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Environmental Review
500 MW Geothermal Development

PRELIMINARY DRAFT

Technical Description
and
Environmental Setting

December 12, 1988

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PART I: INTRODUCTION

A. OVERVIEW

Hawaii presently relies upon petroleum fuel to supply 90 percent of its total energy needs, making the State vulnerable to sudden shortages in supply or escalations in the price of this diminishing source of energy. A major goal for the State in the State Energy Functional Plan (DPED, 1984), is to reduce Hawaii's dependency on oil through the use of alternate forms of energy. As stated in the Functional Plan, it is a priority objective for the State to "Accelerate the transition to an indigenous renewable energy economy by facilitating private sector activities to explore supply options and achieve local commercialization and application of appropriate energy technologies."

Geothermal heat as an alternative energy source 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 degrees 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. A 6,540 foot well was drilled in 1976 in the Lower East Rift Zone and named the Hawaii Geothermal Project (HGP-A).

The State of Hawaii anticipates that by the year 2007 up to 500 deliverable megawatts (MW or MWe) of geothermally-generated electricity would be needed for transmission from the island of Hawaii to the islands of Maui (up to 50 megawatts) and Oahu via an interisland cable system. For this environmental review, the areas considered as potential sources of this power are the three geothermal resources subzones (GRS) within the Kilauea East Rift Zone on the Big Island of Hawaii. Specifically, they are: (1) the Kilauea Middle East Rift GRS; (2) the Kamaili Section of the Kilauea Lower East Rift GRS; and, (3) the Kapoho Section of the Kilauea Lower East Rift GRS (Figure I-1).

B. GEOTHERMAL RESOURCE POTENTIAL

The successful operation and generation of electricity by the HGP-A plant confirmed the resource potential of the east rift zone. In addition, numerous geophysical, geological, and

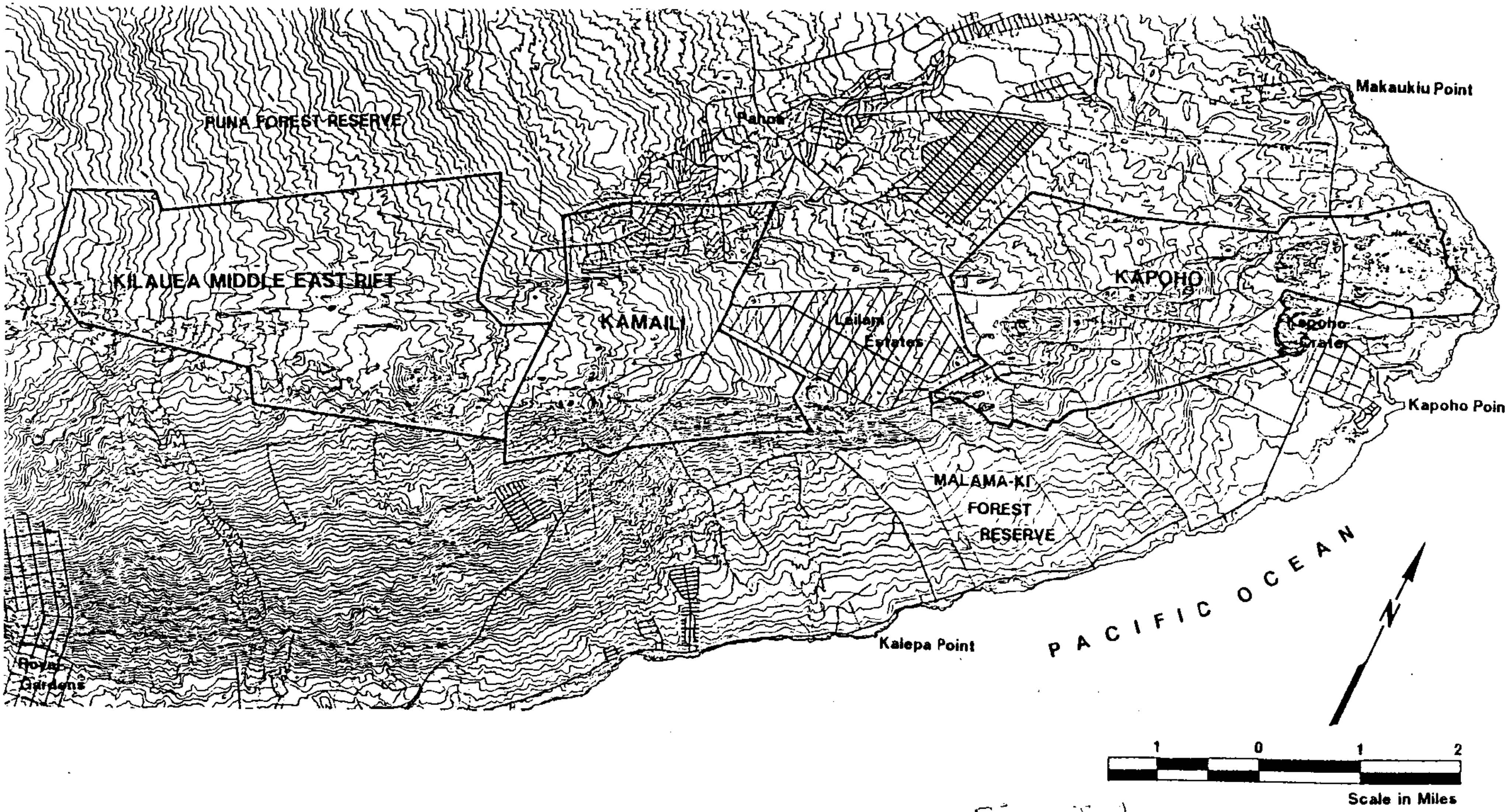


Figure I-1.
Geothermal Resource Subzones.

geochemical studies of the east rift zone that have been performed in recent years further demonstrate the resource potential of the area.

Studies conducted by Holcomb (1980) have shown that the surface volcanic expressions of the entire east rift zone indicate little, if any, change in the geologic character of the rift zone from upper to lower elevations. From these studies it is presumed that the subsurface character will not be much different between the upper and lower portions of the rift zone (Niimi, 1985).

As indicated by the Department of Land and Natural Resources (DLNR, 1985) "Currently available geotechnical data indicated the presence of a geothermal resource along the entire Kilauea East Rift Zone. The assessment of geothermal resource potential was based on a qualitative interpretation of regional surveys based on the following types of data: groundwater temperature, geologic age, geochemistry, resistivity, infrared, seismic, magnetics, gravity, self-potential and exploratory drilling. The evaluation of these data indicated that the potential for a geothermal resource on this rift zone was greater than 90 percent through its entire length." Figure I-2 delineates the estimated percent probability of geothermal resource potential in the GRS areas of the east rift zone. High rainfall on the eastern portion of the Island of Hawaii, and possibly seawater intrusion below the area, provide a large source of water to supply the geothermal system. Further, DLNR (1985) concluded that "...no single geothermal exploration technique, except for exploratory drilling, is capable of positively identifying a subsurface geothermal system...".

Data on the production potential of the subzones is necessary to demonstrate to State agencies and private developers of the interisland cable that sufficient geothermal resources are present on the Big Island to justify proceeding with the costly commercial deepwater cable program.

C. PUBLIC INVOLVEMENT

To facilitate the orderly development of geothermal energy in Hawaii, the State Legislature adopted a number of bills related to this subject in recent years. Act 135, SLH 1978, granted geothermal developers a favorable (one-half of one percent) general excise tax rate on the sale of energy produced from geothermal resources. Act 296, SLH 1983, the Geothermal Resource Subzone Act (amending Chapter 205, Hawaii Revised

LEGEND: —90%— Percent Probability of Geothermal Potential

Source: modified from DLNR, 1985

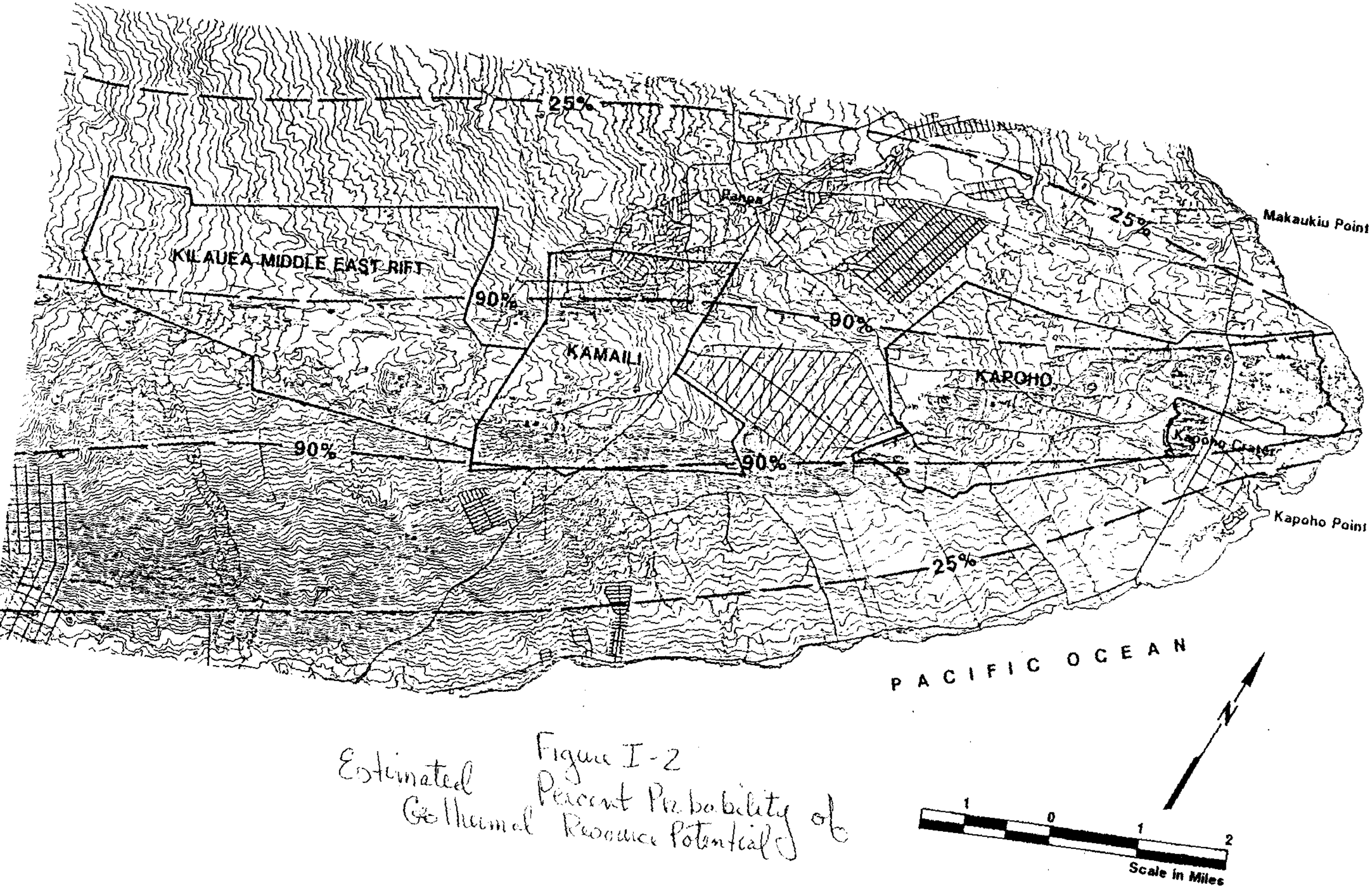


Figure I-2
Estimated Percent Probability of Geothermal Resource Potential

Statutes, provided for the designation of geothermal resource subzones wherein proposals for geothermal development could be considered by appropriate State and County permitting agencies. This act authorized subzones to be established by the State Board of Land and Natural Resources (BLNR) in areas of significant geothermal resources where the potential positive environmental, economic and social benefits of the development to the State as a whole outweigh the potential negative environmental and social impacts. Act 138, SLH 1985, requires the BLNR to fix the payment of royalties to the State for the use of geothermal resources at a rate which will encourage new and continued geothermal production, and geothermal development. Act 237, SLH 1985, tasks the DPED with facilitating and coordinating actions by State agencies and the processing of permits. Act 301, SLH 1988 provides for a coordinated permitting process involving the various state and county agencies that must approve the development of geothermal energy.

During the geothermal subzone assessment process various channels and methods of community input were involved to discuss the social, environmental and economic impacts of geothermal development on them and on the State as a whole. These channels included agencies, public informational meetings, political representatives, regulatory agencies, public and contested case hearings, and community surveys (e.g., by the Puna Hui Ohana and by SMS Research, Inc.).

Throughout the process, from the enactment of Act 296 to the Proposal for Designating Geothermal Resources by BLNR, public comments and participation were encouraged. Eleven public informational meetings were held on the islands of Hawaii and Maui. The objective of these meetings was to open lines of communication between the public and the DLNR. In addition, on July 29, 1985, DLNR mailed letters to concerned parties requesting written comments and information on the proposed geothermal resource subzones. The meetings reported the most likely locations of geothermal resources and focused on the identification of impact issues.

An environmental review workshop sponsored by the Puna Community Council to discuss the production of 600 MW of geothermal energy was held in Pahoa on November 9, 1988. Appendix A provides an overview of the workshop.

D. ENVIRONMENTAL CONSIDERATIONS

The establishment of a geothermal industry in Hawaii requires a sound understanding of the environmental impacts of geothermal development and suitable regulations to protect the environment and the health of the populace. This comprehensive review, synthesis and evaluation of existing environmental information has been undertaken in order to assess the potential environmental effects of generating 500 (net) megawatts of geothermal energy within the Kilauea East Rift Zone.

An environmental assessment for an interisland cable system that would deliver a net 500 MW of geothermal-generated electricity to Maui and Oahu from the Kilauea East Rift Zone was recently prepared by Parsons Hawaii under the Hawaii Deep Water Cable Program (Parsons Hawaii, 1987). This environmental review is intended to complement the interisland cable assessment and possibly form the basis for a future Environmental Impact Statement (EIS) for the generation and transmission of geothermally-generated electricity. At the least, this comprehensive environmental review should form the basis for future environmental impact analyses of individual developments as they prepare to come on-line.

E. ORGANIZATION OF THE ENVIRONMENTAL REVIEW

This report is organized in the following manner:

o. Part I gives an overview of the geothermal development and discusses the potential resource and public involvement.

o. Part II describes the development concept being reviewed in this report and sets forth the assumptions on which the evaluation was based. It also discusses the technical characteristics of a generic 500 (net) MW geothermal development.

o. Part III describes the physical, terrestrial and cultural environment in the vicinity of the proposed development.

o Part IV discusses social and economic characteristics of the proposed geothermal development.

o. Part V identifies potential impacts of developing 500 (net) MW of geothermal power on the environment and includes mitigating measures and recommendations for further study.

o. Part VI discusses policies and plans that relate to the proposed development and lists permits required for each individual project.

PART II: DESCRIPTION OF THE DEVELOPMENT CONCEPT

A. OVERVIEW OF THE GEOTHERMAL ENERGY TO ELECTRICITY CONVERSION PROCESS

To understand the potential of geothermal energy it is necessary to understand what is happening beneath the surface of the land. Deep in the earth's crust (usually 20 miles) is a mass of molten rock called magma. In some areas, such as Hawaii this magma is closer to the surface due to crustal fractures and it heats the layers of rock above it. If underground water is present, a geothermal reservoir is created. It is this liquid-vapor reservoir which is tapped to provide the source for geothermally-generated electricity.

The production wells and pipes bring the geothermal fluid to the separator for flashing; a process that separates the steam from the fluid or brine. The majority of the dissolved minerals remain in the brine and any gasses remain in the steam fraction. The separator discharges steam into the steam gathering system. The steam gathering system then transports the steam to the turbine in the power plant. The brine gathering system is responsible for the transportation and disposal of the brine into the injection wells.

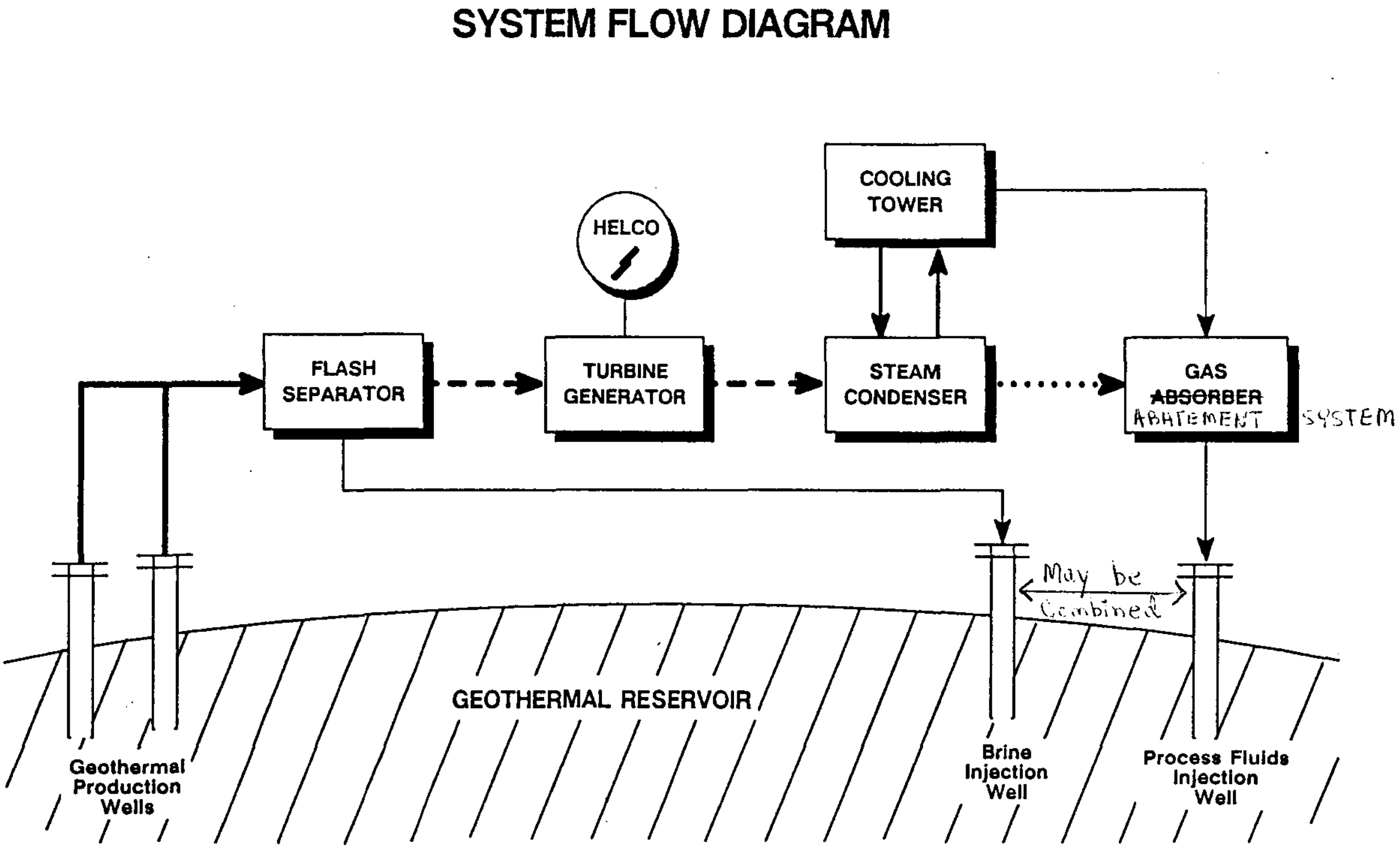
Electricity is generated in the power plant through the use of a steam turbine coupled to an electric generator. The steam turbine converts the energy of the steam into electricity. The steam from each turbine exhausts into a steam condenser/heat exchanger which condenses the steam. The steam condensate drains from the top of the condenser into the hotwell in the bottom. The non condensable gases and uncondensed steam would be discharged to a state-of-the-art gas abatement system. The resultant process fluids would be combined with the spent brine and reinjected or reinjected separately depending on the type of systems designed into the plant (Figure II-1).

In the development concept presented in this report, the electrical power generated would be transmitted as AC to a Converter Station where it would be converted into DC and then exported via the transmission line to the termination station of the submarine cable.

B. BASIC ASSUMPTIONS

1.0 Development Scenario

For the purpose of this environmental review, the areas considered as potential sources of geothermal-generated power are the three geothermal resource subzones (GRS) within the



Source: modified from Thermal Power (1987)

Figure II-1. System Flow Diagram

Kilauea East Rift Zone on the Big Island of Hawaii. Specifically, they are: (1) the Kilauea Middle East Rift GRS; (2) the Kamaili Section of the Kilauea Lower East Rift GRS; and, (3) the Kapoho Section of the Kilauea Lower East Rift GRS (Figure I-1).

