manner whenever needed.

Comment

Also lacking is the description of the width of zone liable to fissuring and number used for frequency of occurrence. Decision makers don't know if it is 6% or 60% and therefore can not condition the permit properly without this information. They may want to have automatic shut-off valves at the wellhead if the probabilities are very high.

Reply #24

According to the risk study of Slemmons, et al. (1981), the width of the zone liable to fissuring is 3,000 meters, and a conservative estimate of the frequency of occurrence is 1 in 40 years. The average width of the fissures used in the calculations is 1 meter.

Comment

Figure 3-4 incomplete in that it does not have primary and linear structures depicted on it. Is it accurate to surmise that lava flows could cut both access roads and isolate project?

Reply #25

Figure 3-4 of the DEIS does not depict the orientation or layout of primary or linear structures because the scale used is too small. Details and even large scale objects would be poorly represented. Restriction or shutdown of surface access to the site from lava flow incursion is extremely unlikely due to deflection and other early warning and protective measures which would be utilized as part of the emergency response plan. However, should surface access to the site be cut off from lava flow, helicopter access would be employed to shut down and evacuate the facility.

Comment

Lava flow vulnerability - We note that lava flows could inundate Wellpads E and A, and that fissuring or graben formation could sever brine and steam lines to Wellpads F and D.

Reply #26

In general, lowerlying structures (including wellpads and pipelines) are at greater risk of inundation from uprift lava sources. Methodology that can be used to prevent serious damage and/or personal danger include temporary diversion barriers, burial of relevant structures in cinders and enclosed wellheads. If an imminent threat of lava flow inundation of project structures were to arise, production wells could be shut in and the plant shut down while emergency response procedures were enacted. Pipelines could be shut down and depressurized within one hour.

If fissuring or graben formation were to occur directly beneath any main structure, damage would occur. The key element to concentrate on is the probability of any such event occurring through the life of the project. There

have been no distinct graben development in the project a. . Broad, sinusoidal uplifts or shallow subsidence has been recorded by leveling lines which transect the middle and lower East Rift Zone. These have generally been associated with thermal contraction or withdrawal of magma from deep parts of the dike system (Slemmons, et al., 1981). The closest mapped graben lies to the east of the project site and ends at the junction of the Puu Kii and 1955 flows. Total movement has been less than 2 meters. For these reasons, graben formation as a serious cause for concern is not justified. Building and piping design will accommodate the more broad and lower magnitude uplifts and subsidence which generally characterize movements in the project area.

The probability of ground rupture affecting piping, especially longer segments oriented perpendicular to the trend of the rift zone, is large enough to require special planning, design, and mitigation measures. Pipelines will be built to withstand a large thermal expansion flex, strict seismic standards, and average fissure openings as defined by Slemmons et al. (1981).

Comment

What is the thickness of lava flows in the area? There is data from all 4 previous drillings.

Reply #27

The average thickness of previous lava flows in the project area has been found to be 18 feet with a range of 3 to 37 feet (Slemmons et al., 1981). The detailed evaluation of mud logs and/or rock cuttings from the four previously drilled wells at the site necessary to define the thickness of local lava flows has not been done. The data needed to evaluate these thicknesses may not exist (i.e., rock cuttings may no longer be available for study). In addition, existing lava flow information is believed to be of high quality and therefore no further data is deemed necessary.

Comment

Mud discarded on surface of property - Mud drilling can last up to two months per well, 24 hours a day. What is the quantity of spent drilling muds that is being proposed to dump at the PGV site? Page 4-13.

Reply #28

Approximately 1,200 barrels of drilling fluids may be placed in the unlined sump on each wellpad during the drilling and completion of each Puna geothermal well.

Comment

Circulating mud in the wellhole entrains contaminants like arsenic and heavy metals in Geysers, along with mud additives, these contaminants cause it to be classified a toxic waste at Geysers, with special disposal requirements, including lined sumps to keep it from leaching into the water table.

Reply #29

Toxicity tests of drilling fluids previously placed in the Wellpad A sump show no EPA established toxicity levels. Arsenic, lead, and mercury were among the metals measured in these 1985 tests. Neither wellbore fluid losses while drilling nor drilling sump residues are indicated to approach toxic levels or to impact the existing geothermally contaminated groundwater.

Comment

What additives are there for Hawaii's muds? Of specific concern in California were Magcobar Foam #44, Magcogel, bentonite clay, tannithin, and lignite. Geyser documents state that Magcogel was found toxic to trout at concentrations of 10 ppm, and the other contaminants proved to also be toxic to fish life.

Reply #30

No additives to be used in any drilling fluid at the PGV site are indicated to be toxic at the levels which will be utilized.

Besides the fresh water and clays (Bentonite and sepiolite) used to make the drilling mud, there will be a number of specialty additives used. These additives are used for viscosity, pH, flocculation and foam control. All of these materials are nontoxic.

Comment

What kind of testing will be done to show that gas and brine reinjection is physically and economically feasible for the PGV project?

Reply #31

The plant will be started in phases while all aboveground pipes and structures are tested. During this test period, injection of brines and noncondensable gases will commence. Throughout the initial start-up procedure, lines and injection wells will be monitored for flow rate, pressure, temperature, injectable chemistry, and annulus pressure to ensure that the system is working properly and efficiently. Monitoring of injection wells will be maintained throughout the life of the project to detect possible malfunctions and/or changing reservoir parameters.

Comment

Controversy whether there is contamination of existing groundwater - EIS presents an "upwelling" model invoking existing pollution of groundwater, therefore not needing monitoring wells, and at the same time saying that there is an "impenetrable seal of caprock" that will keep injected gases and brines from working their way back up into the water table. Page 4-19.

Reply #32

The Puna geothermal reservoir is characterized by a very high temperature (in excess of 600°F) and high pressure (2,000 pounds per square inch gauge psig). Such thermodynamic conditions are considered rare among geothermal systems throughout the world. In order to maintain this reservoir state, the reservoir must be "effectively" sealed by a low permeability zone which is referred to as a caprock or seal. The term "effectively" is used because it is also known that the geothermal reservoir is leaking fluids into the overlying intermediate and shallow groundwater system (Iovenitti, 1986; McMurtry et al., 1977; Thomas, 1987). The caprock must be broken to allow leakage from the reservoir. However, because of the Puna geothermal reservoir's thermodynamic state, the break in the caprock is considered to be small or very local in extent. These local breaks in the seal are sufficient to cause the thermal and chemical contamination of the overlying groundwater system but are not extensive enough to cause a reduction in the temperature and pressure conditions of the reservoir.

Comment

At what depth is PGV getting "contaminated" water of 2,000 tds? Are there viable potable water aquifers above this "contaminated" water?

Reply #33

Groundwater of 2,000 ppm Total Dissolved Solids (TDS) or worse occurs at a depth of approximately 600 feet below ground surface in the vicinity of the PGV project site. There are no viable potable water aquifers above this contaminated zone in the vicinity of the site.

Comment

Cooling tower sludge on-site disposal - SC is concerned about this concentrated sludge being put in the well pad sump for evaporation and percolation (with the solids being covered over with soil). There is potential for pollution plume in the 120 inches of rainfall a year area.

Reply #34

Sludge will accumulate in the cooling tower basins. The sludge consists of inorganic sulfites, iron, and bacterial growth. The sludge will be tested for toxicity, and if found to be nontoxic, will be placed in one of the wellpad sumps. The exact quantities, composition and frequency of removal will not be known until an operating history is established for the plant, but are expected to be small and infrequent. No significant impacts from sludge are expected.

Comment

PGV overlooks contamination possibilities from reinjection wells - Are there absolutely no scenarios of reinjection well casing breakage or leakage? SC feels there should be monitoring and concurs with Department of Health (letter from Lewin to Patterson 4/3/87) stating that there should be a minimum of 3

monitoring wells per liquid or gas injection well. In consultation with DOH, PGV should decide on factors involved in locating monitoring wells.

Reply #35

DOH recommended monitoring wells when noncondensable gases were to be injected into the geothermally-contaminated groundwater aquifer. PGV has since changed its injection design. Noncondensable gases and all liquids will be injected into the geothermal reservoir beneath the cap rock. No monitoring wells are deemed necessary due to the relatively small volume of injectate, the "closed system" nature of the injection loop, and the natural geothermal fluid leakage which has contaminated the overlying aquifer to the point of being unusable as a drinking water source. The injection well will be protected with a hangdown string inside the 9-5/8-inch casing. The operating parameters of the injection process, such as injectate chemistry, pressure, temperature and flowrate will be closely monitored. This procedure will provide an early warning in the event of a malfunction as well as information on the efficiency of the process.

Comment

SC concurs with DOH that "a geothermal signature to groundwater does not necessarily render the water unfit for human consumption." Ibid. Also, it could be used for agriculture or livestock.

Reply #36

A geothermal signature to the groundwater does not necessarily render the water unfit for human consumption, but the strength of the signature determines whether the water is marginal or unsuitable for any use. Most of the groundwater samples to date fall closer to the second classification than the first. This contrasts sharply with the very fresh groundwater that can be found outside the LERZ and is consistent with the reliance on catchment water by residents in the area. In a few cases the marginal water can be used in agriculture, but the high chloride and other mineral content of the water generally rules out this application as well. As geothermal fluid leakage occurs from the reservoir, the area immediately above the leakage point(s) are the most contaminated and are generally unusable for any purpose. As this water migrates and mixes with fresher water, the "geothermal signature" becomes less intensified. No fresh water has been found in the project site area or hydraulically down gradient.

Comment

Water quality monitoring after decommissioning is important. We suggest an escrow account be created so that monitoring can be funded for five or ten years after decommissioning.