The review and evaluation of potential environmental effects associated with the production of 500 net MW of geothermal energy from the three GRS which follows, is based on the following basic assumptions:

- o. Delivered capacity is assumed to be 500 MW. In order to account for line losses and maintenance downtime, however, generating capacity would be somewhat higher, up to a total 600 MW. A conceptual 600 MW system, which is most likely an overestimate of the generating capacity required to yield 500 MW (net), is used in this analysis in order to evaluate the worst case scenario for air quality and other environmental factors.
- o. The underground reservoir in each GRS is assumed to be uniformly distributed and thus each GRS would be capable of producing at least 200 MW of gross power.
- o. For purposes of evaluating environmental effects, the conceptual geothermal development scenario for each GRS consists of four hypothetical 50 MW power plants and associated well fields. This distribution was intended to allow each subzone to be assessed on more or less similar development assumptions. Actual development would probably consist of fewer plants; most likely of 55 MW capacity. In all probability, these plants would not be evenly distributed throughout the three GRS. The technical description which follows in this chapter is based on available specifications for a typical 55 MW power plant.
- o. In the development scenario, power plants are sited a minimum one mile apart in order to meet air quality standards; each plant would require from five to eight acres of land area.
- o. Because the actual location of geothermal reservoirs and the economic production potential of the resource can only be determined by deep drilling and by testing each successful well, the drilling sites identified in each GRS are only conceptual.
- o. Each exploration/development (E/D) area would have from three to five primary drilling sites connected by service roads. The drilling sites would occupy from two to three acres; up to 6 E/D wells would be drilled from one or more drilling sites.

2.0 Phasing

The development schedule for producing 500 net MW of geothermal power for transmission by undersea cable to Oahu is based on the "Undersea Cable to Transmit Geothermal-Generated Electrical Energy from the Island of Hawaii to Oahu: Economic Feasibility," (DAHI, 1988). Appropriate adjustments were made to the quantities given in the DAHI report to reflect the fact that larger but fewer power plants are assumed. It should be noted that, in order to be consistent with the above referenced report, ten 55 MW (gross capacity) plants were assumed to be required to produce 500 net MW of power.

The first power plant is projected to come on line in 1995; additional power plants would become operational at a rate of approximately one per year. Development would begin three years before the first plant becomes operational. Consequently, construction would span a 14-year period. The economics and specific phasing of this geothermal development are discussed in Section IV.

C. DEVELOPMENT CONCEPT

1.0 Overview

Figures II-2 (Kilauea Middle East Rift), II-3 (Kamaili Section of the Kilauea Lower East Rift) and II-4 (Kapoho Section of the Kilauea Lower East Rift) locate the three GRS areas and present a layout of a conceptual geothermal system within each GRS. Table 2-1 indicates the total estimated acreage required within each GRS for the systems diagrammed in the aforementioned figures.

In the development concept illustrated in the referenced figures, generation of 500 net MW (up to 600 gross MW) of geothermal energy on the Big Island would involve a number of interconnected components, including:

o. up to twelve 50 MW power plants which include standard steam-driven turbine generators, steam condensers, and pollution control devices;

o. a network of surface pipes to deliver the steam to twelve power plants;

o. surface piping to deliver water which has been condensed from steam to injection wells;

o. injection wells to dispose of this water; and,

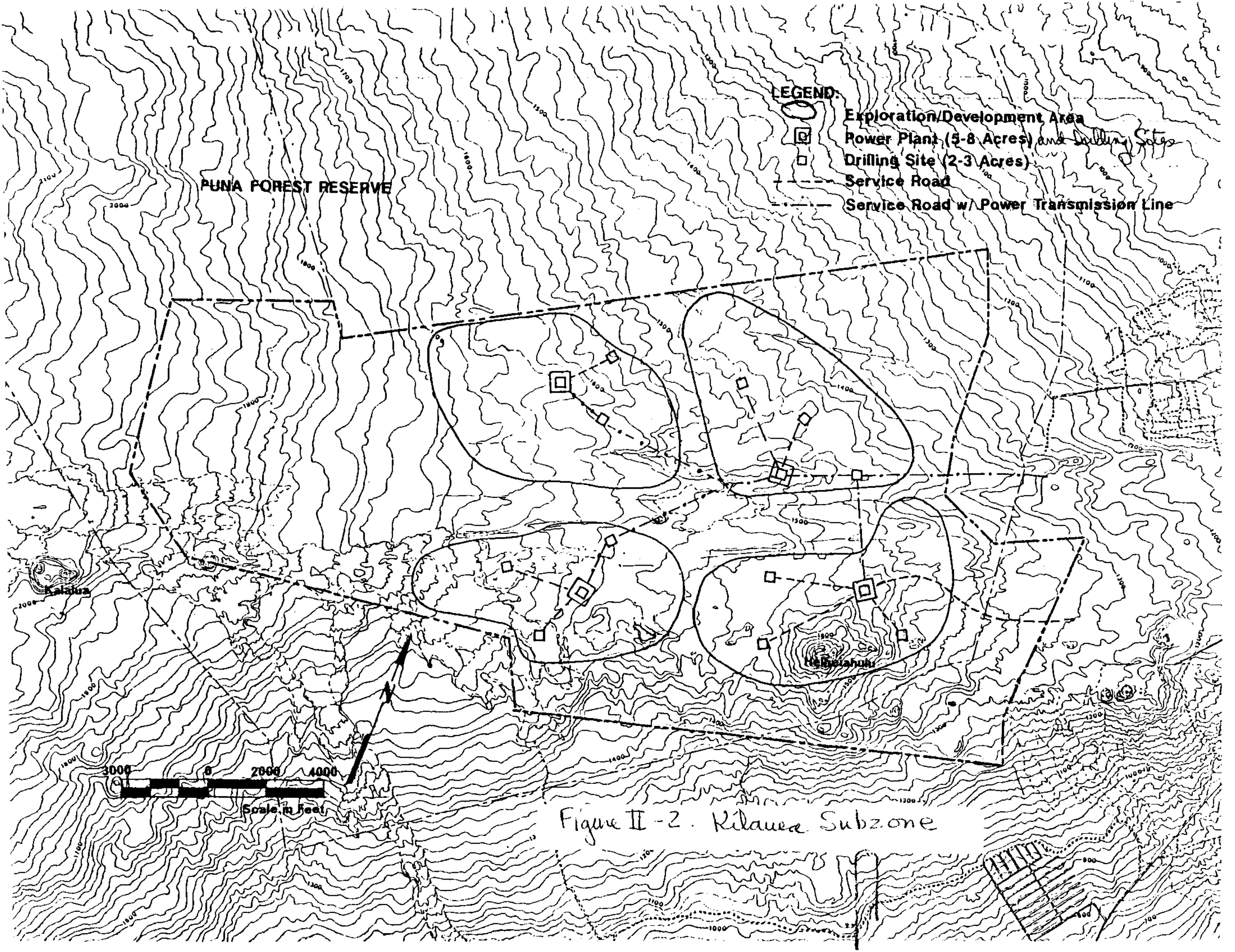


Figure II-2. Kilauea Subzone

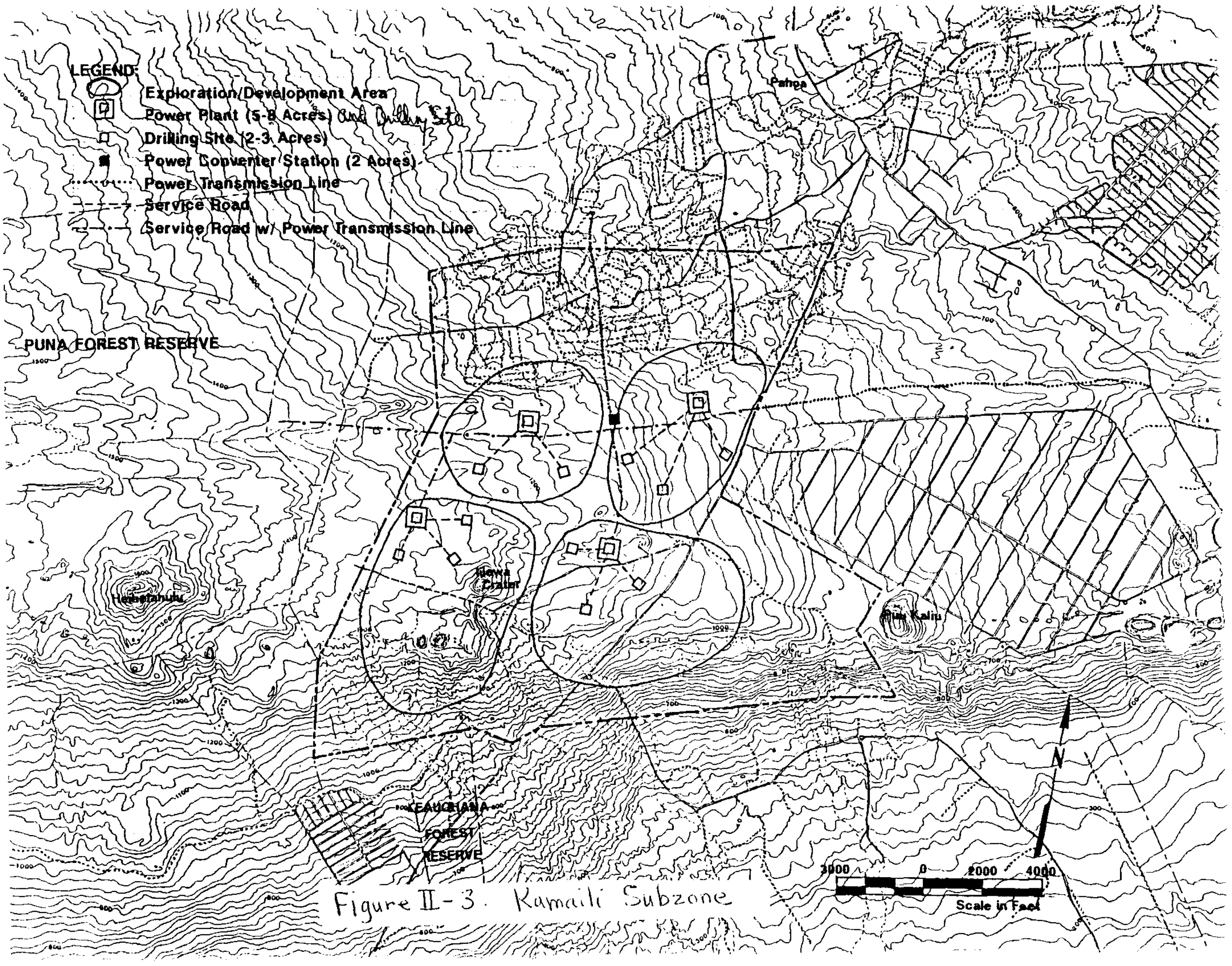


Figure II-3. Kamaili Subzone

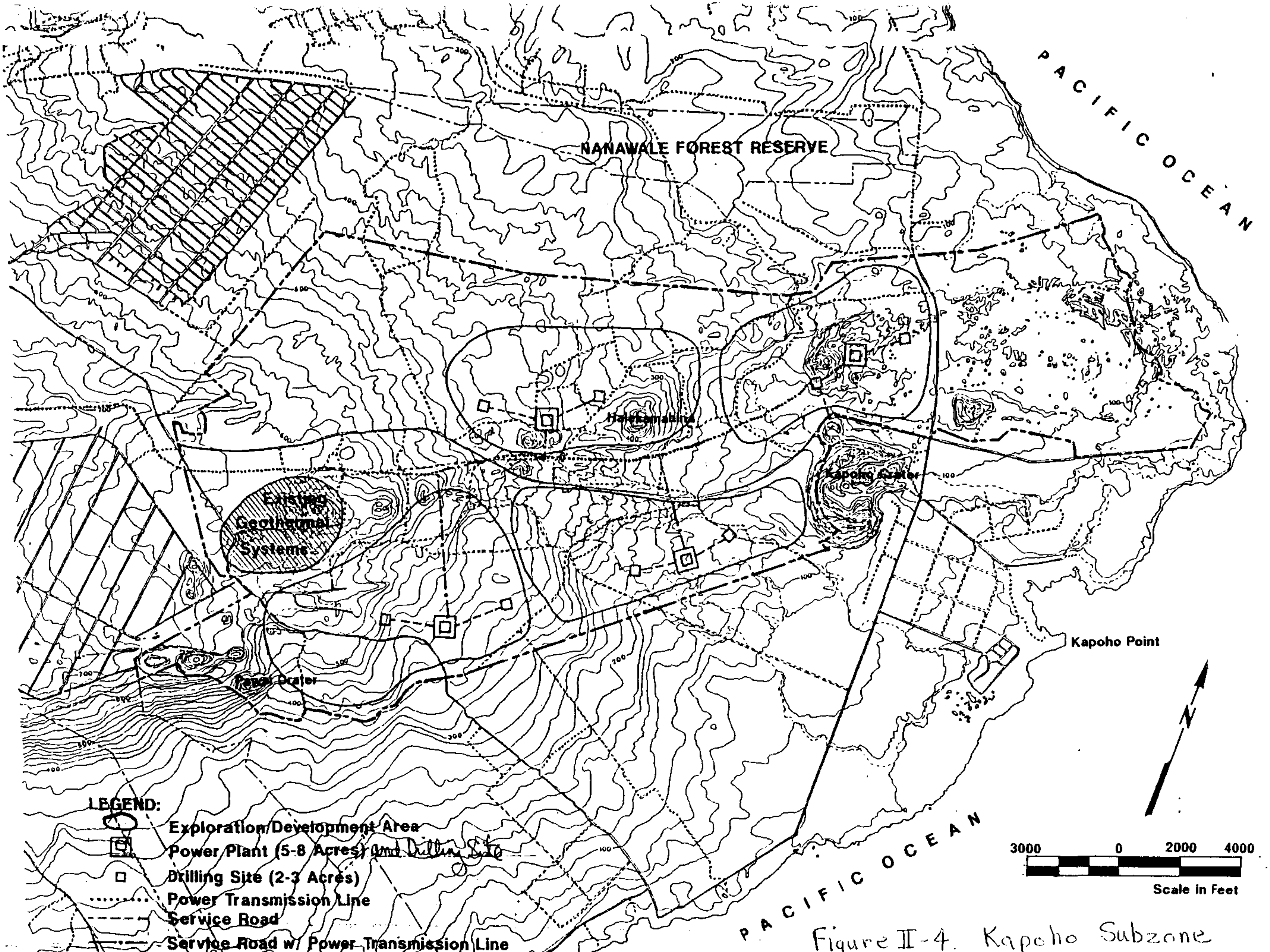


Figure II-4. Kapoho Subzone

to be Revised by RMT

TABLE 2.1
ESTIMATED LAND AREA REQUIRED FOR DEVELOPMENT

LAND USE	LENGTH	WIDTH	AREA	GRS AREA
A. KILAUEA MIDDLE EAST RIFT GRS				
Power Plant Sites (4)			5-8 Ac Ea	20-32 Ac
Drilling Sites (15)			2-3 Ac Ea	38-57 Ac
Primary Service Roads	7.8 mi.	30 ft		28 Ac
Well Field Service Roads	7.9 mi.	20 ft		19 Ac
Geothermal Fluid Lines	8.9 mi.	10 ft		11 Ac
Power Transmission Lines	7.8 mi.	48 ft		45 Ac
Miscellaneous Use				16 Ac
			Total GRS Area =	177-208 Ac
B. KAMAILI SECTION OF THE KILAUEA LOWER EAST RIFT GRS				
Power Plant Sites (4)			5-8 Ac Ea	20-32 Ac
Drilling Sites (15)			2-3 Ac Ea	30-45 Ac
Primary Service Roads	3.7 mi.	30 ft		13 Ac
Well Field Service Roads	4.6 mi.	20 ft		11 Ac
Geothermal Fluid Lines	4.6 mi.	10 ft		6 Ac
Power Transmission Lines	5.0 mi.	48 ft		29 Ac
Power Converter Station (1)			2 Ac	2 Ac
Miscellaneous Use				10 Ac
			Total GRS Area =	121-148 Ac
C. KAPOHO SECTION OF THE KILAUEA LOWER EAST RIFT GRS				
Power Plant Sites (4)			5-8 Ac Ea	20-32 Ac
Drilling Sites (12)			2-3 Ac Ea	24-36 Ac
Primary Service Roads	2.6 mi.	30 ft		9 Ac
Well Field Service Roads	2.6 mi.	20 ft		6 Ac
Geothermal Fluid Lines	3.1 mi.	10 ft		4 Ac
Power Transmission Lines	9.3 mi.	48 ft		54 Ac
			Total GRS Area =	127-151 Ac
			TOTAL SURFACE AREA =	425-507 Ac

- o. overhead AC power lines to deliver the geothermally-generated energy to a nearby AC-to-DC converter station.
- o. overhead DC power lines to transmit the electricity from the converter station to the termination station of the submarine cable.

Inherent in this process is preliminary exploration which is necessary in order to fully define the extent and characteristics of geothermal reservoirs in the three geothermal resource subzones (GRS) of the east rift zone.

2.0 Siting and Development Criteria

Within the GRS, surface areas for geothermal development would be selected on the basis of the following factors:

- o. geological analyses of the rift zone;
- o. an evaluation of surface expressions that are indicative of earlier volcanic activity;
- o. the presence or absence of environmentally significant and developed areas (which must be avoided);
- o. the slope of the surrounding terrain;
- o. avoidance of those sections of the active rift zone with significant faults and cracks; and,
- o. a preference for sites where the presence of surface features along the rift zone would tend to minimize the potential for lava flows into the development area (see Section III-A).

Based on the above considerations, exploration and development within a GRS would most likely occur on both sides of the rift zone.

Prospective drilling sites would be evaluated by the factors listed above and by:

- o. the need to locate wells at sufficient distance from other wells to assure the maximum effective exploration/development effort over the area with a minimum amount of drilling; and,
- o. the need for appropriate spacing to enhance the production life of discovered reservoirs;

Depending upon drilling results and testing, the final surveyed location of each proposed well would be identified in each application for a drilling permit for each well.

Power plant sites would be located within two miles of the furthest well site supplying steam to the plant. In order to insure that air quality standards can be met, there is a minimum distance of one mile between plants.

Service roads and transmission pipelines would be constructed between wells and power plants and transmission lines would connect the power plants to the converter station.

Sections D through H, which follow, present generic descriptions of the components of geothermal power generation. The information was compiled from existing literature relating to proposed geothermal developments in the area (e.g. Revised Environmental Impact Statement for the Kahauale'a Geothermal Project, R.M. Towill Corporation (1982) and Final Supplemental Environmental Impact Statement to the Revised Environmental Impact Statement for the Kahauale'a Geothermal Project, True/Mid-Pacific Geothermal Venture (1986).

D. TECHNICAL DESCRIPTION OF THE DESIGN, CONSTRUCTION AND OPERATION OF GEOTHERMAL WELLS

1.0 Drilling and Well Testing

a) Well Site Description

The conceptual geothermal system (Figures II-2, II-3 and II-4) indicates a grouping of well sites for each power plant. The well field would include the drilling sites that feed geothermal fluids into the power plant and the associated well field roads and pipeline corridors. The layout presented in the figures shows a preliminary distribution of drilling sites and well fields based upon the presumed uniform distribution of the underground geothermal reservoir. The drilling, operation and maintenance of geothermal wells are closely regulated by the State regulations, "Rules on Leasing and Drilling of Geothermal Resources," Chapter 183, HRS.

Ideally, well fields would be developed in areas of highest geothermal resource potential and least volcanic hazards potential. A siting constraint in the conceptual system is that no geothermal power plant of greater than 50-55 MW capacity should be constructed in any one location, to avoid any possible overload effect on the environment. In addition, a power plant well field must be located within a two-mile radius of the power plant to limit costs and to prevent unacceptable heat losses in the movement of the hot fluids to the plant. The ultimate pattern of the developed well fields would evolve with time as the productive geothermal resource zones are identified and developed. All drilling sites would be validated by ground surveys.

Power plants would generally be located adjacent to the rift zone. The well fields, of necessity, must extend down to and through the rift zone to tap the most probable geothermal resource location. In most cases, well field roads would traverse the rift zone at a right angle to minimize the obstacles in crossing the faults and cracks of the rift zone, and to provide the most direct routes away from the rift zone in case of volcanic activity. A reasonable offset distance from all property boundaries is desirable for all surface construction activity, e.g., drilling sites and well field roads. Actual underground drilling may be conducted to within 100 feet of all property boundaries through use of directional drilling from the drilling sites.