Reply #37

No specific monitoring program of off site water quality is planned or is necessary under the injection scenario as proposed by PGV. As previously discussed, the reinjection of the relatively small volume of brine and process

fluids into the geothermal reservoir environment beneath the overlying seal to be reincorporated into the resource should have no significance on overlying aquifer systems. Natural leakage of geothermal fluids is occurring and will continue to occur during and after operation of the PGV facility. This leakage has and will continue to negatively impact groundwater quality of the aquifer system. No additional monitoring of this natural occurrence is or will be necessary.

Comment

While PGV should be commended for its noise abatement program developed during its exploration phase, the DEIS indicates that long term industrial noise pollution will accompany this industrial project.

Reply #38

The DEIS concluded that noise generated by the project, together with planned mitigation measures, will not significantly impact nearby residents, recreational areas, or biological resources (p. 6-49). During normal plant operation, noise levels will not be significantly higher than measured background noise levels at residences. Some short term operations will generate louder noise levels than during normal operations; however, these impacts cannot be construed as "long term industrial noise pollution."

Comment

Table 9-4 Summary of Noise Levels is Incomplete. Rupture disk events and pipeline cleaning events are missing. Worse yet, the text on Page 9-11 indicate that "Operations which are conducted 24 hours per day such as well drilling or well workovers may sometimes slightly exceed the night time levels as shown in Table 9-4. The true impacts of noise are being concealed from the public and the decision makers. This deficiency should be corrected in the revised EIS.

Reply #39

Pipeline cleanout and rupture disk event noise levels are included in Table 9-3. These events generate noise levels similar to well venting which is included in Table 9-4. The noise levels presented in the EIS are conservative since no attenuation was assumed for vegetation and terrain effects. The DEIS clearly identified and discussed noise generating activities from the project. PGV's experience and studies have indicated that noise has not and will not be a problem.

Comment

The series of figures from 6-3 to 6-14 should be revised to include short term noises. They are intrusive impacts and people do hear them.

Reply #40

Noise contours were only presented for long duration events because residents are more significantly impacted by them. However, pipe impact noise was assumed to occur 10% of the time during well drilling and well workover operations as noted on pages 6-12 and 6-16 of the DEIS. The contours were developed based on this assumption.

Comment

Incomplete noise disclosures - Well Pad E is especially troublesome because of its noise impacts on the highway and the closest residences. It was disappointing to see that Figures 6-3 to 14 do not disclose the true noise impacts on the surrounding residents and environment. Page 6-43 states that no short term noise sources were included for any of the above figures.

Reply #41

The statement on page 6-43 has been clarified to indicate that well casing placement and cementing operation noise levels are not included in Figures 6-3 through 6-14. It is not appropriate to include short-term operations in the noise contours. Pipe impact noise levels are included in these figures, as noted on pages 6-12 and 6-16 of the DEIS.

Comment

Incomplete noise impact disclosures - Lava Tree State Park normal impacts and worst case is given at 38-42 dba at southern boundary of Park, but also say that pipe impact noises will be higher; how much higher?

Reply #42

Pipe impact noise was assumed to occur 10% of the time for well drilling and well workover operations, as stated on pages 6-12 and 6-16 of the DEIS. This assumption was used to develop the noise contours and estimated noise levels at Lava Tree State Park.

Comment

Permit conditions should include phone person (not an answering machine) to contact for noise complaints. Could work with County compliance officer.

Reply #43

Typically, a noise complaint handling procedure must be submitted to the County Planning Department or the DOH prior to construction. This procedure will include the names and phone numbers of persons responsible for handling complaints.

Comment

Native Hawaiian values - The phone poll discusses on Page 10-32 included data that Hawaiians were twice as inclined to be "strongly unfavorable" to the undersea transmission cable as any other ethnic group. This may reflect the controversy surrounding geothermal development and the Pele practitioner's legal efforts to stop the desecration of their religion.

Reply #44

Your comment is noted.

Comment

Figure 8-3 Location of Residences is misleading. DEIS indicates that noise and air pollution impacts can be felt one mile and more away. Scale of 1/2 mile is insufficient; it should include a one mile radius and possibly a one and 1/2 mile radius ring.

Reply #45

Figure 8-3 was designed to identify the proximity of residences to the power plant and wellpads. A 1-mile radius has been added to the Figure.

Comment

Traffic congestion - We feel PGV underestimates the amount of traffic congestion that already exists on the overcrowded Pahoa Highway and also underestimates the hazards generated by more industrial traffic.

Reply #46

Existing traffic information at the intersection of Highway 132 and 130 has been added to the final EIS. We feel the potential hazards of the additional traffic associated with the project are adequately described in the draft EIS.

Comment

Workers training needed - Only a crew of 36 will be needed to drill wellfield, and up to 100 construction jobs. How many are estimated to be filled by imported labor?

Reply #47

It is difficult to know how many jobs will be filled by imported labor. It is likely that most or all of the drilling and construction jobs will be filled with local (Big Island) labor. If local workers have skills listed in Table 10-14, they will be eligible. Assuming skill levels are the same, a local worker will have preference over an imported laborer.

Comment

Page 2-41 states that only 19 employees will be needed for operation and maintenance of facility. We call for ways to start and fund a training program for local people to get some of these jobs.

Reply #48

Many local workers already possess the necessary skills to be hired for the project. Training will be provided on an as-needed basis, but the need for a more comprehensive program is not apparent at this time.

Comment

Page 16-3 - Transmission Line Concerns - The DHM Consultants corridor recommendations were unsatisfactory to subdivision communities. What effect will a delayed/contested corridor decision have on project?

Reply #49

An electrical transmission system is required by the project to deliver power to the utility. If a suitable system were not available, the facility would be unable to operate.

Comment

Project security lights should be shielded to prevent glare from bothering neighbors, a major sore point with residents of Cobb, a small town in Lake County, CA.

Reply #50

Site lighting will be mitigated by shielding as needed to conform with all lighting regulations.

Comment

The bleak picture presented in the noise impacts sections suggests that the Hawaiian I'o will not stay in the vicinity of industrial noises that persist over 35 years.

Reply #51

PGV believes that the Hawaiian hawk will not be adversely affected by the facility. A monitoring program of the hawk will continue throughout the life of the project. If adverse affects are observed, additional mitigation measures will be promptly taken.

Comment

We are relieved that this project is not occurring in the unique Hawaiian rain forests of Puna. The disruption to native habitats and species would have been far greater.

Reply #52

Your comment is noted.

Comment

We are concerned that the nesting and hunting hawks will relocate due to the constant industrial noises that will occur during the 35 year life of the project.

Reply #53

See Reply #51.

Comment

There is need for independent verification of industrial impacts upon bird behavior. Are the assurances stated on Page 7-20 enforceable now by County or State personnel?

Reply #54

See Reply #51.

Comment

Missing from Section 14 is any discussion of "energy conservation" as a clean alternative to building new generating capacity. Every geothermal developer should discuss this environmentally benign alternative.

Reply #55

A discussion of energy conservation has been added to Section 14 of the final EIS.

Comment

Section 12 Aesthetics analyzes visual impact, but does not give heights or elevations of towers, buildings. Height of building turbine is not yet set, but must accommodate 30 foot interior ceiling, Page 2-36.

Reply #56

The final EIS has been modified to incorporate this comment.

Comment

While the DEIS states that there will be 40 foot high cooling towers (Page 2-37) near the top of Puu Honuaula (which stands 150 feet above the surrounding land), DEIS does not disclose that steam plumes can often reach 200 feet above the cooling towers. (Contested Case Testimony Kahaualea's Geothermal Project.)

Reply #57

Steam plumes produced by operation of the facility will not normally be visible due to the warm temperatures and average humidity conditions that exist in the Puna region. Visibility increases as the ambient temperature declines and humidity increases. It is highly unlikely that steam plumes would reach 200 feet above the cooling towers, but under certain weather conditions this is possible.

We thank you for your interest in our project.

Sincerely,

Ralph A. Patterson, Jr.
Hawaii Project Manager

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University of Hawaii at Manoa

Environmental Center
Crawford 317 • 2550 Campus Road
Honolulu, Hawaii 96822
Telephone (808) 948-7361

September 21, 1987
RE:0471

Mr. Albert Lono Lyman, Director
Planning Department
County of Hawaii
25 Aupuni Street
Hilo, Hawaii 96720

Dear Mr. Lyman:

Draft Environmental Impact Statement (EIS)
Puna Geothermal Venture Project
Puna, Hawaii

This project proposes the building of a 25 megawatt geothermal electric plant in the Puna District near the Lower East Rift Zone of the Kilauea volcano. The proposed project is located on approximately 500 acres within the Kapoho Geothermal Resource Subzone. Legislation passed in 1983, directed the Board of Land and Natural Resources (BLNR) to designate subzones. In areas designated as geothermal subzones, the BLNR has determined that the positive economic and social benefits of the development outweigh the potential negative environmental and social impacts. This review was conducted with the assistance of Anders Daniels and Thomas Schroeder, Meteorology; P. Bion Griffin, Anthropology; Edwin Murabayashi, Henry Gee, and Y.S. Fok, Water Resources and Research Center; Roy Takekawa, Environmental Health and Safety; Donald Thomas, Hawaii Institute of Geophysics; and Steven Armann, Environmental Center.

General Comments

Our reviewers noted both general and specific concerns in a variety of areas. The Executive Summary should include broader discussions of anticipated impacts, mitigation plans and irreversible commitment of resources. In addition, the summary could be improved with inclusion of some assessment of comparative impacts of the considered alternatives.

We feel that the Draft EIS has not adequately addressed the impacts of silica precipitation occurring in the system. Further discussion of silica precipitation in the separator and in the lines, including estimates of the quantity of precipitate and expected effects on injection, should be provided.

Please note that a review of the air quality section of the Draft EIS was conducted at our request by the UH Meteorology Department, and is attached as an addendum to this review.

Specific Comments

The following comments and questions relate to specific page references in the Draft EIS:

Page 1-4 indicates the acreage for the Kapoho Geothermal Resource Subzone as 6,800 and on page 13-7 acreage is listed at 8,600.