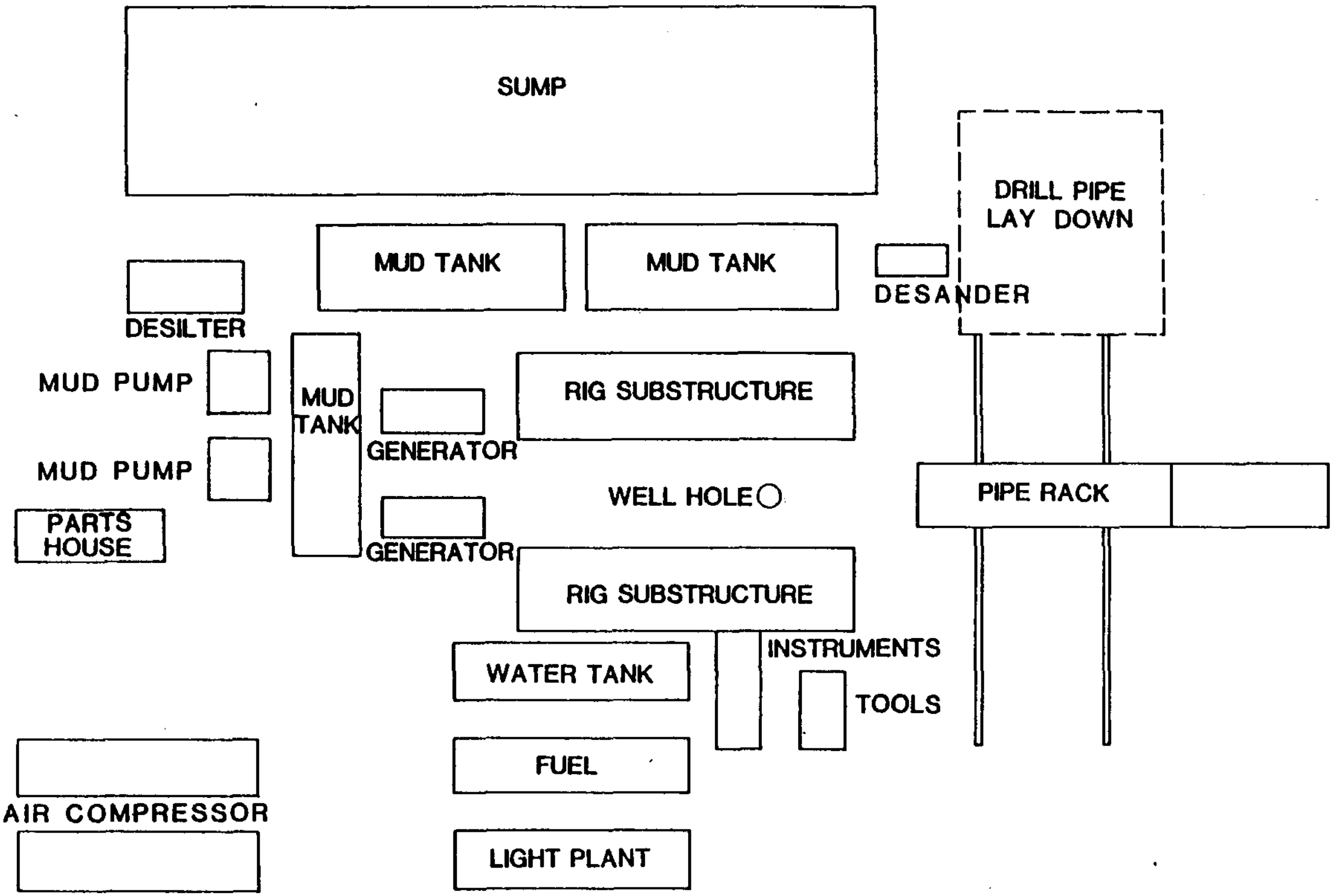
Each multiple well drilling site would encompass approximately five acres of land, however, only about two acres would have to be cleared initially for the first well drilled. Only if the exploration results in a discovery of a producible resource, would the drilling site be expanded to five acres.

A single well site (Figure II-5) would consist of a cleared rectangular area, approximately 500 feet in length by 300 feet wide, with a 60-foot wide perimeter for safety and control. Multiple production wells would be drilled directionally from the same site, using small (30 to 50-foot) offsets from the previous well holes on the drilling site. The site would also include a 750,000 gallon (100,000 $ft.^3$), ten to twelve foot deep disposal sump.

b) Drilling

Figure II-6 illustrates the basic elements of a rotary drilling rig, typical of the type that would be used in developing the GRS. The rig is capable of drilling to depths of 13,000 feet using 4-1/2-inch drill pipe with 3-1/2-inch drill pipe below 11,000 feet.

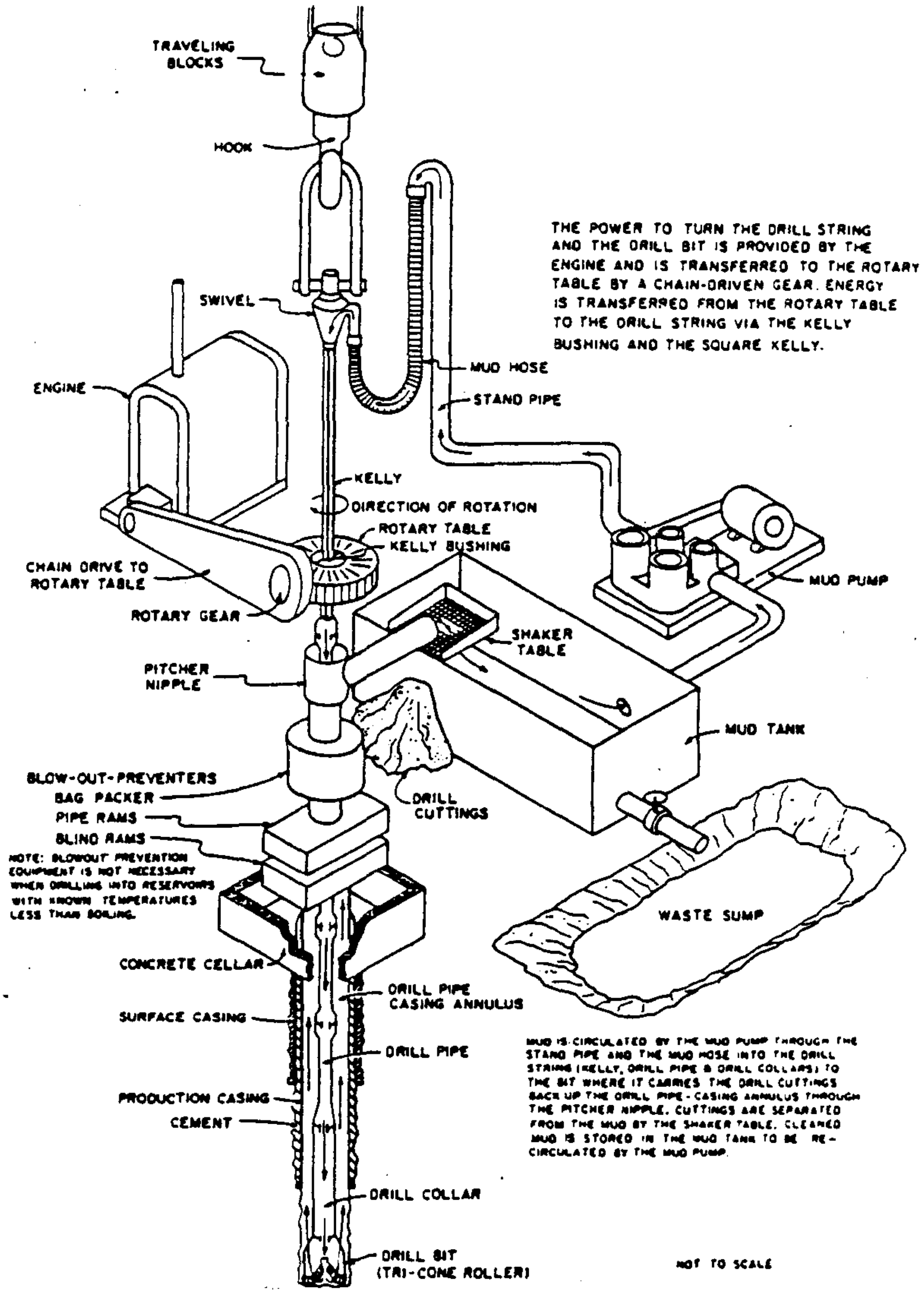
Transportation of the drilling rig, auxiliary equipment and supplies into the project area would require three-axle trailers with tandem tractors able to haul loads up to 40,000 lbs. Transfer of all equipment and supplies to a drill site would be expected to take three days.



(NOT TO SCALE)

FIGURE ~~2-8~~ II-5

DRILLING SITE LAYOUT



THE POWER TO TURN THE DRILL STRING AND THE DRILL BIT IS PROVIDED BY THE ENGINE AND IS TRANSFERRED TO THE ROTARY TABLE BY A CHAIN-DRIVEN GEAR. ENERGY IS TRANSFERRED FROM THE ROTARY TABLE TO THE DRILL STRING VIA THE KELLY BUSHING AND THE SQUARE KELLY.

NOTE: BLOWOUT PREVENTION EQUIPMENT IS NOT NECESSARY WHEN DRILLING INTO RESERVOIRS WITH KNOWN TEMPERATURES LESS THAN BOILING.

MUD IS CIRCULATED BY THE MUD PUMP THROUGH THE STAND PIPE AND THE MUD HOSE INTO THE DRILL STRING (KELLY, DRILL PIPE & DRILL COLLARS) TO THE BIT WHERE IT CARRIES THE DRILL CUTTINGS BACK UP THE DRILL PIPE - CASING ANNULUS THROUGH THE PITCHER NIPPLE. CUTTINGS ARE SEPARATED FROM THE MUD BY THE SHAKER TABLE. CLEANED MUD IS STORED IN THE MUD TANK TO BE RE-CIRCULATED BY THE MUD PUMP.

NOT TO SCALE

FIGURE ~~2-9~~ II-6

BASIC ELEMENTS OF A ROTARY DRILLING RIG

The drilling program would usually be divided into phases, according to the type of drill pipe or casing to be installed at various depths. All geothermal wells (Figure II-7) would be cased with standard drill pipe to protect the environment, groundwater resources, geothermal resources, life, health and property. Casing is normally classified according to depths installed or function as follows:

- <u>Conductor Pipe.</u> The first string of pipe installed, normally 20-inch diameter to 150 feet (100 lbs./ft.), set in a 26-inch hole.
- <u>Surface Casing.</u> 13 3/8-inch-diameter API grade to 2,500 feet (50 lbs./ft.), set in a 17 1/2-inch-diameter hole.
- <u>Intermediate Casing.</u> Nine and 5/8-inch-diameter to 3,600 feet (36 lbs./ft.), set in a 12 1/4-inch hole. Set with hanger in 13 3/8-inch casing.
- <u>Production Liner.</u> Seven-inch-diameter from the top of the producing interval to total depth installed in a eight and 3/4-inch-diameter hole. It also would be set with hanger in a nine and 5/8-inch-diameter casing.

Each well would have a casing head installed on the surface casing; a master gate valve would be installed to this and would be left on the well. In addition, a hydraulically operated master gate valve with annular preventer would be installed; when air drilling is being conducted, a rotating head would be installed for positive control.

If the subsurface geology permits, air drilling would normally be conducted from the surface to total depth. Two low stage compressors with 1,200 CFM and one high stage compressor for pressure up to 400 psi would be used, providing the formations drilled are compatible. Air drilling is generally successful in hard rock, where there is no influx of formation waters.

When air drilling is not possible, mud drilling would be conducted. The typical rig to be used has three steel mud tanks with 750 bbl capacity each; also an earthen reserve or storage pit would be dug and lined to handle excess fluid. The lowest weight per gallon ratio possible and the least viscosity possible would be used to remove the cuttings from the formations drilled. Mud drilling in the softest formations would require

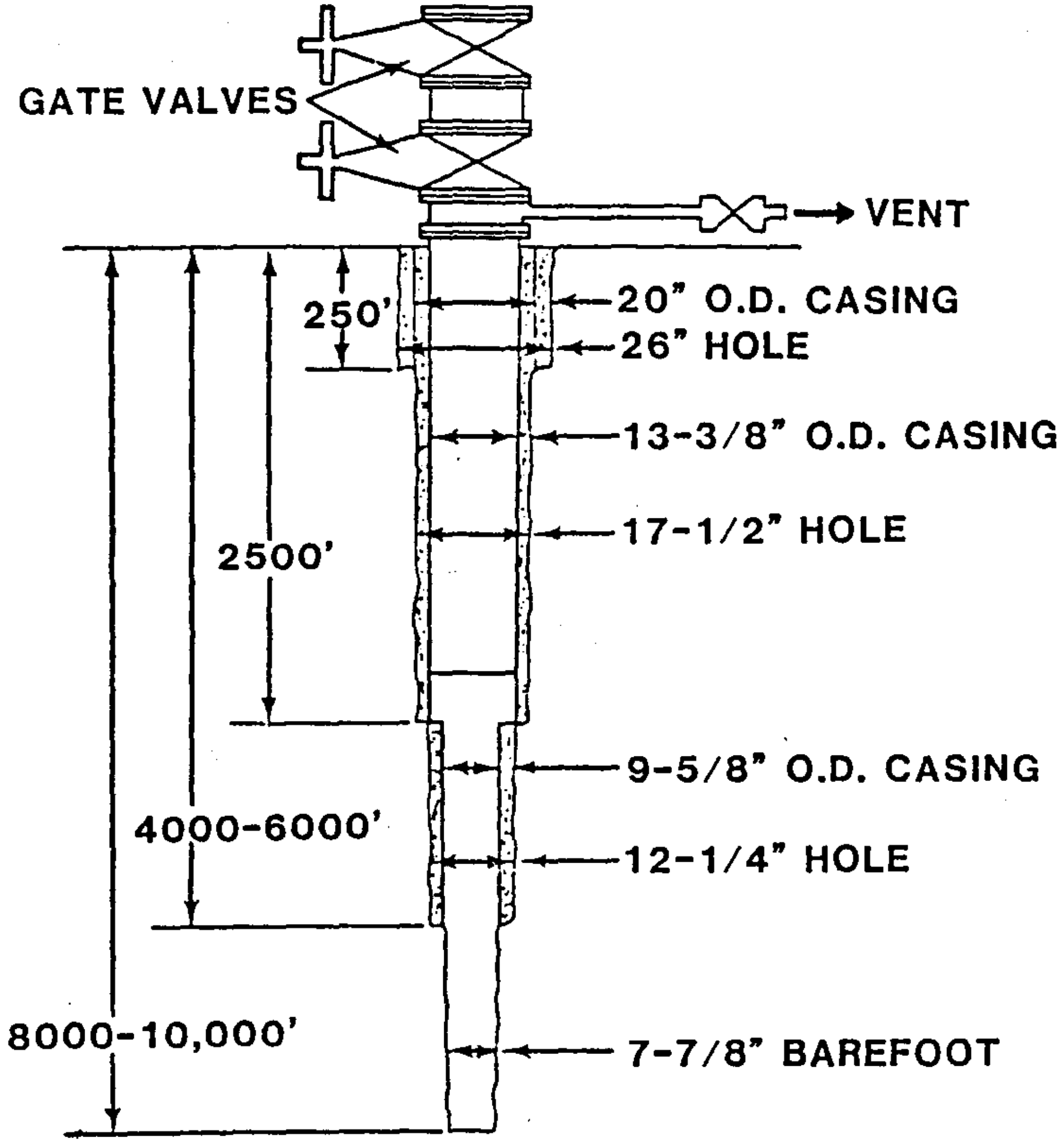


FIGURE ~~2-10~~ II-7

TYPICAL WELL PROFILE

approximately 2,000 barrels of water per day; approximately 100 barrels per day would be required when drilling in hard formations. Rain catchment systems could be used as supplemental sources to meet on-site water requirements.

All casings would be joined and cemented to assure the integrity of the well bore from surface to the producing interval. The objectives of cementing the casing are twofold: (1) to completely in-fill the cased and open hole annuli in order to resist landslides and groundwater movement; and, (2) to anchor the casing sections to each other and to the ground. The cement sheath is intended to protect the casing against possible corrosion by thermal brines and gases; prevent uncontrolled flow of thermal water and steam outside the casing; and minimize creep due to thermal expansion. The casings would be cemented using Type G cement from the bottom of casing to the surface in accordance with industry standards. The nine and 5/8-inch casing would be landed with hanger which would be cemented from the hanger point to the top of the producing interval. If necessary, the seven-inch liner would also be landed with hanger, from the base of the nine and 5/8-inch casing to total depth.

c) Safety Considerations

The following standard safety devices are typically used to protect against a blowout from the well:

- One Double Gate preventer with CSO rams plus 4-1/2-inch drill pipe rams, 12-inch 900 series.
- One Annular Preventer 12-inch 900 series.
- One Rotating Head when air drilling.

The blowout prevention system would be individually designed for each cemented casing string. Safety would be stressed in all aspects of the operation. All employees would be instructed in closing and opening the hydraulically operated blowout preventers (BOP's). (Figure II-8 shows a typical blowout preventer system designed for high pressure wells).

Hydrogen sulfide (H_2S) is a constituent of the geothermal fluid (in varying degrees) as a noncondensable gas. Abatement systems would be installed to control H_2S emissions during extended well testing as well as during power plant operations. H_2S detectors would be

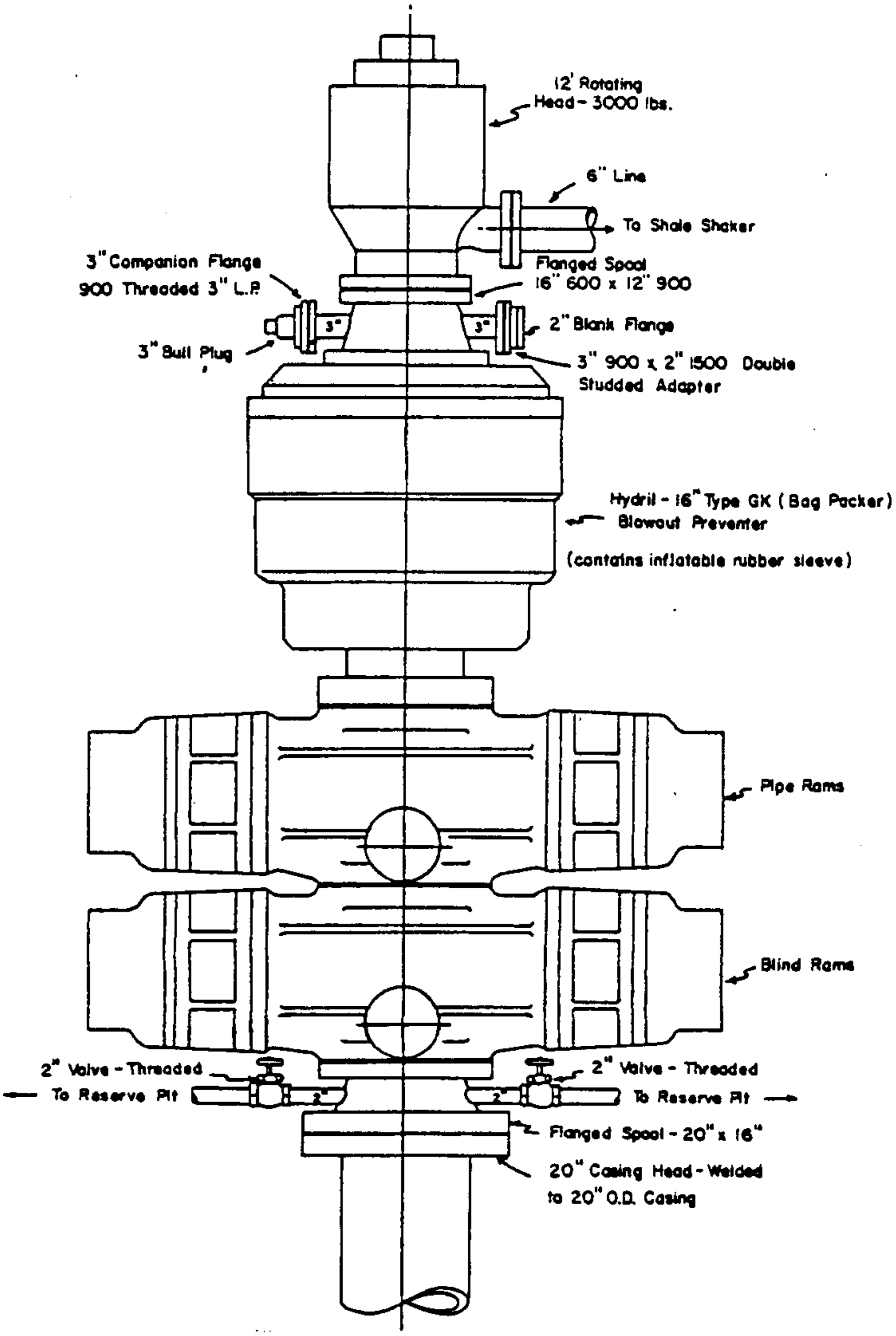


FIGURE ~~2-11~~ II-8

BLOWOUT PREVENTER SYSTEM

mounted at various locations throughout the active area of operations for emission monitoring and control.

While drilling, all data would be logged by a well site geologist. If it is later determined that a well must be abandoned, data from the logs would be analyzed in order to determine the formations that would need to be covered by cement. The plugging would be performed through open ended drill pipe using Type G cement in accordance with industry standards. After the downhole plugging is completed, a cement plug would be placed in the top of the surface casing.

d) Well Testing and Reservoir Evaluation

The following criteria would be used to determine the potential of a reservoir to support a power generation operation at full capacity for 25-30 years:

o. Depth and subsurface structure.

o. Temperature of the fluid.

o. Downhole enthalpy.

o. Flow rate of each well.

o. Chemistry of the geothermal fluid.

o. Reservoir and production zone dimensions (reserves).

o. Reinjection potential.

Well testing would be most likely accomplished by following a procedure similar to that used when the HGP-A well in Puna was tested. (In that instance, both noise and environmental pollution abatement was achieved by use of a "sparging pit" and also injecting caustic soda to remove unwanted hydrogen sulfide gas). Tests would also be conducted on the integrity of the well to bottom hole through casing, logging of the cementing tests, and pressure testing.

The initial test conducted, after each well is completed, would be for the purpose of obtaining an approximation of its electric power production potential. If the well is judged to have commercial production potential, portable flow testing equipment would be installed in order to acquire complete data on the physical and chemical characteristics of the reservoir fluids. The testing equipment would include: a flash steam separator; skid-mounted flow metering and temperature measurement equipment for steam and brine; noncondensable gas sampling equipment; and, injection and mixing equipment for H_2S abatement with caustic soda.

A warm-up pond or reserve pit would be constructed at each producing well site to receive the geothermal fluid flow during the production tests. The reservoir fluids from each well would be evaluated and appropriate regulatory agencies would be contacted in order to determine whether the fluid could be percolated into the ground or if pond liners would be required. The chemistry of the well fluids would be expected to be relatively benign and, due to the highly porous nature of the topsoil and near surface formations, should percolate readily into the ground.

During production tests, production rates, steam water ratio, hydrogen sulfide content, salinity, fluid chemistry, and noncondensable gas content would be monitored. The data base developed from the monitoring process is necessary in order to evaluate the production capability and reliability of the resource. The data is also required to provide design criteria for the power plant and associated pollution abatement systems.

2.0 Operations and Maintenance

a) The Production System

Fully implemented well field production systems would consist of production wells, well head equipment, pipelines and disposal systems which would be managed through an integrated operations and maintenance system. Well field production systems for each area would be essentially the same, except where applications of new technology are made.

The geologic and geo-hydrologic characteristics of the Island of Hawaii are unique in comparison to other producing geothermal resources in the world, therefore, it is not possible at this stage of experience with the Kilauea east rift system to predict the long-term response of the wells to sustained high volume production. There is little published data available on production histories of the various reservoirs. Therefore, based on a study of the Cerro Prieto field in Mexico by J. de J. Sanchez R. and A. de la Pena L., it is assumed that each 55 MW plant will require eight replacement production wells and four replacement disposal wells over a 30 year period.

b) Geothermal Fluid Gathering System

The design of the gathering system that would carry the geothermal fluids to supply the power plants would be based on the following resource characteristics:

- o. Enthalpy (downhole)
- o. Wellhead Pressure
- o. Wellhead Temperature
- o. Flow Rate
- o. Well Spacing
- o. Projected Well Flow Decline with Time
- o. Reservoir Chemistry

The gathering system used to collect the hot geothermal brine would most likely consist of a pipeline network designed for two-phase flashing flow from the well sites to a flash steam separator at the power plant. The two-phase flashing flow design would simplify the gathering process by not requiring wellhead or satellite separators, and eliminate the need for two pipelines. Considerations of topography, flow characteristics, and economy in the pipeline network would be utilized to optimize the final design of the network.

The gathering system piping would be of carbon steel, four to six feet above ground, mounted on saddles, with anchors and expansion loops as required by dynamic forces and thermal movements. The 16 to 22-inch pipes would be insulated to minimize heat loss. Additional lateral restraints might be required to protect against possible lava flow hazards.

The separator (or flash tank) would be the primary component involved in the flashing process. Mixed brine and steam flow would enter the separator at the inlet from the gathering main, and that portion of the flow flashed to steam would be directed to the single stage turbine. All unflashed brine would flow to the silica drop-out pond and then to the suction header of the injection pumps. The separator would have provisions for pressure control and would be equipped with safety relief valves which would open in the event of a turbine trip or other occurrence causing the main steam stop valves to close.

c) Geothermal Fluid Disposal System

Hydrothermal fluids with chemistry similar to that expected to be found in the east rift zone are known to begin precipitating silica as they cool below 150 degrees C. Because the residence time in the flashing equipment would be less than three minutes, only a nominal amount of silica scaling would be expected at that stage. In order to eliminate potential plugging in the injection piping and wells, however, the spent fluids would be cooled in ponds to drop out silica prior to transfer to the injection pumps. The cooled fluids would be mixed with the spent caustic stream from the H_2S abatement system and the neutralizing cooling tower blowdown and pressured through polishing filters. The silica system would probably be sized to provide an hour of residence time and cooling to about 70 degrees C.

Injection pumps at the power plant would be installed to return effluent from the silica dropout system and transfer clear effluent into the ground at a suitable injection site near the geothermal reservoir. The injection pumps would receive effluent primarily from the flash separator, the cooling tower basin blowdown pumps and the bypass stream H_2S abatement system. The pumps would be rated to deliver effluent through the solids polishing filters and then to the wellheads at a wellhead pressure adequate to inject the design flow into appropriate geological formations. It is possible that injection wells would be required to dispose of the residual fluids of geothermal power generation in order to avoid environmental degradation to the area and to minimize temperature loss within the production field.

It is estimated that 65 to 75 percent of the original reservoir fluid would be available for injection. It can be assumed that a disposal well would consume more fluid than a production well can produce because of the added effect of the hydrostatic column of water. Thus, only one disposal well may be required for every three operating production wells.

The following criteria for the design and operation of disposal wells are stated in approximate order of importance:

- On the basis of flow and interference tests there should be communication between injected fluid and production wells.
- Disposal zones should be at least as deep as production zones, to allow for reheating and upwelling of the injected fluid. This would enhance the maintenance of reservoir mass and

pressure, with minimum loss of temperature. Disposal depth must be set at a distance below freshwater aquifers, if they exist, to avoid possible degradation of the quality of these waters.

- Wherever possible, disposal wells should be downslope of the power plant, to allow for gravity flow disposal, at significant savings in energy.
- Wherever possible, unsuccessful wells should be used as injection sites rather than drilling additional disposal holes. This would significantly reduce drilling costs as well as reducing the environmental impacts of drilling.
- Disposal wells should be located at or as close as possible to the power plant to reduce pipeline costs and the amount of disturbance to the land.

It is evident from the above criteria that disposal sites should not be selected until well testing is completed. If long-term tests show that there is no direct communication between holes in some quadrant of the field, and if permeability is adequate, unsuccessful wells in that quadrant could be converted to disposal wells. This would be the most economical disposal solution.

If the use of unsuccessful wells is not feasible, disposal sites should be selected at or just beyond the field margins, utilizing downhill flow at short distances from the power plant. Disposal wells should then be drilled at these sites. If field boundary-definition wells have been drilled at the same time as the production wells, it would be easy to convert non-producing wells of this type into disposal wells. Productive boundary-definition wells would serve to extend the field and increase the estimated reserves of geothermal energy.

The injection system piping would be similar to the gathering network; the pipes would be constructed of carbon steel and mounted aboveground. All piping would be nominally insulated, as required, to preclude temperature losses which could lead to scale build-up in the injection system piping, and for protection of personnel.

In the event of unexpected drops in power demand, load shedding would require some venting of production steam, which would have separate abatement equipment for H_2S control. The H_2S abatement of the bypass steam could be accomplished by neutralizing with caustic soda in a scrubber or such other techniques as might be available. The H_2S would then be injected in the chemically-bound condition as sodium sulfide (Na_2S) together with the effluent from the main scrubber. Due to the remoteness of the proposed plant sites, the normal noise attenuation provision for geothermal power plants would be expected to minimize noise effects on human populations that might be caused by a bypass flow of a portion of the resource production.

d) Composition of the Geothermal Fluid

The composition of the geothermal fluids in the Puna Geothermal Region have been characterized for four wells in the region, three from the Puna Geothermal Venture (PGV) site (Site KS-1, KS-1A and KS-2), and one at the HGP-A well. Composite data for geothermal fluid chemical composition and noncondensable gas composition from these wells are presented in Tables 2.2 and 2.3, respectively.

E. TECHNICAL DESCRIPTION OF THE DESIGN, CONSTRUCTION AND OPERATION OF GEOTHERMAL POWER PLANTS

The following discussion describes the design, construction and operation of 55 MW geothermal power plants. Descriptions of 12.5 MW and 25 MW plants are presented in Appendix B.

To permit assessment of the impact of power plant construction and operations in the GRS, drawings of typical operating units are included in this section. These drawings depict plants that have been designed and are in operation at other locations. The power plants that would be constructed for a 600 MW system would be expected to be similar to those described. The actual design would be based on the nature and characteristics of the resource discovered; the most appropriate abatement system available at the time of construction would be utilized.

1.0 Power Plant Design

a) Building and Site Characteristics

o. <u>General Description</u>. The 55 MW geothermal plant is shown in perspective in Figure II-9. This scale of operation would require a sizeable hydrogen sulfide abatement facility and silica drop-out system. The overall site acreage requirement is approximately 8 acres, including a 60-foot cleared area around the site for security and control purposes. Figure II-10 illustrates a conceptual site layout and a

TABLE ~~2-1~~ 2.2

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	0.10
Ca	40 - 920	0.10
Mg	1 - 2	<0.1
Fe	<1 - 8.4	0.05
Mn	<1 - 8.5	--
B	4 - 11	<0.05
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_3	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.

Source: Fluor Technology, Inc. (1987)

TABLE ~~3-2~~ 2.3

NONCONDENSABLE GAS COMPOSITION
COMPOSITE DATA[a]

7

GAS	Observed Steam Content 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

---

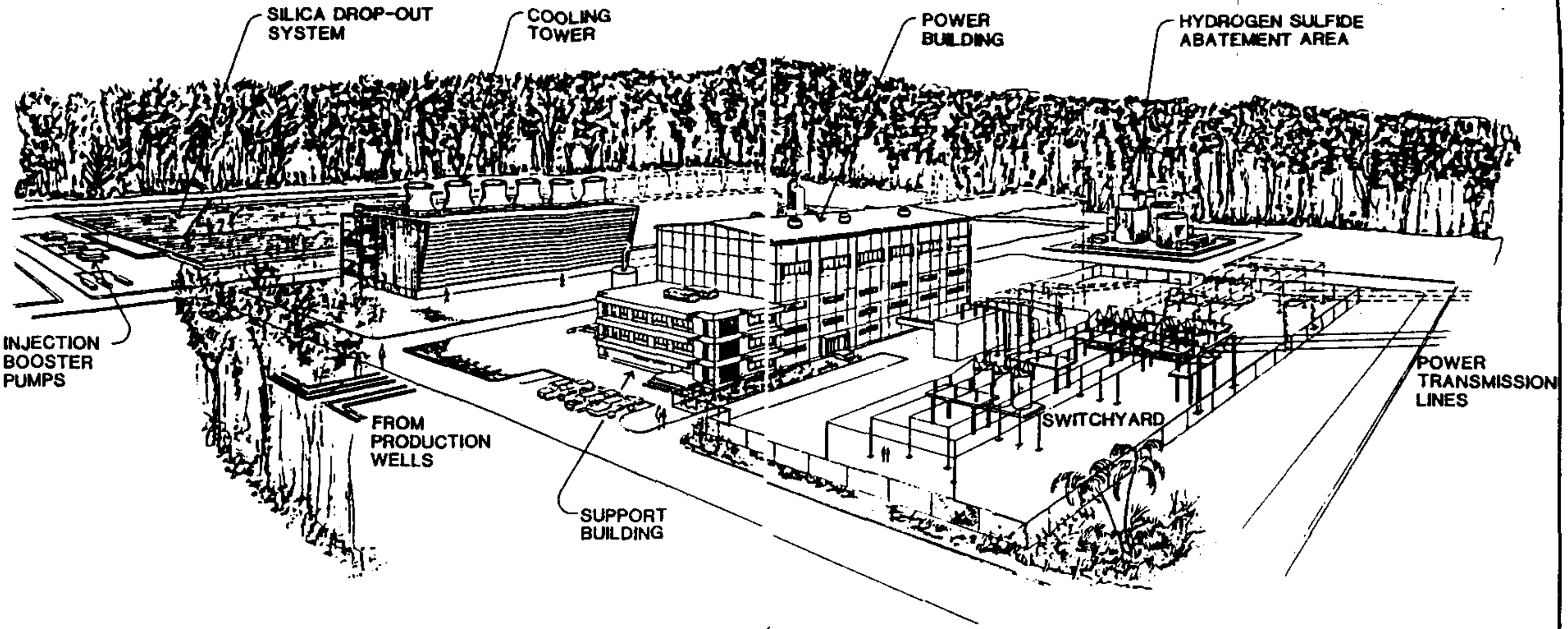
[a] Composite data from three wells on the PGV site (KS-1, KS-1A, and KS-2) and the HGP-A well.

[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).

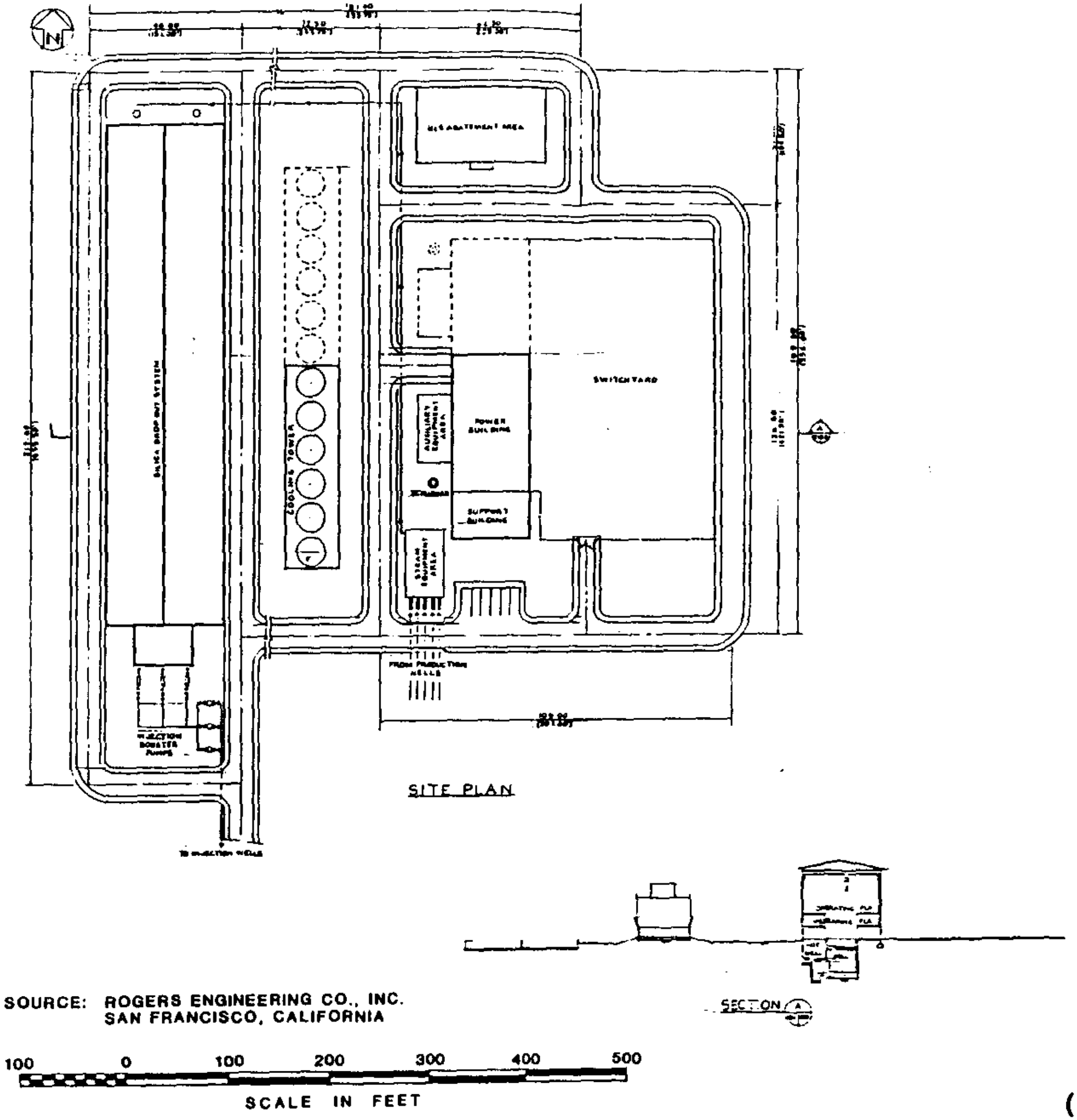
Source: Fluor Technology, Inc. (1987)



SOURCE: ROGERS ENGINEERING CO., INC.
SAN FRANCISCO, CALIFORNIA

FIGURE ~~2-18~~ II-9

PERSPECTIVE
55MWe POWER PLANT
(WITH EXPANSION TO 110MWe)



NOTES
1. BUILDING CAN BE EXPANDED TO THE NORTH IF AN ADDITIONAL 55 MW UNIT IS REQUIRED.
2. COOLING TOWER CAN BE EXPANDED TO THE NORTH IF AN ADDITIONAL 55 MW UNIT IS REQUIRED.

SOURCE: ROGERS ENGINEERING CO., INC.
SAN FRANCISCO, CALIFORNIA

FIGURE ~~2-19~~ II-10

SITE PLAN AND SECTION
55MWe POWER PLANT
(WITH EXPANSION TO 110MWe)

typical section cut through the facility for the 55 MW plant.

The overall dimensions of the 55 MW building would be approximately 170′ x 80′ and 75 feet high; a transverse section of the building is shown in Figure II-11. The power plant building for a system capable of producing 55 MW would be comprised of a fully enclosed 2-story structure, containing all of the major mechanical and electrical equipment, approximately 75 feet high in combination with a 3-story control/administrative. The power plant building is identified by the six bays at the right of Figure II-11. The lower portion of the structure, shown on the left of the Figure, is the "Support Building" - a three-level structure which contains administrative offices, the main control room, and most of the storage and maintenance facilities.