Page 2-5. The steam condensate compositions given reflect the amount of brine carry-over from the steam/brine separator and hence will only be a function of the efficiency of the power plant separator design. As such, the non-volatile elements or ions should be included in the steam condensate analysis or should not be included only with an appropriate explanation or design requirement.

Page 2-25. Experience at the HGP-A facility indicates that the use of a caustic/peroxide abatement system is not warranted for removal of H_2S from the steam phase: the increase in scrubbing efficiency is minimal, less than 5 percent, and the increase in the personnel hazard associated with the transportation, storage and use of peroxide is substantial.

Page 2-28. The gas abatement system that is proposed has not been tested or proven in commercial application. More data are necessary to validate the reliability and the H_2S removal efficiency of this design.

Page 2-30. How "unlikely" an event is the malfunction of the primary system, and on what data is that assessment based?

Page 2-31. Abatement of H_2S in the cooling tower would be much more effective if the pH control of the circulating water were maintained at pH8 or above. Control of pH in the cooling tower should also be a normal design requirement of the cooling tower in order to minimize corrosion.

Page 2-38. Same comment as above re: caustic/peroxide abatement system.

Page 4-13. Comments regarding the relative volumes of recharge and geothermal brine to be disposed of at the surface should be backed up with some quantitative data.

Page 4-15. Although there is ample evidence that the groundwater in the basal lens along the east rift zone is heavily contaminated with natural geothermal discharges, it would help to make the case if groudwater data were presented to validate contentions that no fresh water exists beneath or downgradient of the project site.

Page 5-1. Control of pH of the cooling tower should be able to reduce the H_2S emissions levels well below those listed (presumed that the primary system operates according to their projected efficiencies). BACT would seem to require the use of such control since it is a proven method of abatement and its costs are not excessive.

Page 5-12. The listed limitation on maximum ambient H_2S levels is only part of the proposed DoH standards; an incremental standard also limits the increase in H_2S to less than 35ug/m^3 above prevailing background which would be less than a maximum of about 40 ug/m^3.

Page 5-24. The comments regarding the background concentrations of sulfide and the increments associated with production are not clear. The entire section on modeling of H_2S emissions and impacts seems confused and is not particularly informative. A clearer presentation of the assumptions and conditions for the modeling would be very helpful in understanding how often maximum concentrations are likely to occur, where they are likely to occur, and whether additional considerations or methods could be applied to minimize the impacts on the community.

Page 5-28. Calculations of the radon concentrations should be presented; this is especially true since the radon concentrations are presented in pCi/l for both liquid and gas phases and it is not clear whether the conversion of one to the other was done properly. Does the concentration of radon at the cooling tower refers to intake or output?

Page 5-31. The caustic effluent from the SO_2 scrubber will be sodium bisulfite and sulfite, not bisulfate and sulfate.

Page 5-32. Radon 222 monitoring at the Woods Site will be upwind of the facility; if radon monitoring is going to be done it should be done downwind. The state has made a commitment to TPC to decommission HGP-A when the TPC plant goes on-line; how will this affect the fenceline H_2S monitoring station?

Page 6-43. What are the predicted noise contours for well venting? These should be included if other contours are presented.

Page 6-46. Can the discharge line for rupture disk events be vented to the rock muffler so that the noise levels from these events can be reduced?

Page 14-3. The comparison of pollutant emissions for geothermal versus other generation technologies (Table 14-2) is useful, but the statement that the numbers listed for pollutants represent conditions for which no pollution control equipment is used is incorrect: H_2S emissions from geothermal, given as SO_2, would be much higher if this were the case. In our opinion, emissions rates for all technologies should be presented on the basis of those that would be permitted under current regulations.

Page 14-39. What is the basis for the projected efficiency for the H_2S absorber unit?

Thank you for the opportunity to comment on this Draft EIS. We hope our comments and questions will help in preparing the final document.

Yours truly,

John T. Harrison
Environmental Coordinator

cc: L. Stephen Lau
Ralph A. Patterson,
Thermal Power Company
OEQC
Anders Daniels
Henry Gee
P. Bion Griffin
Y.S. Fok
Edwin Murabayashi
Thomas Schroeder
Roy Takekawa
Donald Thomas
Steven Armann

UNIVERSITY OF HAWAII

Honolulu, Hawaii 96822

October 2, 1987

MEMORANDUM

TO: Albert Lono Lyman, County of Hawaii
Relph A. Patterson, Thermal Power Co.
Office of Environmental Quality Control
L. Stephen Lau
Anders Daniels
Henry Gee
P. Bion Griffin
Y.S. Fok
Edwin Murabayashi
Thomas Schroeder
Roy Takekawa
Donald Thomas
Steven Armann

FROM: Environmental Center

SUBJECT: Draft Environmental Impact Statement
Puna Geothermal Venture Project
Puna, Hawaii

Please include the enclosed review of air quality by Anders Daniels and Thomas Schroeder to our letter of September 21, 1987 to Mr. Albert Lono Lyman regarding the Puna Geothermal Venture Project DEIS. Thank you.

An Equal Opportunity Employer

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OCT - 6 1987

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Review of Air Quality Section of

Draft Environmental Impact Statement
Thermal Power Company
Puna Geothermal Venture Project

by

Anders Daniels, Ph. D.
Thomas Schroeder, Ph. D.

The Air Quality Section of above document (Chapter 5) was prepared using strictly EPA recommended models and wind data from a site near the project. The discussion of local weather is liberally borrowed from a somewhat dated publication on climates of the United States. There are no indications the preparers have any in situ knowledge of the climate near their development site. They evidently think that inserting wind data into an EPA recommended model is all that is required assuming that the model covers all site and weather conditions. They fail to realize that the EPA models are only recommended models for average conditions and simple terrain (even though the model used is called COMPLEX) and that the models are not a substitute for a professional survey of actual meteorological conditions.

If the preparers had conducted such a survey they would have found that the most adverse condition from a diffusion point of view is a stagnation of the night time drainage flow during moderate to strong trade winds. Such a stagnation is relative common and can, at the site in question, last for four to eight hours. The air stratification under this condition is very stable and the air movement very weak. Obviously the EPA model used does not cover this situation. If e.g. steam stacking was to occur during this condition lasting for four hours with a mean wind speed of 0.5 mph the concentrations one mile away would be about 600 ppb as compared with the preparers estimate of 24 ppb. For production the corresponding value is about 125 ppb compared to the EIS estimate of 6 ppb. The proposed Hawaii AQS is 25 ppb.

There are several other erroneous statements in the report but we do not elaborate on them here as obviously the whole air quality section is totally inadequate and must not be approved. Higher abatement percentages might well be required.

Diamond Shamrock
Thermal Power Company

Ralph A. Patterson, Jr.
Hawaii Project Manager

November 16, 1987

Mr. John T. Harrison
Environmental Coordinator
Environmental Center
University of Hawaii at Manoa
Crawford 317
2550 Campus Road
Honolulu, Hawaii 96822

Dear Mr. Harrison:

Thank you for your letter of September 21, 1987 expressing comments on the Puna Geothermal Venture Project's Draft Environmental Impact Statement.

Your concerns are addressed below:

Comment

The Executive Summary should include broader discussions of anticipated impacts, mitigation plans and irreversible commitment of resources. In addition, the summary could be improved with inclusion of some assessment of comparative impacts of the considered alternatives.

Reply #1

The Executive Summary of the final Environmental Impact Statement (EIS) will include a broader discussion of the environmental setting, anticipated impacts, and mitigation measures that are detailed in the body of the document. Other significant details from the report have been be included in the Executive Summary.

Comment

We feel that the Draft EIS has not adequately addressed the impacts of silica precipitation occurring in the system. Further discussion of silica precipitation in the separator and in the lines, including estimates of the quantity of precipitate and expected effects on injection, should be provided.

Reply #2

Kindle, et al., in Geothermal Injection Treatment: Process Chemistry, Field Experiences, and Design Options, 1984, developed a methodology to calculate silica precipitation rates (scaling) in aboveground piping. Using this method

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to calculate potential silica scaling rates at the Puna Geothermal Venture (PGV) site suggests that a maximum buildup of about 2 millimeters per year could occur. This equates to about 0.5 inches in a six year period, which would not threaten the operations of the PGV plant. Should silica scale progress to the point of significantly restricting piping diameters, pipes would be cleaned periodically by chemical or mechanical means. An additional discussion of silica has been included in the final EIS.

Comment

Page 1-4 indicates the acreage for the Kapoho Geothermal Resource Subzone as 6,800 and on Page 13-7 acreage is listed at 8,600.

Reply #3

The discrepancy noted is a typographical error that should have been 6,800 acres.

Comment

Page 2-5. The steam condensate compositions given reflect the amount of brine carry-over from the steam/brine separator and hence will only be a function of the efficiency of the power plant separator design. As such, the nonvolatile elements or ions should be included in the steam condensate analysis or should not be included only with an appropriate explanation or design requirement.

Reply #4

The data presented in Table 2-1 is a composite chemical analysis of steam condensate samples collected downstream of the separators of four different wells. All separators have some carryover of the liquid phase to the steam which contributes to nonvolatile components in the steam composition, but particulate carryover is also a factor. It would be inappropriate to exclude this composition data, and somewhat confusing, to identify the reasons that nonvolatile components are found in the steam phase. Steam utilized in the facility is expected to have a composition similar to the data presented.

Comment

Page 2-25. Experience at the HGP-A facility indicates that the use of a caustic/peroxide abatement system is not warranted for removal of H_2S from the steam phase; the increase in scrubbing efficiency is minimal, less than 5 percent, and the increase in the personnel hazard associated with the transportation, storage and use of peroxide is substantial.

Page 2-38. Same comment as above regarding caustic/peroxide abatement system.