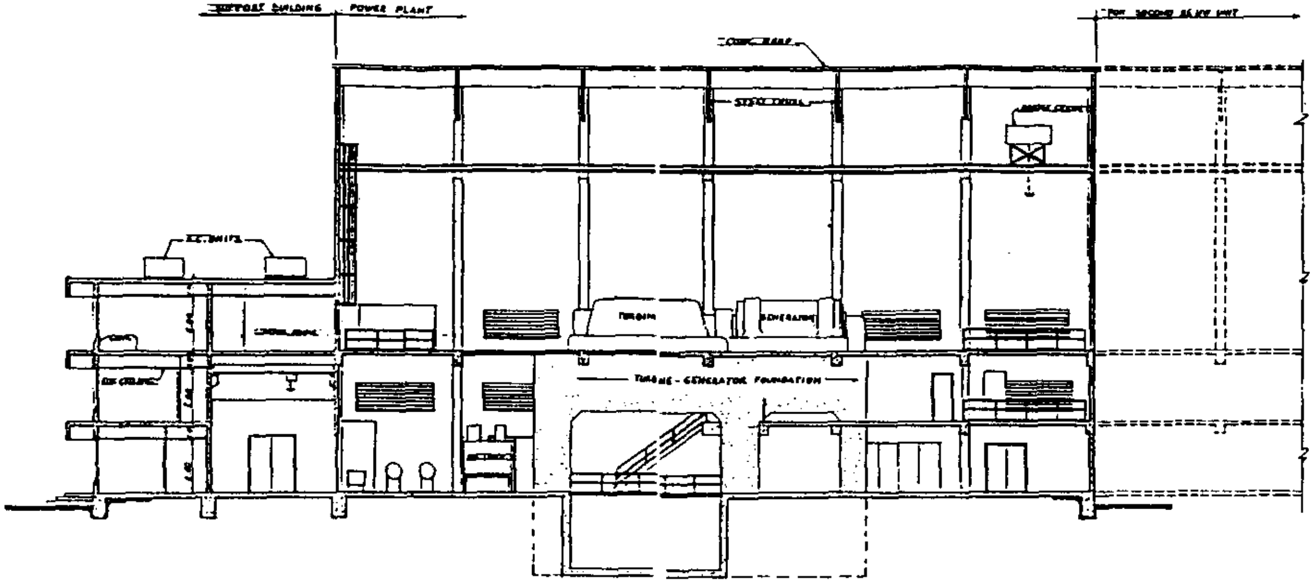
The main operating floor, 22 feet above the ground floor, would be comprised of steel framing with a concrete-filled steel deck designed for 250 psi. Certain areas would have steel grating. The general structural arrangement of the main building would be rigid steel frame designed on 24-foot bays, with girts and purlins, respectively, to accommodate galbestos, or similar, wall and roofing panels. A bridge crane would be incorporated to traverse the entire length of the building.

o. <u>Ground Floor Area</u>. The ground floor of the plant building proper would accommodate the following areas and major equipment:

(a) Loading and Unloading
(b) Machine Shop
(c) Main Condenser
(d) Switchgear
(e) Motor Control Center
(f) Air Compressors
(g) KV Switchgear Control Panel

o. <u>Operating Level</u>. The operating level would accommodate the following areas and equipment:

(a) Turbine Generators
(b) Laydown Area
(c) Clean Parts Storage



TRANSVERSE SECTION 'A-A'

SOURCE: ROGERS ENGINEERING CO., INC.
SAN FRANCISCO, CALIFORNIA

10 0 10 20 30 40 50
SCALE IN FEET

FIGURE ~~2-20~~ II-11

TRANSVERSE SECTION
55MWe POWER PLANT
(WITH EXPANSION TO 110MWe)

Concrete pedestals on rigid mat foundations would support the turbine generators and main condenser units. The pedestals would be of ample rigidity such that no resonance in the natural frequency of the pedestal foundation and the turbine-generator unit would occur. The turbine generator pedestals for the 55 MW units would extend approximately 25 feet below ground level to allow space for the main condenser. The "hot wells" for the main condensate pumps would extend further to about 33 feet below ground.

To suit the functional requirements of the bridge crane in connection with turbine-generator maintenance and access to the laydown area, the ground floor loading area would be open for the full height of the building and open to the operating floor. Fixed windows would extend the full length of the main building; plant generated heat would be dissipated using a system of operable wall louvers in conjunction with open steel grating at the operating level, and roof mounted motor-operated discharge fans.

o. <u>Control/Administrative Modules</u>. The ground floor of a control/administrative module would accommodate the following areas:

(a) Main Entrance/Reception Lobby
(b) Men's and Women's Restrooms
(c) Janitor Supply Room

The second level (mezzanine) of a control/administrative module would accommodate the following areas:

(a) Administrative Office
(b) Staff Room
(c) Restroom
(d) Laboratory
(e) Air Conditioning Equipment

The upper floor of the control/administrative module accommodates the control and clean parts storage.

o. <u>Environmental Control</u>. Instrumentation equipment enclosures, switchgear room and associated electrical equipment, and enclosed personnel areas would be air conditioned and slightly pressurized to maintain a positive air flow of clean filtered air from the equipment and personnel areas to the exterior.

b) Gathering and Injection System

Figure II-12 illustrates the gathering and injection system for a 55 MW power plant. It diagrams the flow of the geothermal fluids from the well field into the power plant. The hot mixed brine and steam flow first enter a high pressure flash drum, followed by entry into a low pressure flash drum. The portions flashed to steam are directed to the double pressure, double flow steam turbine. The unflashed brine is directed to the flash steam mufflers, the silica drop-out system and the injection well pumps.

c) Turbine-Generator System.

The steam turbine for a 55 MW plant would be a double pressure, double flow, impulse/reaction type condensing unit with single cylinder, direct-coupled to a totally enclosed hydrogen-cooled generator.

o. <u>Plant Gross Production</u> (One 55 MW Turbine Generator)

Machine Minimum Capacity	14,000 KW Gross Generation
Machine Normal Capacity	55,000 KW Gross Generation
Machine Maximum Capacity	55,000 KW Gross Generation

o. <u>Auxiliary Load</u>

Power Plant	2,400 KW
Gathering	0 KW
Injection	1,200 KW

	3,600 KW

o. <u>Plant Net Production</u>

Plant Minimum Capacity	10,400 KW Net Generation
Plant Normal Capacity	51,400 KW Net Generation

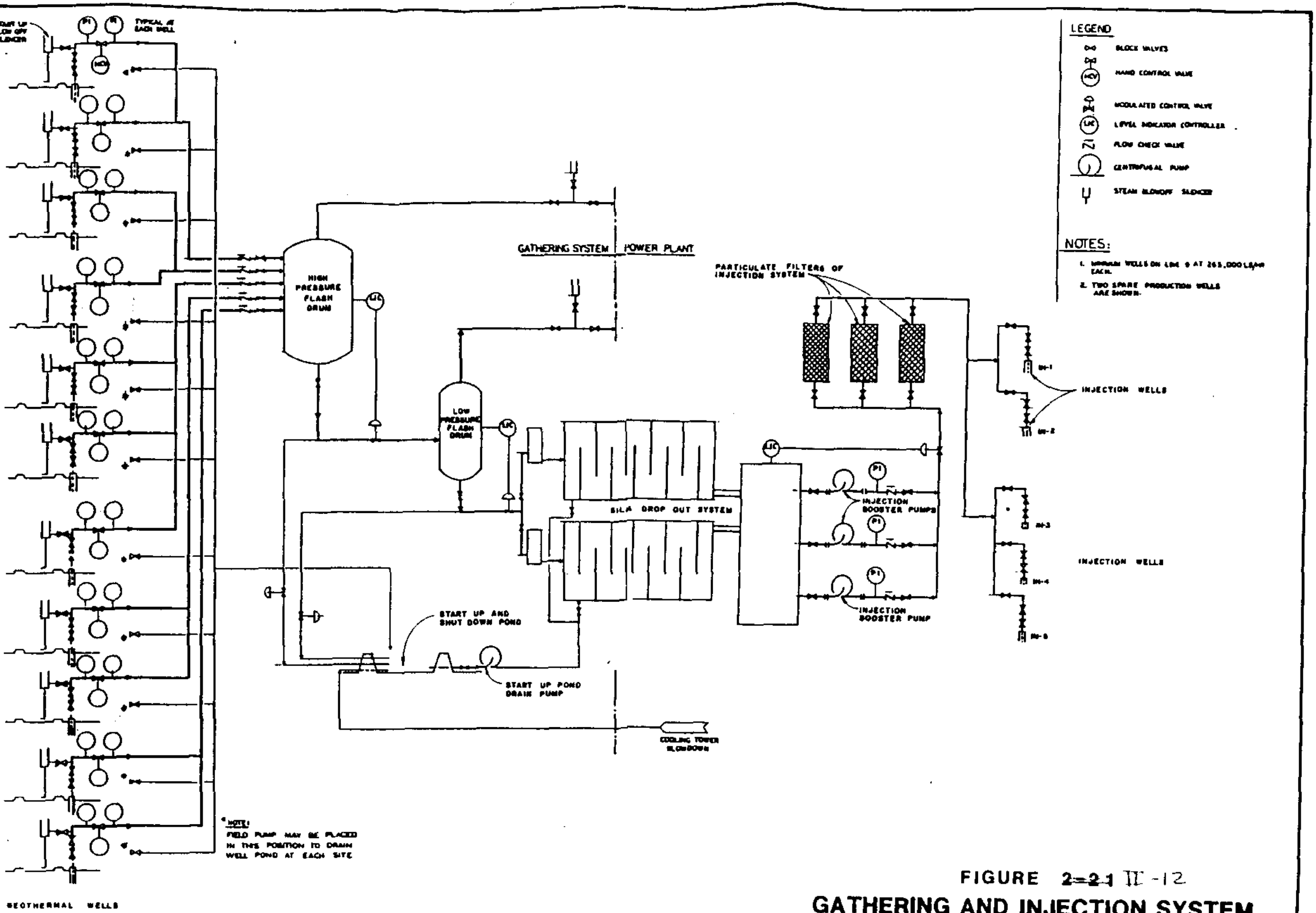


FIGURE ~~2-21~~ II-12

GATHERING AND INJECTION SYSTEM
55MWe POWER PLANT

SOURCE: ROGERS ENGINEERING CO., INC.
SAN FRANCISCO, CALIFORNIA

Plant Maximum Capacity 51,400 KW Net Generation

The turbine generator would be a double pressure admission condensing unit. The equipment would include automatic tripping devices required to protect the unit when a malfunction occurs.

The turbine blading would be stiff and short with stress levels considerably lower than those supplied for comparable fossil fuel steam turbines and would utilize those features which would result in long-term reliable service with geothermal steam. Corrosion resistant materials would be specified for turbine internals in contact with geothermal steam.

The generator supplied with the turbine would be designed in accordance with the latest standards of American National Standards Institute C50.10-75, and C50.13-75 and applicable National Electrical Manufacturers Association and Institute of Electrical and Electronic Engineers, Inc., standards.

The condenser would be designed and constructed, where applicable, to conform with the latest American Society of Mechanical Engineers Code and would be of the surface type. The condenser would be constructed of 316 SS clad carbon steel. Internal parts such as tubes and tube plates would be austentic stainless steel. Water boxes would be carbon steel with epoxy coating. The liquid level in the condenser would be controlled by automatic liquid level controller. All the condensate from the geothermal steam would be returned to the cooling tower. Makeup water for the cooling water system would be provided from the steam condensate.

d) Auxiliary Systems

The auxiliary systems, which would be designed specifically for the special conditions imposed by the utilization of geothermal steam and the site environment, include, but are not limited, to the following:

o. An Auxiliary Cooling Water System

o. A Turbine Generator Lubricating Oil System

o. An Instrument Air System

o. A Fire Protection System

o. Noncondensable Gas Removal System

e) Controls and Instrumentation

A main control panel in the control room would contain electrical and pneumatic controls for the various electrical and auxiliary process systems. In general, pneumatic systems would be used for level, pressure, flow and valve controls. Pneumatic transmitters in the field would provide inputs to the panel- mounted indicators, controllers and recorders. Resistance temperature detectors would provide electrical temperature signals from the field to solid state electronic temperature indicators and controls. Electric control would be used for the turbine generator, switchgear and motors. An annunciator would alert the operator to off normal conditions and indicate causes for turbine trip.

f) Energy Conversion (Process Systems)

Steam from the gathering systems would be supplied to the plant steam lines at the plant boundary (Figure II-13). A steam line pressure relief system would be installed for emergency shutdown of the turbine generator. Steam would be piped to the turbine, and in smaller quantities, to the turbine gland seals, first stage noncondensable gas ejector and second stage noncondensable gas ejector. Turbine steam would be exhausted at 4 in. Hg Abs. downward to the shell side of a surface condenser. Cooling water flow through the horizontal condenser tubes would be in a multi-pass arrangement.

Two full capacity transfer pumps (one spare) would be provided to pump the condensate from the main condenser hot well to the cooling tower basin. Condensate from the inter-condenser would flow by vacuum pressure differential to the main condenser.

Two 60 percent capacity main circulating water pumps would be provided to pump cooling water from the cooling tower forebay through the main condenser, inter-condenser, generator heat exchanger, lube oil cooler, air compressor cooling system, and back to the sprays in the cooling tower. These main circulating water pumps operate when the turbine generator is operating. An auxiliary cooling water pump would be provided to supply cooling water to essential heat exchangers when the turbine generator is shutdown. Cooling tower blowdown would be required and would be based on concentrations of treated makeup water. The blowdown would be pumped into the brine disposal system.

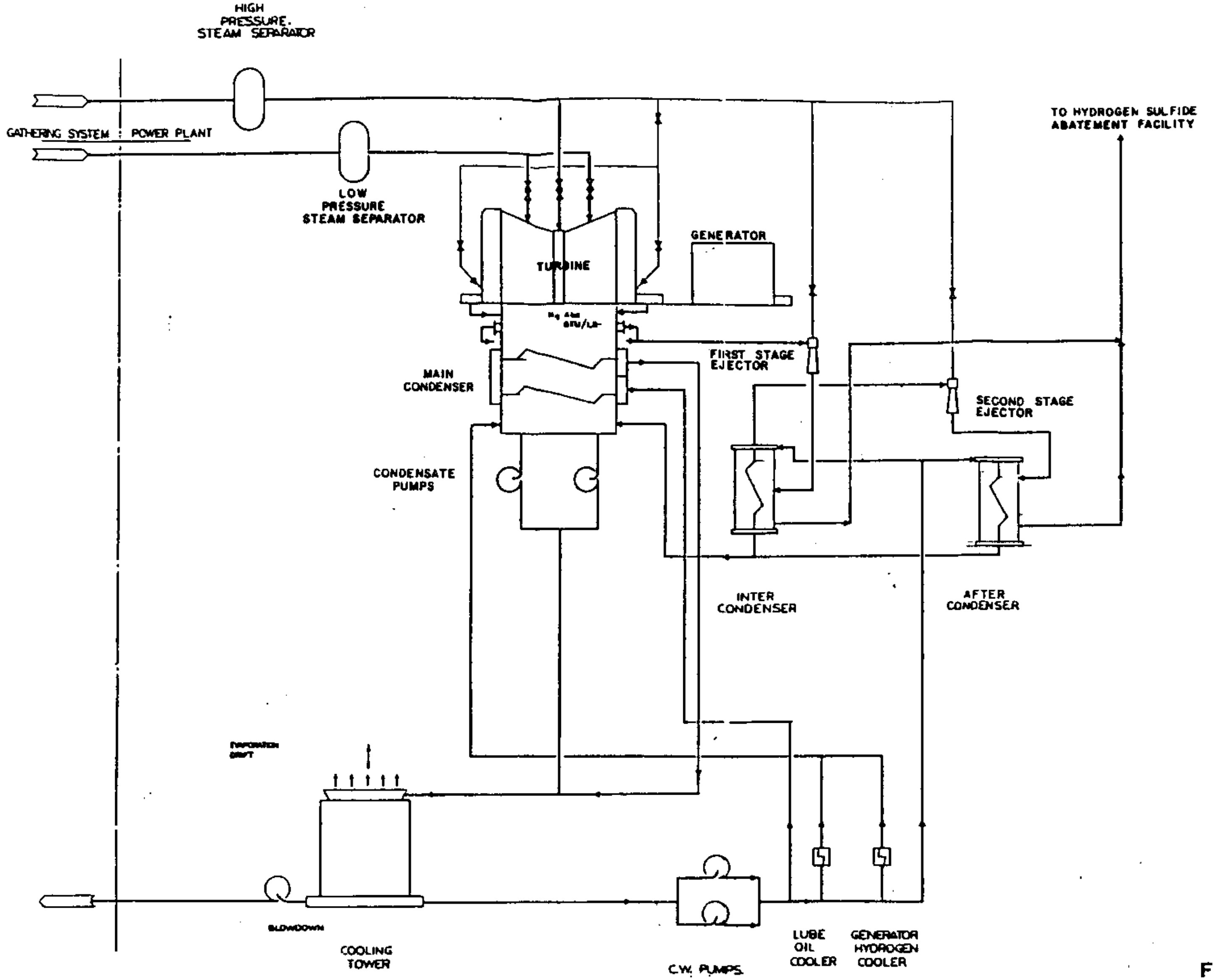


FIGURE ~~2-22~~ II-13

FLOW DIAGRAM
55MWe POWER PLANT

SOURCE: ROGERS ENGINEERING CO., INC.
SAN FRANCISCO, CALIFORNIA

Discharge from the first stage (main condenser) steam jet ejector would enter an inter-condenser where noncondensable gases would be drawn off by a second steam jet ejector discharging to the after-condenser. Surface type condensation equipment would be used in order to permit extraction of the noncondensable gases for environmental cleanup by chemical or incinerator process.

g) Electrical System

Note: Blanks to be completed after discussion with HELCO

Electrical power generated at **** KV would be transmitted to the transmission line through a main step-up transformer. The transformer would be connected to the line through a group operated disconnect switch which would be equipped with a high speed grounding switch. The grounding switch would be operated only in the event of transformer malfunction. Transmission line faults would be cleared by a **** KV circuit breaker. The transformer would be a standard open busing unit, oil filled and equipped with fans. Space would be provided in the switchyard for a future bus and circuit breakers if found to be necessary.

The **** KV station bus would be connected by an air circuit breaker to the generator and the low voltage side of the main step-up transformer. This bus would also supply power to the auxiliary transformer and to the steam gathering and injection pump system through fused load break switches. The **** KV bus would consist of an assembly of metal-clad drawout circuit breakers and fixed position fused switches. The metal-clad switchgear would have a **500** MVA interrupting capacity. A grounding transformer and resistor would be provided since the main step-up transformer would have a **** KV delta winding.

The auxiliary transformer would step down the voltage from the **** KV bus to ?480V? in order to supply the ?480V? switchgear and a motor control center. The auxiliary transformer would be of the unit substation type with fans and a 55/65'C rise. Capacity has been derated due to high ambient temperatures. Electricity to operate the various pumps, cooling tower fans, small motors and transformer for house lighting and other low voltage power requirements would be supplied by the ?480V? motor control center. The ?480V? motor control center bus would split into a normal and critical load bus. The latter bus, which would have limited capacity, would feed the lighting transformer, air conditioning units, plant sump pumps, turbine auxiliary oil pump, instrument air compressors and other small critical motor loads. This bus would feed through a transfer switch either from the ?480V motor control center normal bus or from a separate reserve transformer.

The ?480V? switchgear would consist of a metal-clad assembly of low voltage large air circuit breakers which would be used as starters for motors smaller than 200 HP. Switchgear would be bus connected to the auxiliary transformer.

2.0 Typical Power Plant Construction Activities

Construction at any given plant site would be preceded by extensive design planning and ground surveys. The proposed site would be staked out on the ground for a survey by engineers, ecologists and geophysicists. Site location adjustments would then be made as required. Of particular concern would be the presence of geophysical faults and cracks that could make a planned site dangerous. In general, plant sites would be located on higher ground, if practicable, to minimize volcanic hazards.

Site preparation would begin with vegetation clearing and grubbing. Care would be taken to preserve larger trees if possible and include them in the site landscaping where practicable. Site grading requirements would be minimized to the extent possible by adjusting site structures to the existing elevations. The pahoehoe lava provides an excellent structural foundation, given the absence of lava tubes. The foundation investigations would place particular emphasis upon the definition and avoidance of lava tubes, if any are identified on the sites. The gentle slope of approximately 3 percent would permit structure construction without excessive excavation and embankment.

3.0 Power Plant Operations

Prior to the construction and/or operation of power plants, Authority to Construct (ATC) and Permit to Operate permits must be obtained from the State Department of Health. The ATC permit application would specify the equipment and procedures that would be used to maintain air quality and assure that the power plant would meet all applicable environmental protection regulations. The following sections describe alternative methods of pollution abatement:

a) Hydrogen Sulfide (H_2S) Abatement Systems

Hydrogen Sulfide (H_2S) is a constituent of the geothermal fluid (in varying degrees) as a noncondensable gas. Abatement systems would be installed to control H_2S emissions during power plant operations. H_2S

detectors would be mounted at various locations throughout the active area of operations for emission monitoring and control. The method of abating hydrogen sulfide (H_2S) for 55 MW units would probably be by process equipment, such as the following:

o. <u>Iron Catalyst System:</u> The basic elements of a typical iron catalyst system for H_2S abatement include: the catalyst injection system; the clarifier; transfer pumps; the flocculator/clarifier; and, the sludge handling system. In this system, approximately 70 percent of the noncondensables in the steam dissolve in the cooling water and steam condensate mixture in the condenser hotwell; the balance would be removed from the condenser by the noncondensables ejector system and would be ducted to the cooling tower air stream. (In plants not equipped for H_2S abatement, the gases dissolved (including H_2S in the cooling water/condensate) are air stripped from solution in the cooling tower and released to the atmosphere).

To prevent the emission of H_2S, the cooling water would be doused with ferric ions via injection of ferric sulfate. The ferric ions then react with the dissolved H_2S to yield elemental sulfur, water, and ferrous ions. As the cooling water is aerated in the cooling tower, the ferrous ions react with oxygen to reform ferric ions; continuous regeneration of ferric ions is thus provided to sustain the H_2S reactions, which repeat continuously to yield sulfur. The sulfur thus formed would be removed from the system via clarifiers (after flocculation) as a sludge and dumped at an approved site. The H_2S ducted to the cooling tower as part of the condenser vent gases would be similarly treated after the H_2S is scrubbed from the air stream by the falling water, which would be high in ferric-ion content.