Reply #5

PGV would prefer not to use hydrogen peroxide for the reasons noted in the comment; however, at this time it is felt that information is inconclusive on the scrubbing efficiency. Other commentors feel the 5 percent decrease would be significant, and the use of peroxide is standard in many parts of the

Geysers. Until more information is available, PGV will continue to include peroxide in the development plans.

Comment

Page 2-28. The gas abatement system that is proposed has not been tested or proven in commercial application. More data are necessary to validate the reliability and the H_2S removal efficiency of this design.

Page 2-30. How "unlikely" an event is the malfunction of the primary system, and on what data is that assessment based?

Reply #6

The process of absorption has been demonstrated in many different industries, and the reinjection of noncondensable gases is the installed H_2S abatement system at the recently completed Coso Hot Springs geothermal facility in California. The proposed design for Puna is somewhat different than Coso, but the concept is basically the same. PGV would like to build a pilot absorber demonstration model to verify the theoretical modelling results and has been awarded funding from The Department of Business and Economic Development to conduct such a test.

The reliability of the absorption/reinjection system is primarily a function of design. Equipment design, materials selection, and mechanical equipment redundancy are key components influencing reliability of the system, and good engineering judgement can produce a system that is unlikely to fail. Quantifying the term "unlikely" is difficult without operating experience which is why PGV has chosen to install the back-up burner scrubber. The reliability of the backed up PGV facility to effectively abate H_2S emissions is therefore very high.

Comment

Page 2-31. Abatement of H_2S in the cooling tower would be much more effective if the pH control of the circulating water were maintained at pH 8 or above. Control of pH in the cooling tower should also be a normal design requirement of the cooling tower in order to minimize corrosion.

Page 5-1. Control of pH of the cooling tower should be able to reduce the H_2S emissions levels well below those listed (presuming that the primary system operates according to their projected efficiencies). BACT would seem to require the use of such control since it is a proven method of abatement and its costs are not excessive.

Reply #7

Computer modeling of H_2S in the condensate after adjusting for pH indicates that convection mass transfer dominates the solubility equilibrium and releases H_2S to the environment. There are methods to chemically treat the H_2S in the condensate, but the BACT analysis concluded that a surface condenser with natural oxidation is the BACT.

Comment

Page 4-13. Comments regarding the relative volumes of recharge and geothermal brine to be disposed of at the surface should be backed up with some quantitative data.

Reply #8

The statement on Page 4-13 concerning the relative volume of brine discharged during a flow test compared to the large volume of existing degraded groundwater should be sufficient. The average recharge infiltrating the groundwater is quantified on Page 4-5 as 4,440 acre-ft/yr/mi^2. The brine flow rate from the full 30 MW facility is listed as 280 gpm on Page 2-31. The flow of one well over 10 days is insignificant.

Comment

Page 4-15. Although there is ample evidence that the groundwater in the basal lens along the east rift zone is heavily contaminated with natural geothermal discharges, it would help to make the case if groundwater data were presented to validate contentions that no fresh water exists beneath or downgradient of the project site.

Reply #9

The groundwater data is contained in the referenced report (Iovenitti, 1986) and is briefly summarized on Page 4-10. The conclusions of the report are also presented graphically in Figure 4-3. It is more appropriate to confine the detailed analysis of local groundwater to the report and only summarize the conclusions in the EIS, particularly since there is very little dispute concerning the conclusions.

Comment

Page 5-12. The listed limitation on maximum ambient H_2S levels is only part of the proposed DOH standards; an incremental standard also limits the increase in H_2S to less than 35 ug/m^3 above prevailing background which would be less than a maximum of about 40 ug/m^3.

Reply #10

The comment is correct; however, in the context of the discussion on Page 5-12, only the maximum ambient level is appropriate. The discussion relevant to the incremental standard is contained on Page 5-24 of the draft EIS.

Comment

Page 5-24. The comments regarding the background concentrations of sulfide and the increments associated with production are not clear. The entire section on modeling of H_2S emissions and impacts seems confused and is not particularly informative. A clearer presentation of the assumptions and conditions for the

modeling would be very helpful in understanding how often maximum concentrations are likely to occur, where they are likely to occur, and whether additional considerations or methods could be applied to minimize the impacts on the community.

Reply #11

The discussion on Page 5-24 was only trying to make the point that emissions from the project during normal operation and steam stacking meet the incremental standards. Normal operation and steam stacking also meet the background ambient standard even when the highest recorded background observation is included. The text of the final EIS has been simplified.

PGV and its consultant, Fluor Corporation, have tried to present the assumptions used throughout the document as clearly and accurately as possible. Air modeling is very complex, and a wide variety of assumptions must be made for many different events. Furthermore, the regulations for events can vary. In summary, one years worth of site weather data was used as input to U.S. Environmental Protection Agency (EPA) approved pollution dispersion models. The results for normal operation and steam stacking are below the 1-hour incremental and ambient H_2S standards in the proposed regulations. The locations of maximum H_2S ground level concentrations during normal operation and steam stacking are presented in the final EIS.

A BACT analysis was performed to determine the most effective way to minimize H_2S emissions from the facility. The selected process, reinjection, was the only alternative which provided a full backup system (i.e., the burner/scrubber). Therefore, the selected H_2S abatement system is considered the best method to minimize H_2S impacts on the community.

Comment

Page 5-28. Calculations of the radon concentrations should be presented; this is especially true since the radon concentrations are presented in pCi/l for both liquid and gas phases and it is not clear whether the conversion of one to the other was done properly. Does the concentration of radon at the cooling tower refer to intake or output?

Reply #12

The parameters used in the calculation of radon concentrations have been included in Section 5 of the final EIS. The concentration in the geothermal fluids is in picocuries per liter of steam condensate, while the emission in the cooling tower plume is in picocuries per liter of air.

Comment

Page 5-31. The caustic effluent from the SO_2 scrubber will be sodium bisulfite and sulfite, not bisulfate and sulfate.

Reply #13

Thank you for catching this error. It has been corrected in the final EIS.

Comment

Page 5-32. Radon 222 monitoring at the Woods Site will be upwind of the facility; if radon monitoring is going to be done, it should be done downwind. The state has made a commitment to TPC to decommission HGP-A when the TPC plant goes on-line; how will this affect the fenceline H_2S monitoring station?

Reply #14

The location of the radon monitor was incorrectly identified. It is located at the Schroeder site and there are no plans to move it at this time. It is difficult to speculate at this time on the future of the fenceline monitor at HGP-A. It could remain there after decommissioning, it could be relocated, or it could be replaced.

Comment

Page 6-43. What are the predicted noise contours for well venting? These should be included if other contours are presented.

Reply #15

Noise contours were only presented for long duration events because residents are more significantly impacted by them. Although well venting is a particularly noisy operation, residents will be notified in advance of this short duration event. Therefore, noise contours for well venting were not included.

Comment

Page 6-46. Can the discharge line for rupture disk events be vented to the rock muffler so that the noise levels from these events can be reduced?

Reply #16

The rupture disks on the main steamline will have the lowest set point (i.e., will be most likely to rupture first) and discharge to the plant rock muffler. However, it is not practical to pipe every rupture disk at each wellpad and from each pressure vessel to a rock muffler.

Comment

Page 14-3. The comparison of pollutant emissions for geothermal versus other generation technologies (Table 14-2) is useful, but the statement that the numbers listed for pollutants represent conditions for which no pollution control equipment is used is incorrect: H_2S emissions from geothermal, given as SO_2, would be much higher if this were the case. In our opinion, emissions rates for all technologies should be presented on the basis of those that would be permitted under current regulations.

Reply #17

The comment is correct, and the emissions figures for the alternatives in Table 14-2 have been adjusted to more accurately reflect those at a facility that would be permitted under current regulations.

Comment

Page 14-39. What is the basis for the projected efficiency for the H_2S absorber unit?

Reply #18

Dr. J.M. Prausnitz at U.C. Berkeley developed a computer program based on the thermodynamic model developed at Pitzer. Thermal Power Company's consultant, Fluor Corporation, adapted the program (named TIDES) and used this program to estimate the efficiency of the absorber unit. An allowance has been included; however, a pilot demonstration would be useful in confirming these results. Such a demonstration has been approved for funding by the Department of Business and Economic Development.

Comment

The Air Quality Section of above document (Chapter 5) was prepared using strictly EPA recommended models and wind data from a site near the project. The discussion of local weather is liberally borrowed from a somewhat dated publication on climates of the United States. There are no indications the preparers have any in situ knowledge of the climate near their development site. They evidently think that inserting wind data into an EPA recommended model is all that is required, assuming that the model covers all site and weather conditions. They fail to realize that the EPA models are only recommended models for average conditions and simple terrain (even though the model used is called COMPLEX) and that the models are not a substitute for a professional survey of actual meteorological conditions.

If the preparers had conducted such a survey, they would have found that the most adverse condition from a diffusion point of view is a stagnation of the night time drainage flow during moderate to strong trade winds. Such a stagnation is relative common and can, at the site in question, last for four to eight hours. The air stratification under this condition is very stable and the air movement very weak. Obviously, the EPA model used does not cover this situation. If, e.g., steam stacking was to occur during this condition lasting for four hours with a mean wind speed of 0.5 mph, the concentrations one mile away would be about 600 ppb as compared with the preparers estimate of 24 ppb. For production the corresponding value is about 125 ppb compared to the EIS estimate of 6 ppb. The proposed Hawaii AQS is 25 ppb.

There are several other erroneous statements in the report, but we do not elaborate on them here as obviously the whole air quality section is totally inadequate and must not be approved. Higher abatement percentages might well be required.

Reply #19

The use of air dispersion models for estimating pollutant concentrations is addressed in the Hawaii Air Pollution Control Rules (Hawaii Administrative Rules, Section 11-60-17). The rule states that all required estimates of ambient concentrations shall be based on the applicable air quality models, data bases and other requirements specified in the "Guideline on Air Quality Models" (U.S. EPA, Office of Air Quality Planning and Standards, Research Triangle Park, N.C. 27711, No. EPA-450/2-78-027R, Revised July 1986).

As stated on page 5-5 of the DEIS, meteorology and air quality monitoring studies have been conducted in the Puna region since 1981. Tables summarizing recent monthly average observations at the Woods Site have been included in the final EIS.

The EPA approved models are designed to produce typically conservative results; therefore, the predicted ground level concentrations for the PGV project should be higher than actual concentrations from the operating facility. A valid and adequate discussion of the environmental setting, analysis of air quality impacts, and determination of mitigation measures is included in the EIS.

We thank you for your interest in our project.

Sincerely,

Ralph A. Patterson

Ralph A. Patterson, Jr.
Hawaii Project Manager

RAP:os
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Section 19

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APPENDIX A

NOISE MONITORING INSTRUMENTATION AND PROCEDURE

INSTRUMENTATION

The noise monitoring systems consisted of Metrosonics, Model dB-604, programmable sound level analyzers, each equipped with an Electret condenser microphone, microphone preamplifier, microphone windscreen, and an anemometer wind sensor. A portable digital printer was used to retrieve the data from the monitor after each 24-hour measurement period. An octave band sound level analyzer was also used to sample the ambient noise levels during each test period. Each measuring system was calibrated daily. Instrumentation is listed in Table A-1.

PROCEDURE

A functional check was performed on all measuring systems prior to the start of the noise monitoring survey. A field calibration, using a Gen Rad 1986 sound level calibrator set to 94 dB at 1,000 Hz, was performed on each monitoring system before and after each monitoring period.

After the monitors were programmed and positioned at the selected monitoring locations, the microphones and preamplifiers were weatherproofed for protection against adverse weather conditions, and a windscreen was placed on each microphone to reduce the effects of wind on the noise measurements. The wind anemometer was set to inhibit data collection when the wind speed exceeded 12 mph. The microphone systems and anemometers were placed between 6 and 7 feet above ground on either a tripod or a post.

Table A-1

INSTRUMENTATION

Noise Monitoring Systems

Quantity	Description
2	Metrosonics Model dB-604 Sound Level Analyzer S/N 1068 and S/N 1071
2	Gen Rad 1961-9610 1-inch Electret Condenser Microphone S/N 10311 and S/N 10207
2	Gen Rad 1560-P42 Microphone Preamplifier S/N 5886 and S/N 4450
2	Metrosonics WS 603 Anemometer Wind Sensor
2	Gen Rad 1560-7553 Microphone Wind Screen
1	Metrosonics dB-421 Portable Digital Printer
1	Gen Rad 1986 Omnical Sound Level Calibrator S/N 00108

Octave Band Sound Level System

Quantity	Description
1	Bruel & Kjaer 2215 Precision Sound Level Meter/Octave Analyzer S/N 726052
1	Bruel & Kjaer 4165 1/2 in. Condenser Microphone S/N 682550
1	Bruel & Kjaer UA 0237 Microphone Wind Screen

APPENDIX B

MAJOR ARCHEOLOGICAL STUDIES OF THE PUNA DISTRICT

DATE	RESEARCHER	DESCRIPTION
1906	J. F. G. Stokes	A survey of the religious structures of Hawaii. Stokes recorded two heiau in the Puna District.
1907	T. G. Thrum	Description of Kukii Heiau, in Kapoho and its construction.
1930-1932	A. E. Hudson	Conducted archeological reconnaissance survey on the east coast of Hawaii. Hudson's record provides good general information on the Puna area and was the most comprehensive survey of Puna at that time.
1959	K. P. Emory	Staff of the Bishop Museum conducted research on the natural and cultural history of the Kalapana extension of Hawaii Volcanoes National Park. Although the report does not cover the Kapoho area, it does provide good information on the land and traditional history of the Puna District.
1965	C. Smart	Staff of the Bishop Museum conducted further archeological research for the Hawaii Volcanoes National Park, south of the study area.

APPENDIX B (continued)

DATE	RESEARCHER	DESCRIPTION
1965	E. J. Ladd	Conducted salvage archeology along the Chain of Craters right-of-way, Hawaii Volcanoes National Park.
1966-1968	V. Hansen	Conducted archeological surveys in the Puna area, and recorded, mapped, and located numerous sites for the district.
1970	V. Loo and W. Bank	Compiled inventory of historical sites in the northern portion of the Island of Hawaii, with a good review of the Puna District.
1971	N. Crozier and D. Barrere	Staff of the Bishop Museum conducted archeological and historical surveys of Pualaa, Puna.
1971	W. Barrera and D. Barrere	Staff of Bishop Museum conducted archeological and historical surveys of Kapahua, Puna.
1972	R. Bevacqua and T. Dye	Staff of Bishop Museum conducted archeological reconnaissance of the proposed Kapoho to Kalapana Highway. A good description of the known sites of Kapoho.

APPENDIX B (concluded)

DATE	RESEARCHER	DESCRIPTION
1973	N. Ewart and M. Luscomb	Staff of Bishop Museum conducted archeological reconnaissance of the proposed Kapoho to Keaukaha Highway. A listing of sites to the north of Kapoho.
1974	F. Ching	Archeological Research Center Hawaii conducted archeological reconnaissance south of Kapoho at Kaimu, Puna.
1976	S. Palama	Archeological Research Center Hawaii conducted further research in Kaimu and Kalapana, Puna.
1982	M. Yent	Conducted archeological reconnaissance of part of the Nanawale Forest Reserve (makai portion) north of Kapoho.
1982	J. Kennedy	Conducted literature search for known sites in Kahaualea, Puna.

APPENDIX C

PLANT SPECIES CHECKLIST

Puna Geothermal Ventures Studies, Char and Stemmermann, 1984

Families are arranged within each of three groups: Ferns and Fern Allies, Monocotyledons, and Dicotyledons. Taxonomy and nomenclature of Ferns and Fern Allies follow Lamoureaux's unpublished checklist of Hawaiian ferns; taxonomy and nomenclature of the flowering plants (Monocotyledons and Dicotyledons) follow St. John (1973).

For each species the following information is provided:

1. Scientific name with author citation.

2. Common English or Hawaiian name, when known.

3. Biographic status of the species. The following symbols are employed:

   E = endemic = native to the Hawaiian Islands only, not occurring naturally elsewhere.

   I = indigenous = native to the Hawaiian Islands and also to one or more other geographic areas.

   P = Polynesian = plants of Polynesian introduction; all those plants brought by the Polynesian immigrants prior to contact with the Western world.

   X = exotic or introduced = not native to the Hawaiian Islands; brought here by man accidentally or deliberately after Western contact.

4. Vegetation types. Nine major vegetation types are recognized within the study area. The number heading each of the columns refers to the following vegetation types:

1 = Cultivated Areas

2 = Fallow Fields

3 = Closed Metrosideros Forest

4 = Open Metrosideros Forest

5 = Open Metrosideros-Lichen Forest

6 = Open Metrosideros-Diospyros Forest

7 = Open Metrosideros-Psidium Forest

8 = Mixed Forest

9 = Scrub

Within each of the vegetation type columns the relative abundance of each species (or absence) is given. These ratings are based entirely upon a comparison of the frequency with which a species occurs, as compared to all other species, within the study area. It does not necessarily denote the abundance of that particular species in the Hawaiian Islands. The following symbols for relative abundance are used:

A = abundant = generally the major or dominant species in a given vegetation type.

C = Common = generally distributed throughout a given vegetation type in large numbers.

L = locally common = found only or principally in one or more restricted areas, although within that area it may occur in large numbers.

O = occasional = generally distributed throughout a major portion of a given vegetation type, but in small numbers.

U = uncommon = observed infrequently but more than 10 times in a given vegetation type.

R = rare = observed 1 to 10 times in a given vegetation type.

TAXA	COMMON NAME	STATUS	1	2	3	4	5	6	7	8	9
FERNS AND FERN ALLIES											
ADIANTACEAE											
Adiantum raddianum Presl	Maiden-hair fern	X	-	-	R	-	-	-	R	-	-
ASPLENIACEAE											
Asplenium falcatum Thunb.		I	-	-	U	-	-	-	-	-	-
Asplenium nidus L.	'Ekaha, bird's-nest-fern	I	-	-	U	-	-	R	U	U	-
ATHYRIACEAE											
Athyrium sandwichianum Presl	Hoio	E	-	-	O	-	-	R	U	R	R
BLECHNACEAE											
Blechnum occidentale L.	Blechnum	X	-	-	U	-	-	-	U	-	-
Sadleria cyatheoides Kaulf.	'Ama'uma'u	E	-	-	-	O	U	R	O	U	R
DENNSTAEDTIACEAE											
Microlepia strigosa (Thunb.) Presl	Palapalai, palai	I	-	-	R	-	-	-	U	-	-
DICKSONIACEAE											
Cibotium chamissoi Kaulf.	Hapu'u 'i'i	E	-	-	O	U	-	O	O	-	R
Cibotium glaucum (J.Sm.) H. & A.	Hapu'u	E	-	-	C	U	-	C	C	O	R

TAXA	COMMON NAME	STATUS	1	2	3	4	5	6	7	8	9
ELAPHOGLOSSACEAE											
Elaphoglossum crassifolium (Gaud.) Ander. & Crosby	'Ekaha	E	-	-	U	-	-	R	O	-	-
GLEICHENIACEAE											
Dicranopteris emarginata (Brack.) W.J. Robin.	'Uluhe, false staghorn fern	E	-	-	O	A	R	O	O	O	C
GRAMMITACEAE											
Adenophorus tamariscinus (Kaulf.) H. & Grev.	Wahine-noho-mauna	E	-	-	R	-	-	-	R	-	-
HEMIONITIDACEAE											
Pityrogramma calomelanos (L.) Link	Gold fern, silver fern	X	O	O	-	-	R	-	U	-	O
HYMENOPHYLLACEAE											
Gonocormus minutus (Blume) V.D. Bosh		I	-	-	R	-	-	-	-	-	-
Mecodium recurvum (Gaud.) Copel.	'Ohi'a-ku	E	-	-	R	-	-	-	R	-	-
Vandenboschia cyrtotheca (Hbd.) Copel.	Kilau	E	-	-	O	-	-	R	O	-	-