This method of abating H_2S emissions would be used only with power plants employing direct contact condensers or processes in general in which H_2S would be dissolved in the cooling water and released by air stripping in cooling towers. The system has the advantage of being inherently simple and utilizes conventional in-water treatment systems. Although overall abatement efficiencies of up to 92 percent have been reported, the method has some disadvantages. These include: increased corrosiveness of the cooling water/condensate; potential plugging of the cooling water/condensate piping; and, the need for removal and handling of the sulfur sludge produced by the process.

o. The Stretford Process: In power plants incorporating the Stretford process, a proprietary process widely used to desulfurize process gas streams, the direct contact condenser utilized in the iron catalyst method would be replaced by a surface condenser. As typically applied to geothermal steam power plants, the noncondensable gas purged from the condenser would be washed with an aqueous solution of sodium carbonate, sodium ammonium polyvanadate, and anthraquinone disulfonic acid. The H_2S in the purge gas would be absorbed in the solution and would react with the sodium carbonate to yield sodium bisulfide, which would be subsequently oxidized in the process to elemental sulfur.

Following oxidation, the solution would be recirculated to the absorber column, and a sulfur-bearing froth would be separated, filtered or centrifuged, washed, and melted to produce commercially pure sulfur. Oxidation of the sodium bisulfide would be effected by the vanadate, which would be reduced from a 5- valent to a 4-valent state. The vanadate would be, however, later regenerated to a 5-valent state through mechanism involving oxygen transfer through the anthraquinone disulfuric acid.

The Stretford process would be essentially an independent facility collocated with the power plant and would have no direct influence on the power cycle. It would not have the added corrosion problem associated with the iron catalyst system. In addition, it would not produce a sludge that would require disposal. It does, however, have the disadvantage of being more complex and costly than the iron catalyst system.

o. Other H_2S Abatement Systems: Rogers Engineering Co., Inc., Pacific Gas and Electric Company and other geothermal engineering firms have an on-going program of active study of alternative methods of H_2S abatement. It is probable that some improvement in the state-of- the-art of hydrogen sulfide abatement may be available by the time the 50 (55) MWe generating units are built.

b) Other Effluents of Plant Operation

Other effluents of operation include: (1) the Stretford process fluids; (2) cooling tower blowdown and excess geothermal fluid, which are sent to the injection station; and, (3) geothermal fluid in the form of water vapor and drift droplets, released to the atmosphere from cooling tower exit air.

The vapor and drift released to the atmosphere from the cooling tower would contain small concentrations of dissolved solids and noncondensable gases which are present in the geothermal steam. Although the gases would be present in the same amount, the drift would contain liquid with a dissolved solids concentration similar to the cooling water blowdown. The drift loss would be small and should percolate into the lava.

A lower percentage of the hydrogen sulfide in the fluid that circulates through the cooling tower would be removed by prior treatment, resulting in a very low rate release of hydrogen sulfide to the atmosphere at or below the required standards for emission.

4.0 Power Plant Maintenance

In general, geothermal power plants are designed for long-term, base load operations with minimal operation and maintenance costs. Maintenance would require a total of five weeks per year of which four weeks would be required for the annual scheduled turbine and plant overhaul.

F. POWER TRANSMISSION

1.0 Description

The design, construction, operation and maintenance of all power transmission lines from the geothermal power plants would be the responsibility of the Hawaii Electric Light Company (HELCO) in accordance with its standards for such work on the Big Island.

Electric power at the plants would be generated at 13.8 KV and transmitted to the power transmission lines through main step-up transformers converting the voltage to 138 KV at the plant site. HELCO standards require dual, redundant power lines on the Big Island to ensure continued transmission of base load power from the geothermal power plants. A physical separation between the two power transmission lines, as shown in Figure II-14, would be required.

For 55 MW plants, 138 KV lines would be required. An overall corridor clearance of 78 feet would provide vegetation clearance to a distance of 9 feet outside of the line of poles. The second 138 KV dual line would be constructed 60 feet away from the first line to avoid line interference if one line is damaged and falls toward the other.

A typical wooden power pole would typically reach a height above ground of 69 feet, with an additional 8 feet extending into the ground, as indicated on Detail "B" of Figure II-14. Special steel pole structures may be used at angles, deadends, and for long spans or where special visual or safety considerations exist. The average span length between the poles would be 600 feet. The 138 KV power line would include double bundle capabilities.

The wooden poles for the 138 KV lines would provide a minimum clearance of 27 feet between the ground surface and the conductors. Each of the 138 KV lines would have ???three aluminum conductors, one per phase???.??? Each phase (conductor) would be suspended from the pole structure by a single 7-bell insulator string, with vertical spacing between phases of 6.5 feet.??? The conductors would be protected from lightning strikes by an overhead shield wire mounted on the tops of the wooden poles and connected by ground wires to ground rods driven into the earth at the bottom of the poles. A lot size of about ???150 feet by 135 feet??? would be required for a switching station near the main step-up transformer at the power plant site.

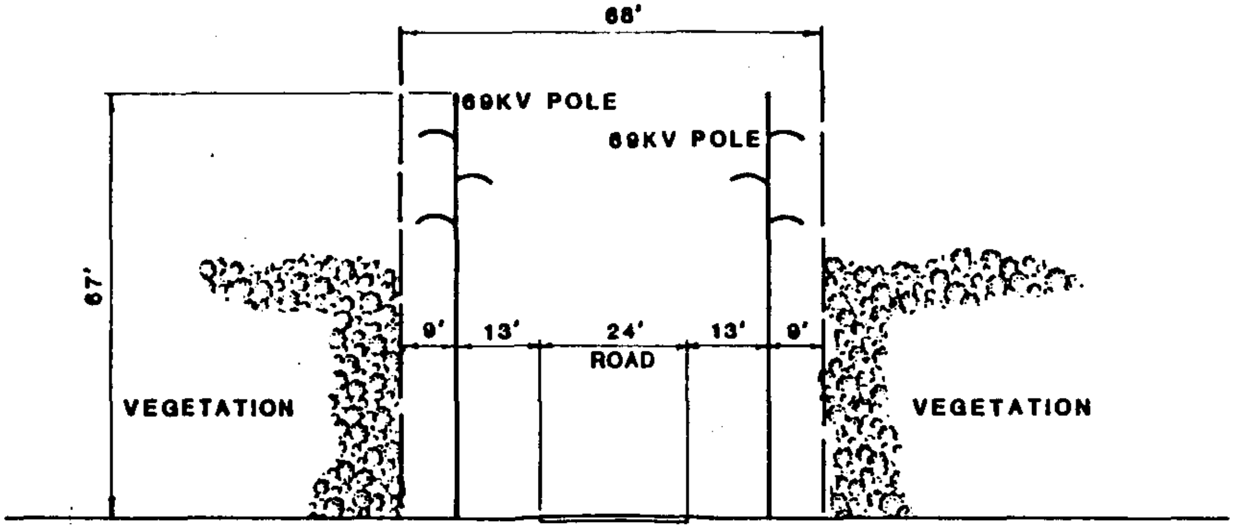
Planning, design and construction of the power lines would proceed with the decision to construct the initial power plant. The initial planning and ground surveys for service roads would include the right-of-way width to accommodate the power lines along the sides of the corridor.

If electrical power is to be transported off island, higher voltage transmission lines may be required. At present there is no HELCO power line on the Big Island that has a higher voltage than 69 KV and none have been designed to date.

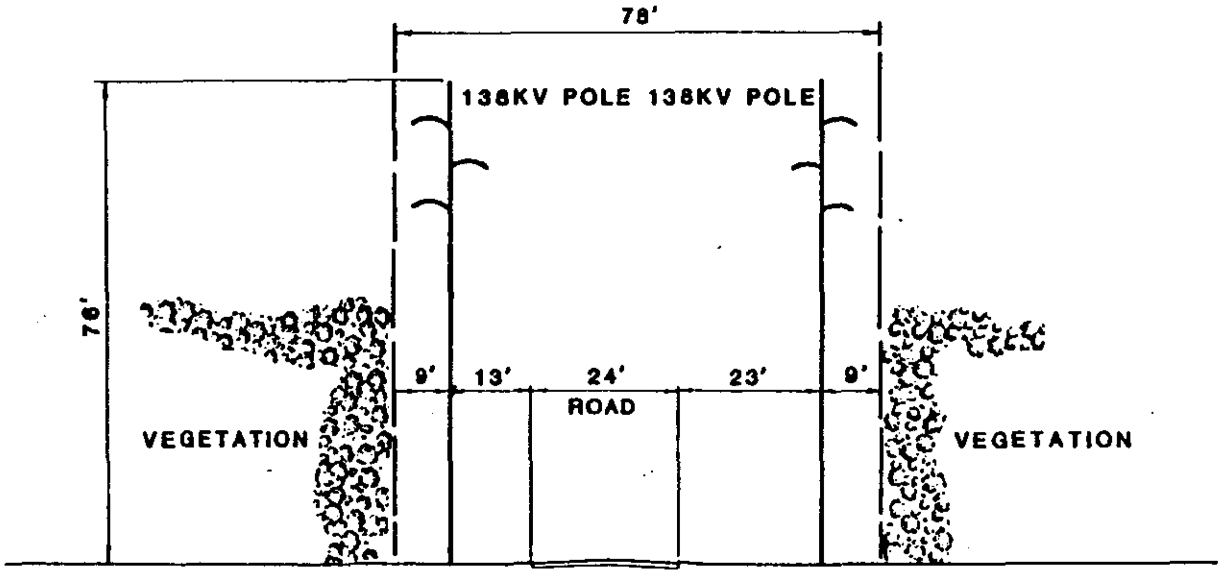
2.0 Construction

Construction of transmission lines would occur after the service roads within each zone are developed; probably at the same time as power plant construction. Construction activities would consist of clearing and site preparation for the right-of-way and pole sites; erection of transmission pole and line stringing; and clean-up and reclamation.

a) Site Preparation and Vegetation Clearing



69KV POWER TRANSMISSION LINE CORRIDOR
(DETAIL "A")



138KV POWER TRANSMISSION LINE CORRIDOR
(DETAIL "B")

SOURCE: HECO
SCALE: 1" : 30'

FIGURE ~~2-23~~ II-14
POWER TRANSMISSION LINE CORRIDORS

Ideally, the power line corridors would be along the intra-zonal service roads, therefore, additional vegetation clearing would be limited to the minimum required (Figures II-2, II-3 and II-4). Outside of the right-of-way, trees that might contact the lines during wind-induced swing would also be removed or topped.

For each transmission pole, a site would be cleared and leveled for structure assembly and erection. Leveling would be accomplished with a bulldozer. In addition to the assembly sites, conductor stringing sites would be leveled and cleared at approximately 3.1-mile intervals along the right-of-way. These stringing sites would be used to pull conductors into place and for tensioning the conductors.

b) Line Construction

A wagon drill mounted on a truck or tracked tractor would be used to dig holes for the poles. The poles would than be transported to each site and erected by crane. After erection and placement of the poles, the holes would be backfilled. Various pieces of heavy construction equipment would be used in the transport, assembly and erection of the poles. Blasting may be required to excavate the pole holes in areas of hard rock.

The transmission line conductors would be attached to the structures by a "tension-stringing" method whereby a bulldozer or helicopter would be used to pull the sock line (a lightweight leader cable) down the center of the right-of-way. The sock line would be then used to pull the conductors into place under tension, using a vehicle operating along the access road and power line centerline.

c) Cleanup and Reclamation

Vegetation cleared during line construction would be left on site, except for any large trees which may be harvested. Disturbed areas would be restored where necessary. All areas disturbed during line construction would be permitted to revegetate with appropriate natural species.

3.0 Operation and Maintenance

HELCO's transmission line responsibilities would include operation and maintenance of the lines. The transmission line corridors would be inspected at least twice a year for possible problems with the power poles and electrical systems. Vegetation would be periodically trimmed, as required, to maintain the desired right-of-way and clearance to the poles and conductors.

G. CONVERTER STATION

It has not been determined at this time where the ultimate off-site power line corridor alignment would be located. In addition, the location of the termination station of the submarine cable on the Big Island has not yet been determined. The location of this station would be very important when designing the export-power transmission system. Also, the location of the converter station would have to be determined. A tentative location for a Alternating Current/Direct Current (AC/DC) power converter station has been selected (Figure II-3) in the central sector of the Kamaili GRS. These locations can only be determined after the geothermal generating unit sites are known and the shoreline termination station of the underwater cable is located.

H. INFRASTRUCTURE AND UTILITIES

1.0 Access and Service Roads

a) Planning and Design

At present there is a limited roadnet within the three GRS of the east rift zone. The conceptual geothermal system (Figures II-2, II-3 and II-4) indicates an ultimate roadnet to support the planned 600 MW production level. As illustrated, there would be access roads leading from existing roads into the GRS and service connecting the separated power plant sites.

The constraints in road design in the east rift zone are severe. They include the need to:

- o minimize road length and width to mitigate environmental impacts;
- o avoid volcanic hazards (geophysical faults and cracks) that characterize the rift zone;
- o avoid areas believed to include unique botanical communities; and,
- o minimize the high cost of construction.

In addition, the service road corridors would need to be essentially straight, in order to accommodate power transmission lines. An evolutionary approach for the service roads would be required for construction, that is, an initial minimal one-lane, unpaved road could evolve into a two-lane paved road with provisions for power transmission line corridors. Figure II-15 shows conceptual road designs for service roads. The main service roads are the roads which interconnect the power plants. The well field roads are service roads leading from the power plants to the drilling sites.

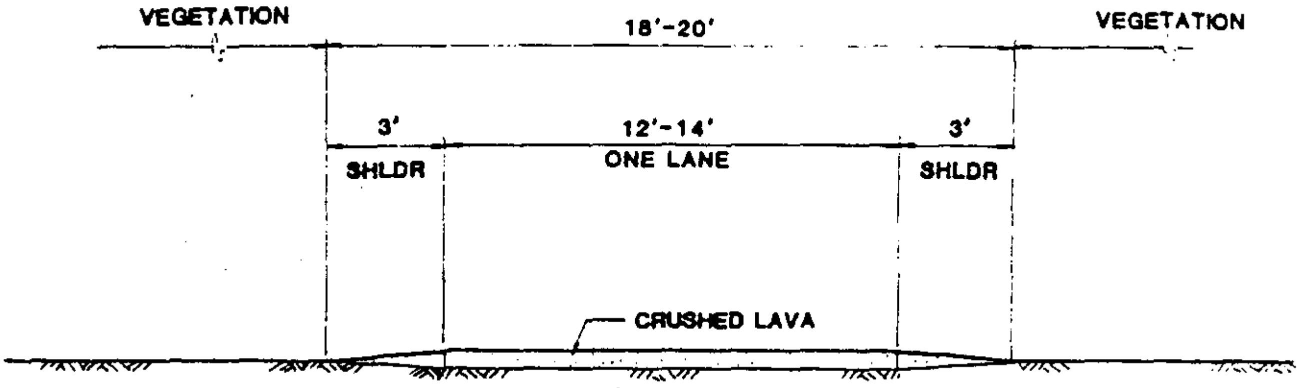
Development of the roads would initially be limited to the access and secondary roads required to move the drilling equipment to the first drilling site. Other alignments would be selected as the development progresses. The initial roads would be designed for low speed movement of trucks and trailers to the drilling sites. An estimated 40 to 50 trailer loads would be used to move the disassembled drilling rig and equipment by truck tractors to the drilling site. Vegetation would be cleared to a width of 18 to 20 feet, which would include shoulders and some width for turnouts and passing.

Fully developed service roads would consist of two-lane roadways (24-foot width) with three-foot shoulders and corridor provisions on each side for 138 KV power lines. Well field roads would also include 10-foot geothermal pipeline corridors with pipelines to carry the hot geothermal fluids from the well sites to the power plants and the spent fluids from the plants to the injection well sites. These steel pipelines would be designed to blend in with the natural background colors and would be elevated on saddles 4 to 6 feet above ground.

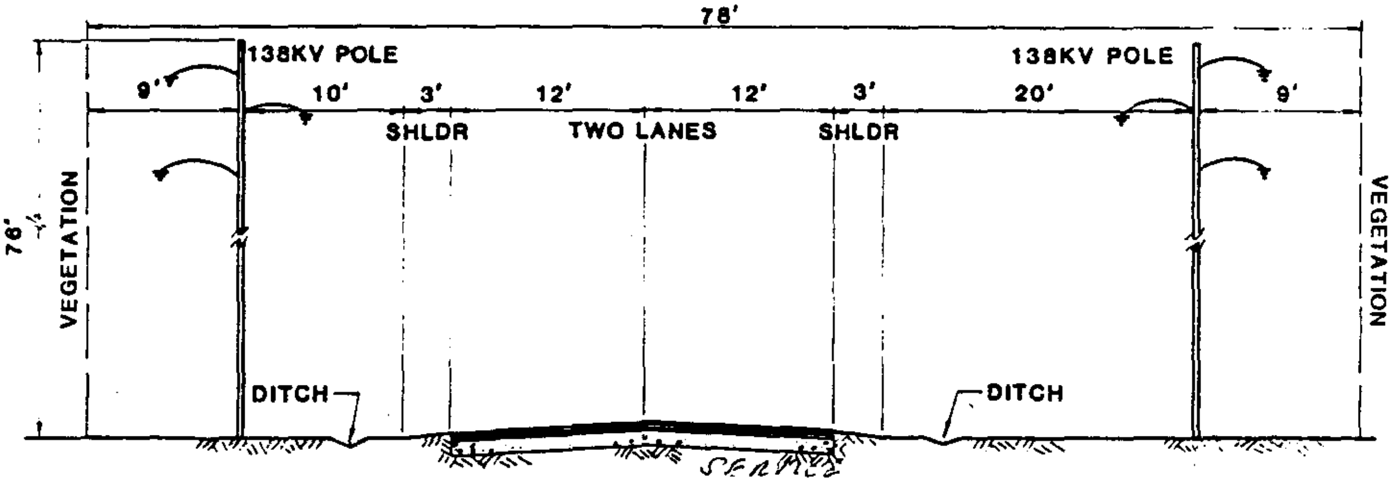
b) Road Construction

Construction of initial service and well field roads would follow existing practices on the Big Island for construction of access roads through forested areas. A large bulldozer would proceed down the alignment, dozing away the vegetation to the desired clearance width. Larger trees that can not be avoided would be cut and removed to the side of the cleared area for later harvesting, if desired. Steel rollers would be used for crushing the lava; a motor grader would shape it to the desired grade and cross section for truck traffic. If required, Aa lava fill material would be trucked in and used to build up the road bed. A 14-foot roadway width would be maintained, except where construction obstacles (e.g., large trees) indicate a reduced 12- foot width.

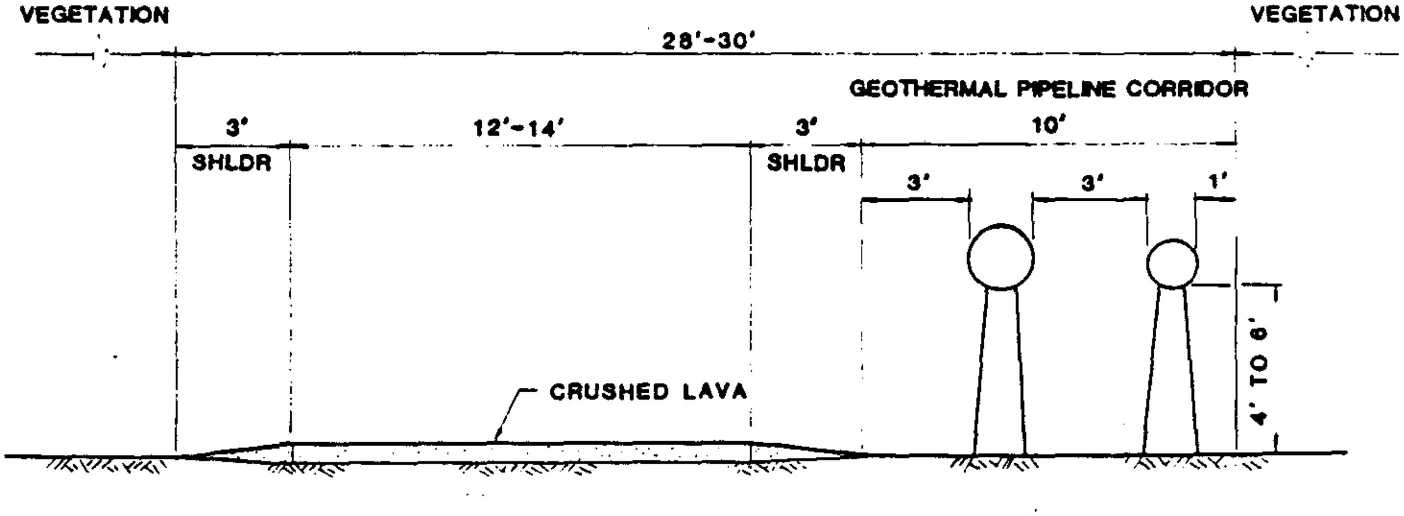
c) Road Operation and Maintenance



INITIAL ~~ACCESS~~ SERVICE & WELL FIELD ROAD
(NOT TO SCALE)



ULTIMATE ~~ACCESS~~ SERVICE ROAD
(NOT TO SCALE)



ULTIMATE WELL FIELD ROAD
(NOT TO SCALE)

FIGURE ~~2-5~~ II-15

ROAD ~~DESIGN~~ PROFILE

Road operation and maintenance activities would be the responsibility of geothermal developers and/or power plant operators. Access would be controlled in the vicinity of power plant sites and well fields; that is, only project and government agency personnel would be permitted to enter the area. In general, public access off the State and County roads would not be permitted in an area of active drilling or power generation operations, due to safety and security considerations.