TAXA	COMMON NAME	STATUS	1	2	3	4	5	6	7	8	9
LINDSAEACEAE											
Sphenomeris chinensis (L.) Maxon	Pala'a	I	-	-	R	U	R	O	O	O	U
LYCOPODIACEAE											
Lycopodium cernuum L.	Wawae-iole	I	-	-	-	O	-	R	O	O	U
Lycopodium phyllanthum H. & A.	Wawae-iole	I	-	-	U	-	R	R	U	-	-
NEPHROLEPIDACEAE											
Nephrolepis cordifolia (L.) Presl	'Okupukupu	I	-	-	U	R	-	-	O	-	-
Nephrolepis exaltata (L.) Schott	Pamoho	I	-	-	O	U	-	-	O	O	-
Nephrolepis multiflora (Roxb.) Jarrett ex Morton	Hairy swordfern	X	-	-	-	U	A	-	C	O	O
OPHIOGLOSSACEAE											
Ophioglossum pendulum L.	Lau-kahi	I	-	-	O	R	-	O	O	O	-
POLYPODIACEAE											
Phymatosorus scolopendria (Burm.) Pichi Sermolli	Lau'ae	X	-	-	R	-	R	-	O	U	U
Pleopeltis thunbergiana Kaulf.	'Ekaha-'akolea	I	-	-	O	-	R	O	O	O	-
Polypodium pellucidum var. volcanicum Skottsb.	A'e	E	-	-	-	-	O	-	-	-	-

TAXA	COMMON NAME	STATUS	1	2	3	4	5	6	7	8	9
PSILOTACEAE											
Psilotum complanatum Sw.	Moa	I	-	-	R	-	-	-	U	-	-
Psilotum nudum (L.) Beauv.	Moa	I	-	-	O	R	R	-	O	O	-
PTERIDACEAE											
Pteris vittata L.	Kilau-o-pueo	X	-	-	-	-	U	-	-	-	U
SELAGINELLACEAE											
Selaginalla arbuscula (Kaulf.) Spring	Lepelepa-a-moa	E	-	-	U	-	-	R	U	-	-
THELYPTERIDACEAE											
Christella cyatheoides (Kaulf.) Holtt.	Kikawaio	E	-	-	U	-	-	-	-	-	-
Christella dentata (Forsk.) Brownsey & Jermy	Oak fern	X	-	O	O	R	-	O	C	O	O
Christella parasitica (L.) Levl.	Oak fern	X	-	-	-	-	-	-	O	-	-
Macrothelypteris torresiana (Gaud.) Ching		X	-	-	U	-	-	-	-	-	-
VITTARIACEAE											
Vittaria elongata Sw. (s.l.)	'Ohe'ohe	I	-	-	O	-	-	R	O	U	-

TAXA	COMMON NAME	STATUS	1	2	3	4	5	6	7	8	9
MONOCOTYLEDONS											
ARACEAE											
Colocasia esculenta var. antiquorum (Schott) Hubb. & Rehd.	Taro, kalo	P	U	-	R	-	-	-	-	R	R
Monstera deliciosa Liebm.	Monstera	X	-	-	-	-	-	-	-	R	-
Scindapsus aureus (Lind. ex Andre') Engl.	Taro vine	X	-	-	-	-	-	-	R	R	-
Syngonium auritum (L.) Schott	Syngonium	X	-	-	-	-	-	-	-	-	R
BROMELIACEAE											
Ananas comosus (Stickm.) Merr.	Pineapple, hala-kahiki	X	R	-	-	-	-	-	-	-	-
COMMELINACEAE											
Commelina diffusa Burm. f.	Honohono	X	-	O	-	-	-	-	O	O	O
CYPERACEAE											
Cyperus brevifolius (Rottb.) Hassk.	Kyllinga, kili'o'opu	X	O	U	-	-	-	R	-	-	O
Cyperus haspan L.		X	-	-	-	-	-	-	-	-	U
Cyperus javanicus Houtt.	'Ahu'awa, 'ehu'awa	I?	R	-	-	-	-	-	-	-	-
Cyperus polystachyus var. texensis (Torr.) Fern		I	-	-	-	-	-	-	-	-	R
Fimbristylis dichotoma (L.) Vahl	Tall fringe rush	I	O	-	-	-	-	-	-	-	O

TAXA	COMMON NAME	STATUS	1	2	3	4	5	6	7	8	9
CYPERACEAE (continued)											
Machaerina angustifolia (Gaud.) Koyama	'Uki	I	-	-	-	U	R	-	-	-	U
Machaerina mariscoides (Gaud.) Kern	'Uki, 'aha-niu	I	-	-	O	O	O	-	U	O	-
Rhynchospora lavarum Gaud.	Kuolohia, pu'uko'a	I	R	-	-	-	-	-	-	-	R
Scleria testacea Nees		E	-	-	-	-	-	-	-	R	-
DIOSCOREACEAE											
Dioscorea pentaphylla L.	Pi'ia	P	-	-	R	-	-	-	U	-	-
GRAMINEAE											
Andropogon glomeratus (Walt.) BSP.	Bush beardgrass	X	-	-	-	U	O	-	R	O	O
Andropogon virginicus L.	Broomsedge	X	-	-	O	O	C	-	R	O	A
Axonopus affinis Chase	Narrow-leaved carpetgrass	X	-	-	-	-	-	-	-	-	U
Axonopus compressus (Sw.) Beauv.	Broad-leaved carpetgrass	X	-	-	-	-	-	-	U	-	-
Bambusa sp. 1	Bamboo	X	L	-	-	-	-	-	L	-	L
Bambusa sp. 2	Bamboo	X	L	-	-	-	-	-	-	L	L
Brachiaria mutica (Forsk.) Stapf	Paragrass, Californiagrass	X	-	A	-	-	-	-	-	C	C
Brachiaria reptans (L.) Gard. & C.E. Hubb.		X	-	-	-	-	-	-	-	-	L
Chloris radiata (L.) Sw.	Radiate fingergrass	X	U	-	-	-	-	-	-	-	-

TAXA	COMMON NAME	STATUS	1	2	3	4	5	6	7	8	9
GRAMINEAE (continued)											
Coix lachryma-jobi L.	Job's tears, 'ohe pu'ohe'ohe	X	U	-	-	-	-	-	-	-	U
Digitaria adscendens (HBK.) Henr.	Henry's crabgrass	X	-	-	-	-	-	-	-	-	U
Digitaria eriantha Steud.		X	-	-	-	-	-	-	-	-	L
Digitaria pruriens (Fisch. ex Trin.) Buse	Itchy crabgrass	X	O	O	-	-	-	-	-	-	U
Digitaria violascens Link	Kukaipua'a-uka	X	-	-	-	-	-	-	-	U	O
Eleusine indica (L.) Gaertn.	Goosegrass, manienie-ali'i	X	U	-	-	-	-	-	-	R	O
Eragrostis sp.		X	-	-	-	-	-	-	-	U	O
Hyparrhenia rufa (Nees) Stapf	Thatchinggrass, jaragua	X	-	-	-	-	-	-	-	-	R
Melinis minutiflora Beauv.	Molassesgrass	X	O	C	O	U	R	-	O	C	C
Oplismenus hirtellus (L.) Beauv.	Basketgrass, honohono-kukui	X	-	-	O	-	-	O	C	C	U
Panicum maximum Jacq.	Guinea grass	X	-	-	-	-	-	-	-	U	-
Paspalum conjugatum Berg.	Hilo grass, mau'u-Hilo	X	O	-	O	-	-	C	C	C	C
Paspalum orbiculare Forst. f.	Ricegrass, mau'u-laiki	X	O	-	-	R	-	-	R	U	O
Paspalum urvillie Steud.	Vaseygrass	X	-	-	-	-	-	-	-	-	U
Pennisetum purpureum Schumach.	Elephantgrass, napiergrass	X	-	C	-	-	-	-	-	C	O
Poa annua L.	Annual bluegrass	X	-	-	-	-	-	-	-	-	U
Saccharum officinarum L.	Sugar cane, ko	P	O	O	-	-	-	-	R	U	O
Sacciolepis indica (L.) Chase	Glenwoodgrass	X	-	R	U	-	-	-	C	O	O
Schizostachyum glaucifolium (Rupr.) Munro	Ohe	P	-	-	L	-	-	-	L	L	R
Setaria geniculata (Poir.) Beauv.	Perennial foxtail	X	-	-	-	-	-	-	O	O	O

TAXA	COMMON NAME	STATUS	1	2	3	4	5	6	7	8	9
GRAMINEAE (continued)											
Setaria glauca (L.) Beauv.	Yellow foxtail	X	O	-	O	-	-	-	-	O	-
Setaria palmaefolia (Koen.) Stapf	Palmgrass	X	-	-	-	-	-	-	-	-	R
Sporobolus africanus (Poir.) Robyns & Tournay	African dropseed	X	-	-	-	-	-	-	-	U	U
LILIACEAE											
Cordyline terminalis (L.) Kunth	Ti, ki	P	O	R	U	U	-	O	O	O	O
Cordyline terminalis var. ferrea (L.) J. G. Baker	Red ti	X	-	-	-	-	-	-	-	R	R
MARANTACEAE											
Calathea ornata (Lem.) Koern.		X	-	-	-	-	-	-	R	-	-
MUSACEAE											
Musa X nana Lour.	Chinese banana	X	O	U	-	-	-	-	-	-	-
Musa X paradisiaca L.	Banana, mai'a	P	O	U	R	-	-	-	R	-	R
ORCHIDACEAE											
Arundina bambusaefolia (Roxb.) Lindl.	Bamboo orchid	X	-	-	U	O	O	O	O	O	C
Phaius tankervilliae (Banks ex L'He'r.) Bl.		X	-	-	R	-	-	R	R	-	-

TAXA	COMMON NAME	STATUS	1	2	3	4	5	6	7	8	9
ORCHIDACEAE (continued)											
Spathoglottis plicata Bl.	Chinese orchid	X	-	-	U	O	O	O	O	O	O
Vanda teres Lindl. X V. hookeriana Reichb. f.	Vanda "Miss Joaquim"	X	U	-	-	-	-	-	-	-	-
PALMAE											
Cocos nucifera L.	Coconut, niu	P	-	U	-	-	-	-	-	U	U
PANDANACEAE											
Freycinetia arborea Gaud.	Ie'ie	E	-	-	C	O	-	O	O	-	-
Pandanus odoratissimus L. f.	Hala, pandauus	I	-	-	-	U	-	O	-	U	-
ZINGIBERACEAE											
Alpinia purpurata (Vieill.) K. Schum.	Red ginger, 'awapuhi-'ula'ula	X	-	R	-	-	-	-	-	-	-
Hedychium flavescens Carey	Yellow ginger; 'awapuhi-melemele	X	-	-	R	-	-	-	-	O	U
Zingiber zerumbet (L.) Roscoe	'Awapuhi kua hiwi	P	-	-	U	-	-	O	U	-	-
DICOTYLEDONS											
ACANTHACEAE											
Odontonema strictum (Nees) Ktze.	Odontonema	X	-	-	-	-	-	-	-	R	-
Thunbergia fragrans Roxb.	White thunbergia	X	O	C	U	-	-	-	O	U	U

TAXA	COMMON NAME	STATUS	1	2	3	4	5	6	7	8	9
ANACARDIACEAE											
Mangifera indica L.	Mango, manako	X	-	-	-	R	-	-	-	O	O
Schinus terebinthifolius Raddi	Christmas berry, nani-o-Hilo	X	-	-	-	-	-	-	-	U	-
APOCYNACEAE											
Alyxia olivaeformis Gaud.	Maile	E	-	-	U	-	-	R	-	-	-
AQUIFOLIACEAE											
Ilex anomala H. & A.	Kawa'u, ka'awa'u	E	-	-	-	-	-	U	-	-	-
ARALIACEAE											
Brassaia actinophylla Endl.	Octopus tree	X	-	-	-	-	-	-	-	R	-
Tetraplasandra hawaiiensis Gray	'Ohe	E	-	-	U	-	-	U	-	-	-
ASCLEPIADACEAE											
Asclepias curassavica L.	Butterflyweed, lau-lele	X	-	-	-	R	-	-	R	-	-
BALSAMINACEAE											
Impatiens sultani Hook. f.	Impatiens	X	-	-	R	-	-	-	R	U	R
BEGONIACEAE											
Begonia sp.	Begonia	X	-	U	U	-	-	-	O	U	U

TAXA	COMMON NAME	STATUS	1	2	3	4	5	6	7	8	9
BIGNONIACEAE											
Spathodea campanulata Beauv.	African tulip tree	X	-	R	-	-	-	-	R	-	-
BIXACEAE											
Bixa orellana L.	Arnotto, lipstick plant	X	R	-	-	-	-	-	-	-	-
CARICACEAE											
Carica papaya L.	Papaya, mikana	X	A	-	-	-	-	-	R	U	-
CARYOPHYLLACEAE											
Drymaria cordata (L.) Willd. ex R. & S.	Drymaria, pipili	X	-	-	-	-	-	-	-	U	O
CASUARINACEAE											
Casuarina equisetifolia Stickm.	Ironwood	X	-	-	-	R	-	-	-	-	-
CELASTRACEAE											
Perrottetia sandwicensis Gray	Olomea, pua'a olomea	E	-	-	-	-	-	-	U	-	-
COMPOSITAE											
Ageratum conyzoides L.	Ageratum	X	O	O	-	R	R	-	U	U	O
Bidens pilosa L.	Beggar's tick, Spanish needle	X	-	-	-	R	-	-	-	R	U
Crepis sp.		X	-	-	R	-	-	-	-	-	-

TAXA	COMMON NAME	STATUS	1	2	3	4	5	6	7	8	9
COMPOSITAE (continued)											
Eclipta alba (L.) Hassk.	False daisy	X	R	R	-	-	-	-	-	-	-
Emilia fosbergii Nicolson	Pua-lele	X	O	-	-	-	R	-	-	-	O
Emilia sonchifolia (L.) DC.	Lilac pua-lele	X	O	-	-	-	-	-	-	-	U
Erechtites hieracifolia (L.) Raf.	Fireweed	X	O	O	O	-	U	U	-	O	O
Erigeron canadensis L.	Canada fleabane, ilioha	X	-	-	R	R	R	-	-	-	O
Eupatorium riparium Regel	Pamakani	X	-	-	-	R	-	-	R	-	O
Pluchea odorata (L.) Cass.	Pluchea, shrubby fleabane	X	C	C	O	O	U	U	U	O	C
Sonchus oleraceus L.	Sow thistle, pua-lele	X	-	-	R	-	R	-	-	-	R
Vernonia cinerea (L.) Less.	Ironweed	X	-	U	-	-	R	-	-	-	R
Wedelia trilobata (L.) Hitchc.	Wedelia	X	-	-	-	-	-	-	-	R	U
Youngia japonica (L.) DC.	Oriental hawksbeard	X	R	-	R	-	R	-	R	U	-
CONVOLVULACEAE											
Ipomoea batatas (L.) Poir.	'Uala, sweet potato	P	U	R	-	-	-	-	-	-	-
Ipomoea congesta R. Br.	Koali-'awania	I	-	R	-	-	-	-	-	-	-
Ipomoea triloba L.	Little bell	X	-	-	-	-	-	-	-	-	R
Ipomoea sp.		X	-	R	-	-	-	-		-	-
Merremia tuberosa (L.) Rendle	Wood rose	X	-	-	-	-	-	-	-	R	-
CRASSULACEAE											
Kalanchoe pinnata (Lam.) Pers.	Air plant, 'oliwa-ku-kahakai	X	-	-	-	-	-	-	-	-	R

TAXA	COMMON NAME	STATUS	1	2	3	4	5	6	7	8	9
CRUCIFERAE											
Cardamine flexuosa f. umbrosa (Gren. & Godr.) O.E. Schulz	Bitter-cress	X	R	-	-	-	-	-	-	-	-
Nasturtium sarmentosum (DC.) Schinz & Guillaumin	Pa'ihi,'ihi-ku-kepau	P	U	-	-	-	-	-	-	-	-
CUCURBITACEAE											
Momordica charantia var. paval Crantz	Balsam apple, peria	X	R	-	-	-	-	-	-	-	-
EBENACEAE											
Diospyros ferrea subsp. sandwicensis (A. DC.) Fosb.	Lama	E	-	-	O	C	-	A	O	O	-
EPACRIDACEAE											
Styphelia tameiameiae (Cham.) F. Muell.	Pukiawe, maiele	I	-	-	-	U	O	-	-	-	U
EUPHORBIACEAE											
Aleurites moluccana (L.) Willd.	Kukui, tutui, candlenut tree	P	-	-	U	U	-	-	O	-	O
Antidesma platyphyllum Mann	Hame	E	-	-	U	-	-	R	U	-	-
Euphorbia glomerifera (Millsp.) L. C. Wheeler		X	O	-	-	-	-	-	-	-	O

TAXA	COMMON NAME	STATUS	1	2	3	4	5	6	7	8	9
EUPHORBIACEAE (continued)											
Euphorbia hirta L.	Garden spurge, hairy spurge	X	O	O	-	-	R	-	-	U	O
Euphorbia prostrata Ait.	Prostrate spurge	X	O	-	-	-	-	-	-	R	O
Euphorbia thymifolia L.	Thyme-leaved spurge	X	U	-	-	-	-	-	-	-	-
Euphorbia sp.		X	O	-	-	-	-	-	-	-	-
Manihot esculenta Crantz	Cassava, manioka, tapioca	X	-	-	-	-	-	-	-	R	-
Manihot glaziovii Muell.-Arg.	Ceara' rubber	X	-	-	-	-	-	-	-	U	-
Phyllanthus debilis Klein ex Willd.	Phyllanthus weed	X	-	-	-	-	R	-	-	R	-
Ricinus communis L.	Castor bean, koli	X	-	R	-	-	-	-	-	-	-
GESNERIACEAE											
Cyrtandra paludosa var. integrifolia Hbd.		E	-	-	R	-	-	R	R	-	-
Cyrtandra paludosa var. irrostrata St. John		E	-	-	R	-	-	R	R	-	-
Cyrtandra sp.		E	-	-	R	-	-	-	R	-	-
GOODENIACEAE											
Scaevola taccada (Gaertn.) Roxb.	Naupaka-kahakai	I	-	-	-	R	-	-	-	-	-
LABIATAE											
Coleus blumei Benth.	Coleus, weleweka	X	-	-	-	-	-	-	-	U	-
Hyptis pectinata (L.) Poit.	Comb hyptis	X	O	O	R	-	R	-	R	O	O