PART III: ENVIRONMENTAL SETTING

A. GEOLOGY AND SOILS

1.0 Regional Geology

The Hawaiian Archipelago is a chain of volcanoes running northwest to southeast across the Central Pacific Basin that have erupted sequentially from the sea floor. The island of Hawaii is the most southerly, the youngest and the largest landmass in the Hawaiian chain. It is constructed of ejecta of at least five volcanoes.

The youngest and most active volcanoes on the island are Kilauea (4,090 ft.) and Mauna Loa (13,677 ft.). Hualalai (8,271 ft.), Mauna Kea (13,796 ft.) and Kohala (5,480 ft.) volcanoes comprise the rest of the island and are considered to be dormant. Loihi Seamount, a submarine volcano, has recently been located off the southeast coast of the island (Macdonald et al., 1983).

Kilauea is still in its very active shield-building stage. Eruptions may continue for long periods of time or they may be sporadic, occurring at intervals of about 18 months. Volcanic activity is located at the summit caldera or along either the southwest or East Rift Zones (identified by large pit craters, ground cracks and cinder cones) which radiate out from the caldera. Kilauea is presently in an extended period of activity. Since January, 1983, activity has centered on Puu O'o in the upper East Rift Zone (ERZ) (Fluor Technology, 1987).

The rocks of Kilauea are divided into the older Hilina Volcanic Series and the younger Puna Volcanic Series. The Hilina Volcanic Series is represented by the earliest exposed lava flows and thin intercalated ash beds. Pahala ash overlies this series and separates it from the younger flows and ash deposits of the Puna Volcanic Series. Lavas of both series are composed mostly of olivine basalts (Macdonald et al., 1983).

The rocks of Kilauea are very porous and highly fractured. There is very little soil cover over most of the shield so the volcano is highly permeable to precipitation (DPED, 1986).

2.0 Local Geology

The Puna District comprises about 15 percent of the island's 4,038 square miles and is its eastern most projection. It is a region of undissected volcanic uplands which slope away from the ERZ to low-lying fields along the sea coast. The geologically older, low-lying fields are covered with fertile soil and lush vegetation while the younger uplands are sparcely covered with immature soils and dotted with ohias.

The ERZ is a topographic crest which slices through the Puna District. It is unusual because rather than radiating straight out from Kilauea caldera, it trends southeast for 4 miles and then turns 65 degrees NE. It extends to Cape Kumukahi, the most eastern portion of the island, and can be traced seaward for an additional 70 miles. At this lowest and most eastern portion above sea level, the ridge disappears into a low-lying area consisting of a series of grabens and spatter deposits (Fluor Technology, 1987).

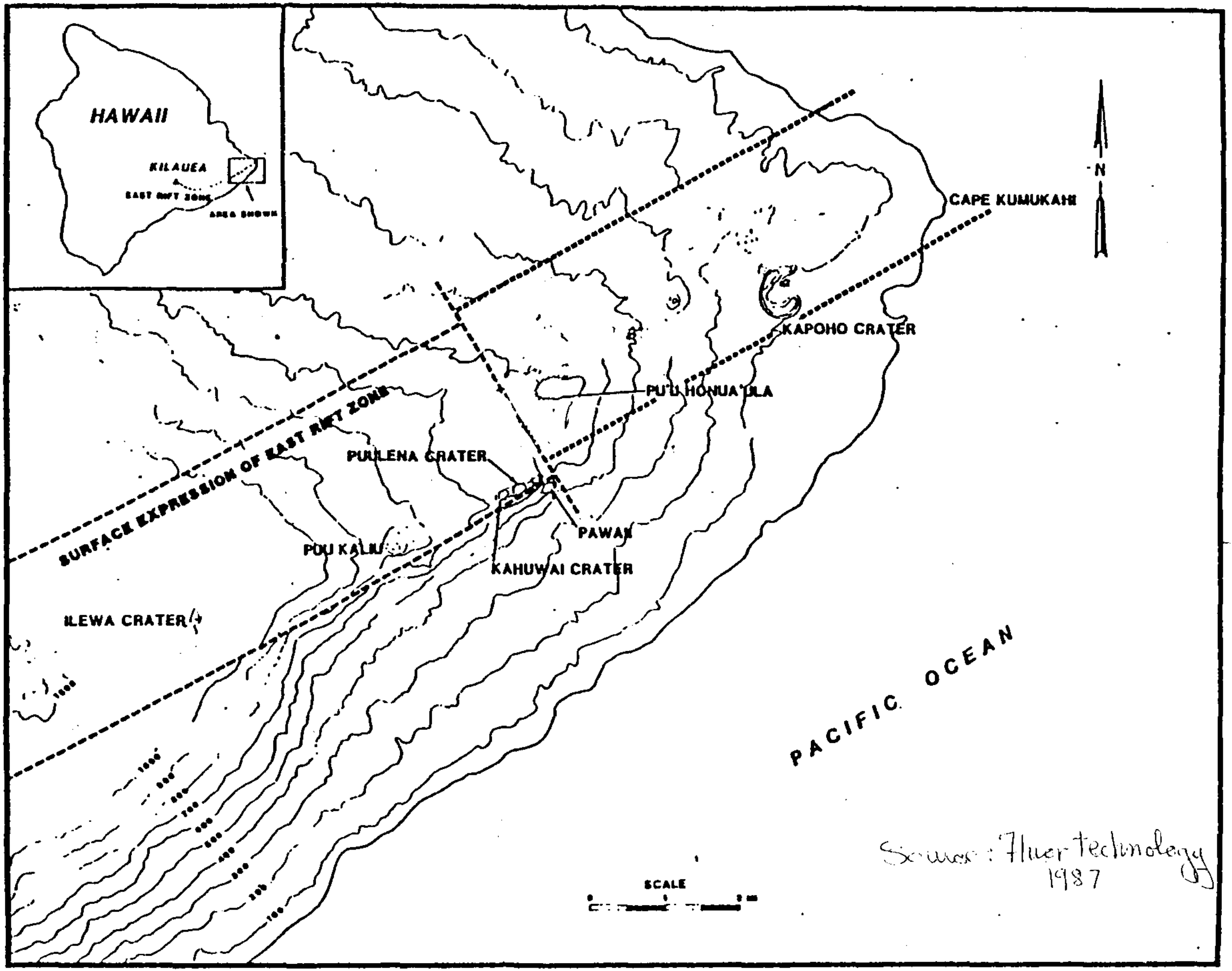
The ERZ, the underground conduit for lateral migration of molten lava from Kilauea's summit, is marked by several distinct physiographic features. A series of unevenly distributed pit craters are located in the upper rift area and link the rift zone to the caldera. About 60 spatter and cinder cones, two parasitic shield volcanoes and several more pit craters are found along the ERZ. Large ground cracks are located along the length of the rift and a number of slightly eroded fault scarps. Kalapana and Kapoho are found in grabens. A tangental fault system which off-sets the ERZ is located east of Pawai Crater in the Kapoho section (Figure III-1).

A 5- to 15-mile wide dike complex underlies the ERZ, and its top is located approximately 4,000 feet below the surface. The complex consists of an aggragate of closely spaced, basically parallel and nearly vertical dikes which intrude sequences of Mauna Loa and Kilauea pillow and subaerial lavas. Local magma chambers are thought to exist beneath the ERZ because high temperatures (1,000 to 1,900 degrees F) and mineral differentiation of the basalts have been reported. The Puna geothermal system is dependent upon the heat of these magma chambers for its thermal energy (Fluor Technology, 1987).

3.0 Site Specific Geology

The three sites designated for geothermal development are located on the East Rift Zone of Kilauea Volcano within established geothermal resource subzones (GRS). Two of the sites, the Kamaili Section (5,405 acres) and the Kapoho Section (6,800 acres), are located within the Kilauea Lower East Rift GRS. The third site is the Kilauea Middle East Rift GRS (9,104 acres) (DPED, 1986). Evidence of local eruptive activity, lava flows, devastated areas and steam vents, are found in the GRS. Lavas from the 1955, 1960, 1961, 1963 and 1977 Kilauea eruptions entered the rift zone and were vented in these subzones (R.M. Towill Corporation, 1986).

a) Kapoho Section, Kilauea Lower East Rift GRS



Source: Fluor Technology 1987

Figure III-1. Surface Expression of lower East Rift Zone

The Kapoho section is the most easterly section. It is about 5.5 miles long by 3 miles wide with elevations ranging from 60 feet to 650 feet. Approximately 35 percent of the section is covered by lavas erupted during the 1955 and 1960 events. During the 1960 activity, one square kilometer of land was added to the island.

This section can be divided into three subsections. The eastern portion is covered by flows from Kapoho (1960), contains several large cinder cones and a few pit craters, and has a very gentle slope. The slope steepens slightly in the central portion where several pit craters are located as well as one of the more prolific 1955 vents. Several large ground cracks, a tangental fault system, a large cinder cone and multiple pit craters are located in the western subsection where the slope decreases slightly. Three grandfathered subzones (established by the Hawaii State Legislature of 1984), the Hawaii Geothermal Project's Well A (HGP-A), and Lava Tree State Park are located in this subsection.

b) Kamaili Section, Kilauea Lower East Rift GRS

The Kamaili section is centrally located and is separated from the Kapoho section by the sparsely developed Leilani Estates subdivision. Elevation ranges from 600 feet to 1340 feet, and the section is 3.8 miles long by 3.2 miles wide. Approximately 15 % of the section is covered by recent lavas erupted in 1955.

This Kamaili section can be divided into three subsections. The northern portion has a slight slope to the north away from the rift axis and is in homesteads. The central rift axis is a flattened region with few geologic features. Most of the volcanic features such as cinder cones, pit craters, ground cracks and recent lava flows (1955) are located in the southern section where the slope drops steeply off to the south from the rift axis.

c) Kilauea Middle East Rift GRS

The Kilauea Middle East Rift GRS is the most westerly of the three subzones and abuts the western margin of the Kamaili section of the Kilauea Lower East Rift GRS. Elevations range from 1200 to 2000 feet, and the section is 6.4 miles long by 3.2 miles wide. Approximately 15 percent of the section is covered by recent lavas erupted in 1961, 1963 and 1977. Most of the subzone is classified as conservation land and is in natural forest reserve.

This GRS can be divided into three sections. As with the Kamaili section, most of the volcanic features are located in the southern portion where the slope drops off steeply to the south, and recent lava flows (1973 and 1977), cinder cones, and Heiheihulu Cone are located. A small 1961 lava flow and many large ground cracks are found along the flattened central rift axis. The slope of the northern section steepens slightly to the north where a few large ground cracks are located.

4.0 Geothermal Resource

In order for a geothermal area to have resource potential at our present state of technology, a potential reservoir must have a temperature greater than 125 degrees C at depths less than three kilometers. The reservior must consist of a permeable zone that permits adequate recharge of water to the reservoir, and an adequate supply of water for recharging must be available (DPED, 1986).

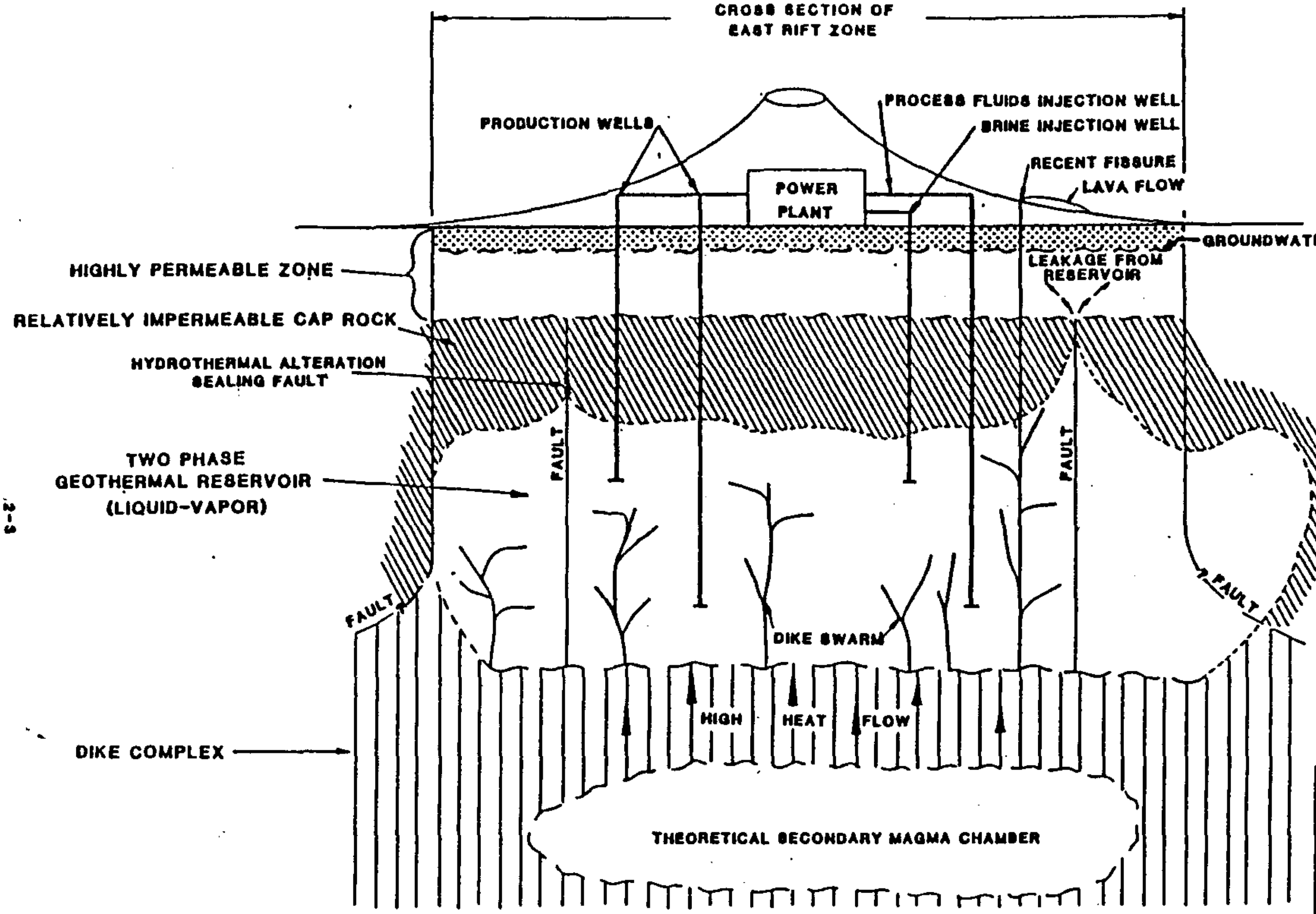
There is a greater than 90% chance of finding low temperature (50 degrees C - 125 degrees C) and high temperature (>125 degrees C) resources at depths less than 3 km for the entire Kilauea ERZ. This statement is based on regional qualitative interpretation of the following types of data: groundwater temperature, geologic age, geochemistry, resistivity, infrared, seimic, magnetic, gravity, self-potential and exploration drilling. Only exploration drilling, however, is capable of positively identifying a subsurface geothermal system (DPED, 1986).

The prolonged activity at Pu'u O'o demonstrates that vast and steady amounts of heat energy are available from Kilauea volcano (R.M. Towill Corporation, 1986). Continued successful generation of electricity at the HPG-A plant confirms the resource potential of the ERZ.

A large source of water supplies the geothermal system for precipitation in the range of 100 inches per year falls over the ERZ. It is possible that seawater intrudes a portion of the rift zone (R.M. Towill Corporation, 1986). These two sources provide a more than adequate supply of water to the geothermal system.

There is a preponderance of evidence that geothermal resources exist along the ERZ and in the GRS. Also, there is little if any change in the surface volcanic expression from the upper to lower the subsurface character will not differ accordingly.

The Puna geothermal reservoir is a two-phase (vapor - liquid) resource that is one of the hottest in the world (>600 degrees C). It consists of a dike complex in which the dikes increase in number with depth (Figure III-2). High temperatures are



NOT TO SCALE

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

Source: Fluor Technology (1987)

III-2

Figure ~~2-1~~ CONCEPTUAL MODEL OF THE PUNA GEOTHERMAL RESERVOIR maintained by high- temperature dikes located over secondary magma chambers thought to be located beneath the reservior (Fluor Technology, 1987).

The top of the reservior is located at about 4,000 feet below the surface while the bottom of the reservior extends to at least 7,200 feet. A relatively impermeable seal that extends upwards from 4,000 feet to about 2,000 feet below the surface caps the reservoir. A zone of vigorous groundwater flow exists from the top of the seal to the water table which is located approximately 600 feet below the surface (Fluor Technology, 1987).

Ground water occurs in porous, permeable and secondarily fractured basalt layers. The cap rock is relatively impermeable but leakage of geothermal fluid into the ground water occurs where the locally broken by geologic structure. The amount of fluid escaping from the cap rock is sufficient to completely alter the fresh water character of the ground water in some locations (Fluor Technology, 1987).

Four productive geothermal wells have been drilled into the geothermal reservoir: HGP-A, KS-1 (Kapoho State 1), KS-2 and KS-1A. The HPG-A well is capable of generating approximately 3 megawatts of electricity and has demonstrated the use of the geothermal fluids as an energy source for electricity generation (Fluor Technology, 1987).

5.0 Geologic Hazards

The Hawaiian Islands were and are being built by volcanic eruptions which are potentially dangerous to people and property. There are two different types of hazards associated with volcanic eruptions: those that endanger people and property directly such as lava flows, tephra falls, volcanic gases and pyroclastic surges; and those that are an indirect result of volcanic activity such as earthquakes, tsunamis, ground fractures and subsidence. Tsunamis are of little or no consequence to the subzones because they do not extend to the shoreline.

Volcanic-hazard zone maps which distinguish zones of differing magnitude of several different hazards have been prepared for Hawaii by Mullineaux et al. (1987). The following discussion is based on these volcanic-hazard zones.

a) Direct Hazards

Lava Flow Hazards. Lava flow hazard zones are based on lava-flow coverage of different areas during specific time periods. The Island of Hawaii is divided into nine hazard zones, and the three geothermal resource subzones are located in zone 1 which is the highest risk zone. Zone 1 is defined by Mullineaux et al. (1987) as, "the summit areas and active parts of the rift zones of Kilauea and Mauna Loa; in those areas, 25 percent or more of the land surface has been covered by lava within historical time, during the 19th and 20th centuries. These areas contain the sites of most historic eruptions, and a large majority of lava flows that will affect other zones in the near future probably will originate in zone 1".

Island volcanoes are constructed of lava flows characterized by very fluid lavas capable of spreading great distances from the vent. Two types of lava, a'a and pahoehoe, are recognized based on contrasting flow behavior and surface features. A'a flows are thicker and more viscous than pahoehoe flows. Hawaiian lava flows range in length from a few yards to more than 35 miles while flow width varies from a few feet to 2.5 miles.

Even though lava flows are usually thin, about one meter thick near the vent, a structure more than five meters high is not immune to buriel by lava. Many flow units are usually generated by a single eruption, and these flows will superpose one upon another. Thus, in the vicinity of the vent, accumulations over 10 meters thick are not uncommon.

Lava flows are more of a hazard to property than to human life for they normally move slower than walking speed. Lava moving down a steep slope, however, has been clocked at speeds as fast as 30 mph. The real danger is to stationary property. A'a lava flows that have moved far from the vent tend to bulldoze, crush, bury and burn any structure in their path. Pahoehoe lava flows tend to flow around objects. In theory, it is possible for a pahoehoe flow to enter a structure, ignite the flammable materials, and soften and distort some of the metalwork. Then, the cooled lava can be removed and the building reoccupied.