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LAURACEAE											
Cassytha filiformis L.	Kaunoa'oa, kaua'oa-pehu	I	-	U	-	-	-	-	-	-	-
Persea americana Mill.	Avocado	X	O	-	R	R	-	-	-	O	R
LEGUMINOSAE											
Albizia falcataria (L.) Fosb.	Albizia	X	-	U	-	R	U	-	-	C	O
Canavalia ensiformis (L.) DC.	Jack bean	X	-	R	-	-	-	-	-	-	-
Cassia alata L.	Candlebush	X	-	-	-	-	-	-	-	-	R
Cassia leschenaultiana DC.	Partridge pea, lauki	X	O	-	-	R	R	-	-	U	O
Crotalaria incana L.	Fuzzy rattle-pod, kukai-hoki	X	-	-	-	-	-	-	-	R	O
Crotalaria mucronata Desv.	Mucronate crotalaria	X	-	R	-	-	-	-	-	-	U
Crotalaria retusa L.	Rattle-box, sauni	X	-	-	-	-	R	-	-	-	-
Crotalaria sp.		X	-	-	-	-	U	-	-	R	U
Desmondium cajanifolium (HBK.) DC.	Tall desmodium	X	C	A	-	-	R	-	-	U	C
Desmodium canum (Gmel.) Schinz & Thell.	Ka'imi	X	-	O	-	-	-	-	-	-	O
Desmodium triflorum (L.) DC.	Three-flowered beggarweed	X	-	-	-	-	-	-	-	U	O
Desmodium uncinatum (Jacq.) DC.	Spanish clover	X	O	C	-	O	R	O	O	O	C
Desmodium sp.		X	C	A	-	-	-	-	-	O	O
Indigofera suffruticosa Mill.	Indigo, 'iniko	X	U	U	-	-	R	-	-	-	O
Leucaena leucocephala (Lam.) de Wit	Koa-haole	X	-	-	-	-	-	-	-	U	U
Mimosa pudica var. unijuga (Duchass. & Walp.) Griseb.	Sensitive plant, pua-hilahila	X	O	C	-	R	R	-	-	O	C

TAXA	COMMON NAME	STATUS	1	2	3	4	5	6	7	8	9
LEGUMINOSAE (continued)											
Mucuna gigantea (Willd.) DC.	Ka'e'e, sea bean	I	-	-	-	-	-	-		R	-
Phaseolus atropurpureus DC.	Siratro	X	-	-	-	-	-	-	-	-	O
Phaseolus vulgaris L.	String bean	X	U	-	-	-	-	-	-	-	-
Samanea saman (Jacq.) Merr.	Monkeypod	X	-	-	-	-	-	-	-	U	R
LOGANIACEAE											
Buddleja asiatica Lour.	Asiatic butterfly bush	X	O	C	R	-	O	-	U	O	O
LYTHRACEAE											
Cuphea carthagenensis (Jacq.) Macbride	Columbian cuphea, puakamoli	X	R	R	-	-	-	-	-	-	O
Lythrum maritimum HBK.	Puakamole	X	-	-	-	-	-	-	-	R	-
Indet.		X	R	-	-	-	-	-	-	-	-
MALVACEAE											
Hibiscus esculentus L.	Okra, gumbo	X	R	-	-	-	-	-	-	-	-
Hibiscus rosa-senensis L.	Red hibiscus	X	-	-	-	-	-	-	-	-	R
Hibiscus youngianus Gaud. ex H. & A.	Hau-hele, 'akiohala	E	-	R	-	-	-	-	-	-	-
Sida rhombifolia L.	Cuba jute	X	-	-	-	R	-	-	-	R	U

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MELASTOMATACEAE											
Clidemia hirta (L.) D. Don	Koster's curse, clidemia	X	-	-	R	-	-	-	-	-	R
Dissotis plumosa Hook. f.	Dissotis	X	R	-	-	-	-	-	-	-	R
Melastoma malabathricum L.	Malabar melastome	X	-	-	O	C	-	O	O	C	C
Pterolepis sp.		X	-	R	R	-	-	-	-	-	U
MENISPERMACEAE											
Cocculus ferrandianus Gaud.	Huehue, hue'ie	E	-	-	O	U	-	-	-	O	U
MORACEAE											
Cannabis sativa L.	Marijuana, pot, pakalolo	X	-	-	R	R	-	-	-	-	-
Cecropia obtusifolia Bertol.	Guarumo	X	-	-	O	U	-	-	U	O	-
Ficus microcarpa L. f.	Chinese banyan	X	-	-	-	-	-	-	-	R	-
MORINGACEAE											
Moringa oleifera Lam.	Horseradish tree	X	-	R	-	-	-	-	-	-	-
MYRSINACEAE											
Myrsine lessertiana A. DC.	Kolea-lau-nui	E	-	-	O	O	-	O	O	-	-
MYRTACEAE											
Eugenia cuminii (L.) Druce	Java plum, palama	X	-	-	-	-	-	-	-	-	R
Eugenia jambos L.	Rose apple, 'ohi'a-loke	X	-	-	-	R	-	-	-	C	-

TAXA	COMMON NAME	STATUS	1	2	3	4	5	6	7	8	9
MYRTACEAE (continued)											
Metrosideros polymorpha Gaud.	'Ohi'a, 'ohi'a-lehua	E	-	R	A	A	A	A	A	C	O
Psidium cattleianum f. cattleianum Sabine	Strawberry guava	X	-	R	C	-	-	O	A	C	C
Psidium cattleianum f. lucidum Degener	Yellow strawberry guava, waiawi	X	-	-	-	-	-	-	U	-	-
Psidium guajava L.	Guava, kuawa	X	-	U	O	O	-	O	C	C	O
NYCTAGINACEAE											
Pisonia umbellifera (J.R. & G. Forst.) Seem.	Papala-kepau	E	-	-	-	-	-	-	R	-	-
ONAGRACEAE											
Ludwigia octivalvis (Jacq.) Raven	Primrose willow, kamole	I	R	R	-	-	-	-	-	-	-
OXALIDACEAE											
Oxalis corniculata L.	Yellow wood sorrel, 'ihi	I	O	-	-	-	-	-	-	U	-
Oxalis maritiana Zucc.	Pink wood sorrel, 'ihi pehu	X	O	-	-	-	-	R	-	-	U
PASSIFLORACEAE											
Passiflora edulis f. flavicarpa Degener	Yellow liliko'i	X	-	-	-	-	-	-	R	U	R
Passiflora foetida L.	Scarlet-fruited passionflower	X	U	-	R	-	-	R	-	U	-

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PIPERACEAE											
Peperomia leptostachya H. & A.	Kupali'i	I	-	-	U	-	-	-	U	-	-
PLANTAGINACEAE											
Plantago major L.	Common plantain, lau-kahi	X	-	-	-	R	-	-	-	U	-
POLYGALACEAE											
Polygala paniculata L.	Polygala	X	C	O	-	R	R	-	-	U	O
POLYGONACEAE											
Polygonum capitatum Ham. ex Don	Polygonum	X	-	-	-	-	-	-	-	-	U
PROTEACEAE											
Macadamia ternifolia var. integrifolia (Maiden & Betche) Maiden & Betche	Macadamia nut	X	O	-	-	-	-	-	-	-	-
ROSACEAE											
Rubus rosaefolius Sm.	Thimbleberry	X	-	R	U	-	-	O	O	O	U
RUBIACEAE											
Bobea sp.	'Ahakea	E	-	-	-	-	-	-	R	-	-
Borreria laevis (Lam.) Griseb.	Buttonweed, spermacoce	X	U	-	-	-	-	-	-	R	-

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RUBIACEAE (continued)											
Borreria sp.		X	C	O	-	R	R	-	-	R	O
Hedyotis corymbosa (L.) Lam.		X	O	-	-	-	-	-	-	R	O
Morinda citrifolia L.	Noni	P	-	-	R	-	-	-	-	-	-
Paederia foetida L.	Maile pilau	X	-	O	O	-	-	-	O	O	O
Psychotria hawaiiensis (Gray) Fosb.	Kopiko	E	-	-	C	O	-	O	O	O	U
SCROPHULARIACEAE											
Castilleja arvensis Schlecht. & Cham.	Field Indian paintbrush	X	O	-	R	R	-	-	-	-	O
Lindernia crustacea (L.) F. Muell.	Lindernia, false pimpernel	X	O	-	-	-	-	-	-	U	O
Lindernia sp.		X	O	-	-	-	-	-	-	-	-
SOLANACEAE											
Lycopersicon pimpinellifolium Mill.	Currant tomato, 'ohi'a-ma-kanahele	X	-	U	-	-	-	-	-	-	
Solandra hartwegi N.E. Br.	Cup of gold	X	-	-	-	-	-	-	-	-	R
Solanum melongena var. serpentinum (Noronha) Bailey	Long eggplant	X	U	-	-	-	-	-	-	-	-
Solanum nigrum L.	Black nightshade, popolo	I?	-	-	-	-	-	-	-	R	O
STERCULIACEAE											
Melochia umbellata (Houtt.) Stapf	Melochia	X	O	O	-	U	-	-	U	C	O
Waltheria indica var. americana (L.) R. Br. ex Hosaka	Hi'aloa, 'uhaloa	I	-	-	-	-	R	-	-	-	U

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THYMELAEACEAE											
Wikstroemia sandwicensis Meisn.	'Akia	E	-	-	U	U	-	O	-	U	-
ULMACEAE											
Trema orientalis (L.) Bl.	Gunpowder tree	X	O	-	-	-	-	R	-	O	O
UMBELLIFERAE											
Centella asiatica (L.) Urban	Asiatic pennywort, pohekula	X	O	-	-	R	-	-	-	O	O
URTICACEAE											
Pipturus hawaiensis Levl.	Mamaki	E	U	-	O	-	R	-	O	O	O
Touchardia latifolia Gaud.	Olona	E	-	-	R	-	-	-	-	-	-
VERBENACEAE											
Lantana camara L.	Lantana, lakana	X	-	-	R	R	-	-	-	-	-
Stachytarpheta jamaicensis (L.) Vahl	Jamaica vervain, owi, oi	X	O	O	R	R	-	O	O	O	O
Verbena litoralis HBK.	Weed verbena, ha'uowi	X	O	R	R	-	-	-	-	U	O