Cooled lava can be removed provided the eruption is fairly short and the flows are thin and friable. A problem with thicker flows is that the crust tends to insulate underlying lava, and cooling time increases exponentially with flow thickness. It could take many months to recover from a long eruption that produced thick flows.

Summit swelling and increasing swarms of volcanic earthquakes can warn of impending eruptions. Past volcanic activity can suggest future activity. Accurate predictions of short-term probabilities of lava-flow coverage for any specific area, however, are clearly not yet feasible (Mullineaux et al., 1987).

Tephra Fall or Pyroclastic Fallout Hazard. An additional volcanic hazard is tephra or pyroclastic fallout. Tephra falls are events in which ash- to cobble-sized molten and solid rock is thrown into the air by lava fountains, magmatic eruptions or phreatic explosions. Spatter, cinder and littoral cones are constructed of the larger pieces while smaller particles are carried downwind forming widespread ash deposits. These events are frequent but generally do not pose a hazard to people. Property and vegetation, however, can be seriously affected. Severe damage is usually limited to areas less than 2 kilometers from active vents.

Proximity to the coast increases the probability of an eruption being powerfully explosive and producing massive amounts of debris. If a vent is within one kilometer of the coast, the probability is close to 100 percent. The explosiveness is caused when steam is generated from magma contacting near-surface groundwater. Lung irritation, poor visibility, anxiety, blockage of escape routes and severe cleanup problems are other dangers from tephra falls.

Pyroclastic Surge Hazard. Pyroclastic surges are infrequent events but do pose a severe hazard to people. They are hot (>100 degrees C) clouds of ash, gases and rock fragments usually generated by steam explosions or by explosions of magma and steam that move laterally away from a source vent at high rates of speed (>35 mph). Surges decelerate rapidly and typically stop within 10 miles from the source. Therefore, the higher hazard areas are those closest to the vent.

A single pyroclastic hazard zone has been determined for Kilauea Volcano, the caldera and an area extending 10 kilometers from its center. Pyroclastic surges could take place anywhere that ground or sea water interact with magma. Thus, it is conceivable that it could happen where the rift zones encounter the shoreline or anywhere along the rift where ground water is encountered.

Asphyxiation by hot ash, impact by rock fragments traveling at high speed and burns from hot, clinging ash are the chief hazards to people. Pyroclastic surge hazards to property are impact and blast effects. Vegetation and structures can be burned, buried and abraded.

Volcanic Gas Hazard. Volcanic-gas emissions from the vent areas are continuous but are a relatively minor hazard to people and property. Water vapor, sulfur dioxide and carbon dioxide are the most abundant constituents of volcanic gas in Hawaii. Various combinations of sulfur, oxygen and hydrogen, such as hydrogen sulfide and sulfur dioxide are the gases of most concern to human health. Carbon dioxide is heavier than air, can collect in depressions and can cause asphyxiation.

The hazard is greatest downwind from an active vent area. Hazard zones are the same as those for tephra falls, the caldera and along the rift zones. They are wind driven and their effects decrease with distance from the vent.

Volcanic gases combine with water (rain) forming sulfuric acid which can damage live tissue, cloth and metals. Brief exposure to volcanic gases by healthy people generally is not harmful. People with lung or heart ailments are in danger when exposed to gas emissions. Kilauea recently (June, 1987) claimed its first victim in many years when a woman with lung disease died after exposure to gas emissions at the Halemaumau Fire Pit. Many types of plants cannot live in areas where volcanic gases are emitted. Some are so sensitive that they cannot live within 30 kilometers of a source.

b) Indirect Hazards

Seismic Hazard. The island of Hawaii is an area classified as Zone 3, the highest risk zone on the Seismic Probability Map published by the Seismological Society of America. In 1975, one of the largest earthquakes to be recorded in the state occurred as magma was injected into the rift zone of Kilauea. The flank of the volcano was shoved outward, and the earthquake was generated when a portion of the south flank subsided along the Hilina Fault System. It generated a surface wave with a magnitude of 5.0 on the Richter Scale (Ms=5.0) (Tilling et al., 1976).

Earthquakes occur in the thousands each year in the state of Hawaii and most of them occur on the island of Hawaii. They are generally volcanically related, and are the result of magma moving at shallow depths in association with volcanic eruptions. Most earthquakes are generated at the summit area or along the rift zones of an active volcano. A few earthquakes originate within or at the base of the volcano, and some of these are probably generated in the crust of the earth beneath the volcano. Such earthquakes are considered to be tectonically related (Mullineaux et al., 1987).

Both people and property are directly endangered by earthquakes which cause landslides, shaking of structures, and ground fracturing and settlement. In the past, earthquakes have disrupted water, sewer and telephone lines, and damaged buildings, water tanks and bridges.

<u>Surface Deformation Hazards</u>. Surface deformation in Hawaii is generally caused by magma movement resulting in ground swelling and horizontal extension of the surface, which in turn causes fissuring and normal faulting. In the summit areas and along the rift zones of active volcanoes, fractures caused by magma movement are numerous. Deformation occurs prior to volcanic events such as eruptions or magma intrusion at depth. A failed dike can be expressed at the surface by a large ground fracture or crack (DPED, 1986). Ground shaking, caused by earthquakes or gravitation subsidence, can trigger a large landslide or form a graben.

Ground fractures pose a minor but persistent danger to people and animals. Cracks can form slowly or rapidly. A crack that opens suddenly could trap somebody. It would pose a hazard as long as it is opened. Often, large cracks are hidden by thick vegetation. Potential property damage from ground cracks includes damage to roads, buildings, and utility lines (telephone, water, electric, gas and sewer).

Volcanically or tectonically caused subsidence in Hawaii is usually associated with volcanic rift zones. Magma injection into the volcano causes the flank to inflate and become destabilized. Eruption or withdrawal of magma causes further instability by removing underlying support of the surface. Large blocks may slump along a fault system, grabens may form when a block subsides between two faults, pit craters may form as lava is withdrawn, or a lava tube may collapse (Mullineaux et al., 1987).

Subsidence does not pose much of a hazard to people but property can be endangered. Rapid subsidence may damage or destroy structures by tilting, shaking or fracturing the ground. Also, subsided areas may become more vulnerable to inundation by lava flows and water.

c) Geologic Hazards at the Proposed Sites

The three geothermal resource subzones are located in the active Kilauea ERZ where a constant source of heat (evidenced by the recent volcanic activity) creates a hazardous environment. Lava flows, explosive eruptions, ground deformation, subsidence and earthquakes are the potential hazards. Any geothermal development activity along the ERZ is subject to these hazards. In fact, any volcanically active area is subject to similar risks. Presently, successful geothermal plants are being operated in the shadow of active volcanoes in Iceland, Central America and the Philippines at considerably more dangerous locations than any in Hawaii. The challenge is to reduce the risks associated with developing a geothermal resource in an active region to an acceptable level by using adequate safeguards.

Volcanic activity producing lava flows has occurred in the ERZ historically at intervals ranging from 4 years, based on the period from 1950 to present, to about 40 years, based on the period from 1790 to 1950 (R.M. Towill Corporation, 1986). Activity at Pu'u O'o, beginning in 1983, is one of the longest eruptive series and has included numerous eruptive phases spaced at intervals of a few weeks (Fluor Technology, 1987).

In the past 30 years, activity has been concentrated in the upper and lower ERZ and lava flows have entered all three subzones. Volcanic activity has been rather uniformly distributed along the entire length of the ERZ from the historic perspective (1790 to 1988). Any given plot of ground within the ERZ has approximately a 0.5 probability of being buried within a century according to historical records. It should be noted that there is no instance in the historical record of a new operative fissure occurring over a previously existing fissure (R.M. Towill Corporation, 1986).

Holcomb (1980) in mapping flow ages of Kilauea volcano found that the flows along the northern flank of the ERZ are considerably older than those of the ERZ axis and the southern flank. From a safety perspective, the less active northern flank of the ERZ appears to present a safer environment for development.

The Kamaili Section, Kilauea Lower East Rift GRS and the Kilauea Middle East Rift GRS are discussed together because of their proximity to one another for the purpose of describing the site specific geologic hazards. The Kapoho Section, Kilauea Lower East Rift Zone GRS is geographically separate and has distinctive geologic features.

Kapoho Section, Kilauea Lower East Rift Zone GRS. The presence of large cinder and spatter cones aligned with numerous ground cracks, eruptive fissures, and pit craters situated within a graben indicates that the Kapoho section is located along a section of the ERZ that has seen much recent activity. In such a region there are potential hazards from lava flows, explosive eruptions, surface deformation, earthquakes and subsidence.

In the Kapoho section virtually all of the surface is younger than 500 years and about 45 percent is younger than 40 years. Since 1790 there have been five eruptions on the lower rift zone, an average of one every 40 years. Of those, half have been within the past 30 years. The average flow covers an area of about 11 square kilometers; the 1955 eruption generated a 16 square kilometer flow (DBED, 1986).

Most of the recent lower rift eruptions have occurred along the southern boundary of the rift zone, as the 1955 eruptions did, or along the central axis of the zone as in the case of the 1960 Kapoho event. The risk of a site being overrun by lava from a vent located outside the site area is largely a function of topography. Sites can be impacted by lava flows produced up slope. Topography of the Kapoho section is generally flat so that the section could easily be overrun if a flow generated up-rift reached the area. A review of historic eruptive events indicates that an average lava thickness of about 18 feet has accumulated with ranges between a few feet and 37 feet (DPED, 1986).

During the 1960 Kapoho eruption, magma contacted groundwater causing an explosive eruption which showered the surrounding area with wet black ash. The likelihood of this type of eruption occurring increases significantly with proximity to the coast and approaches 100% within one kilometer from the shore (Mullineaux et al., 1987).

The hazard to property caused by arching, uplift and tilting associated with magma movement would not be significant because the deformation would not be of sufficient magnitude or acceleration. Fissuring and faulting, however, do pose a threat to property. Numerous fissure systems have been identified within the ERZ and several large fissures are located in the western portion of the section. Many of these systems have formed <u>en echelen</u> fissures which are individually straight and parallel to the rift margin. Since new eruptive fissures do not appear to occur over a previously existing fissure, each new eruption is accompanied by new fissuring.

Based on the average width of a fissure, the frequency of occurrence, and the dimensions of an engineered structure, there is an estimated 5 percent probability of damage to a primary structure within a given 40-year period (Fluor Technology, 1987). Linear structures, such as pipelines, are the most likely to suffer damage.

The most common type of earthquake in the ERZ is volcanically related and is usually caused by magma movement at shallow depths. Earthquakes in the ERZ have had a maximum magnitude of Ms = 5.0 on the Richter Scale. The only nearby source of tectonically related, potentially higher magnitude earthquakes is the Hilina Fault System to the southwest of the ERZ. The 1975 Kalapana earthquake (Ms = 7.2) was caused by movement along this system. Smaller magnitude earthquakes occurred in 1954 (Ms = 6.5), in 1951 (Ms = 6.5 - 6.9) and in 1929 (Ms = 6.5). On April 2, 1868, the largest historically recorded earthquake (Ms = or > 7.5) originated along the fault system near South Point (Fluor Technology, 1987).

Within the next 40 year period, a maximum earthquake of about Ms=6.75 with an epicenter within 15 miles from the ERZ is likely and should be assumed for planning purposes. Despite the magnitude of historic earthquakes, little structural damage has occurred and acceleration has rarely exceeded 0.49 g. During the 1979 Kalpana earthquake (Ms = 7.2), an acceleration of 0.22 g was recorded at Hilo (Fluor Technology, 1987).

Subsidence due to withdrawal of geothermal fluids is of little concern because the geothermal reservoir is composed of self-supporting, dense pillow basalts overlain by subaerial lava flows. The compressive strength of these rocks is not affected by fluid removal (Fluor Technology, 1987).

Subsidence due to natural causes has some potential for damaging effects. Island settling, or regional subsidence, is estimated to occur at a rate of approximately one foot per century and poses little threat to GRS development. Localized settling of discrete blocks on the order of a few feet may occur in the ERZ within the life of a project due to subsurface withdrawal of magma. Subsidence of this type would happen in elongate, fault bounded blocks, approximately parallel to the trend of the rift zone, and this possibility should be considered during the project design to block slumping along coastal margins or lava tube collapse, should not pose a significant threat to development within the GRS (Fluor Technology, 1987).

<u>Kamaili Section, Kilauea East Rift Zone GRS and the Kilauea Middle East Rift Zone GRS</u>. There is very little change in the surface volcanic expression from the Middle East Rift GRS through the Kamaili Section of the Lower East Rift GRS. As stated previously, the majority of volcanic activity is localized in the southern portions of the subzones as evidenced by the presence of large cinder cones aligned with eruptive fissures, pit craters and large ground cracks. Thus, the potential hazards are due to lava flows, tephra falls, surface deformation and earthquakes.

Nearly 50% of the land in the ERZ has been covered with historic lava flows at least once and approximately 15% of these two subzones has been overlain with lava since 1961. The southern portion of the Kamaili Section was invaded in 1963 by lavas which erupted in the Middle East Rift GRS. As stated previously, topography is the primary factor determining the likelihood of lava coverage. The probability that any given area within the rift zone will experience lava flows at least once in a century is 0.5 as has been stated for the Kapoho section (R.M. Towill Corporation, 1986).

During the past 30 years tephra falls at vents have built eight large cinder and spatter cones along the 32-mile length of the ERZ. Thus, there is an approximate probability, based on historic records, that a cinder or spatter cone could be formed anywhere in the ERZ every 25 years (R.M. Towill Corporation, 1986).

Large ground cracks are found along the rift axis of the Middle Kamaili Section GRS. They become more numerous with proximity to the more volcanically active caldera and are possibly surface expressions of failed dikes (R.M. Towill Corporation, 1986). Again, there is the same estimated 5% probability of damage to a primary structure within a given 40-year period as stated for the Kapoho Section (Fluor Technology, 1987).

The earthquake potential for these two subzones is very similar to that of the Kapoho Section. Because they are located within the East Rift Zone, the volcanically related earthquake hazard is the same. Tectonically related earthquake hazards are also very similar because all three subzones are oriented similarly and located approximately 15 miles from the Hilina Fault System (Fluor Technology, 1987).

6.0 Soils

(May include soils maps)

In this section the U. S. Department of Agriculture, Soil Conservation Service (1973) soil classifications for each of the subzones is listed. A description of each soil classification follows.

a) Soil Classification of the Kapoho Section, Kilauea Lower East Rift GRS

Approximately 35 percent of the land in this section has been classified as Lava Flow A'a (rLV), Lava Flow Pahoehoe (rLW) and as Cinder Land (rCL). The soils in this section are classified as Opihikao extremely rocky muck, 3 to 25 percent slopes (rOPE); and as Malama extremely stony muck, 3 to 15 percent slopes (rMAD).

b) Soils Classification of the Kamaili Section, Kilauea Lower East Rift GRS

About 30 percent of the land has been classified as Lava Flow A'a (rLV), Lava Flow Pahoehoe (rLW) and as Cinder Land (rCL). The majority of the soils in this section have been classified as either Keaukaha extremely rocky muck, 6 to 20 percent slopes (rKFD), or as Papai extremely stony muck, 3 to 25 percent slopes (rPAE). Small sections are classified as Malama extremely stony muck, 3 to 15 percent slopes (rMAD);

as Opihikao extremely rocky muck, 3 to 25 percent slopes (rOPE); as Olaa extremely stony silty clay loam, 0 to 20 percent slopes (OlD); as Olaa silty clay loam, 0 to 10 percent slopes (OaC); and as Panaewa very rocky silty clay loam, 0 to 10 percent slopes (PeC).

c) Soils Classification of the Kilauea Middle East Rift GRS

The majority of the soils in this section have been classified as Keei extremely rocky muck, 6 to 20 percent slopes (rKGD). Small sections are classified as Kiloa extremely stony muck, 6 to 20 percent slopes (rKXD) and as Papai extremely stony muck, 3 to 25 percent slopes (rPAE). About 15 percent of the land has been classified as Lava Flow A'a (rLV) and as Lava Flow Pahoehoe (rLW).

d) Descriptions of Soil Types

A brief description of soil types follows:

o Opihikao Extremely Rocky Muck, 3 to 25 Percent Slopes (rOPE)

This soil type is a very dark brown muck about 3 inches thick. The muck is strongly acid and is underlain by pahoehoe lava bedrock. It is rapidly permeable, but the lava is slowly permeable. However, water moves rapidly through the cracks. Runoff is slow and erosion hazard is slight. This soil is in native forest or is used for pasture.

o Malama Extremely Stony Muck, 3 to 15 Percent Slopes (rMAD)

This soil type is a very dark brown muck about 3 inches thick. The muck is strongly acid and is underlain by a'a lava bedrock. It is rapidly permeable, runoff is very slow and the erosion hazard is slight. This soil is used for pasture, woodland and orchards.

o Keaukaha Extremely Rocky Muck, 6 to 20 Percent Slopes (rKFD)

This soil type is a very dark brown muck about 8 inches thick. The muck is strongly acid and is underlain by pahoehoe lava bedrock. It is rapidly permeable, but the lava is slowly permeable. However, water moves rapidly through the cracks. Runoff is medium and erosion hazard is slight. This soil is in native forest or is used for pasture.

- o Papai Extremely Stony Muck, 3 to 25 Percent Slopes (rPAE)

This soil type is a very dark brown muck about 8 inches thick. The muck is slightly acid and is underlain by fragmental a'a lava. It is rapidly permeable, runoff is slow and the erosion hazard is slight. This soil is used for pasture and woodland.

- o Olaa Extremely Stony Silty Clay Loam, 0 to 20 Percent Slope (O1D)

This soil type has a surface layer of very dark brown extremely stony silty clay loam about 16 inches thick, and a dark-brown extremely stony silty clay loam subsoil 9 inches thick. It is underlain by a'a lava. The soil dehydrates irreversibly into gravel-sized aggregates. It has a medium acid surface layer and a slightly acid subsoil. It is rapidly permeable, runoff is slow and the erosion hazard is slight. This soil is used for sugarcane.

- o Olaa Silty Clay Loam, 0 to 20 Percent Slopes (OaC)

This soil type is similar to Olaa extremely stony silty except that the surface layer is nonstony, and the slope is generally less than 10 percent. This soil is used for sugarcane.

- o Panaewa Very Rocky Silty Clay Loam, 0 to 10 Percent Slopes (PeC)

This soil type has a surface layer of very dark brown silty clay loam about 12 inches thick, and a dark-brown, very cobbly, silty clay loam subsoil 4 inches thick that is mottled with yellowish red. It is underlain by pahoehoe lava bedrock. The subsoil dehydrates irreversibly into fine gravel-size aggregates. It has a medium acid surface layer and a strongly acid subsoil. It is rapidly permeable, runoff is slow and the erosion hazard is slight. This soil is used for sugarcane, pasture and woodland.

- o Keei Extremely Rocky Muck, 6 to 20 Percent Slopes (rKGD)

This soil type is a very dark brown muck about 10 inches thick. The muck is strongly acid and is underlain by pahoehoe lava bedrock. It is rapidly permeable, but the lava is slowly permeable. However, water moves rapidly through the cracks.

Runoff is medium and erosion hazard is slight. This soil is used for pasture.

o Kiloa Extremely Stony Muck, 6 to 20 Percent Slopes (rKXD)
This soil type is a very dark brown muck about 10 inches thick. The muck is strongly acid and is underlain by a'a lava bedrock. It is rapidly permeable, but the lava is slowly permeable. However, water moves rapidly through the cracks. Runoff is medium and erosion hazard is slight. This soil is used for woodlands and pasture.

e) Descriptions of Miscellaneous Land Types

The following are descriptions of the miscellaneous land types:

o Lava Flows, A'a (rLV)
This lava is rough and broken and has practically no soil covering and is bare of vegetation except for mosses, lichens, ferns, and a few small ohia trees. It is a mass of clinkery, hard, glassy, sharp pieces piled in tumbled heaps. In areas of high rainfall, it contributes substantially to the underground water supply, and is used for watershed.

o Lava Flow, Pahoehoe (rLW)
This lava has practically no soil covering and is bare of vegetation except for mosses, lichens, ferns, ohelo berry, ohia trees, and aalii. This lava has a billowy, glassy surface that is relatively smooth. The surface is broken and rough in some places, and there are hummocks and pressure domes. Some flat slabs of pahoehoe lava are used as facing on buildings and fireplaces. In areas of high rainfall, the lava contributes to the underground water supply, and is used for watershed.

o Cinder Land (rCL)
This land type consists of bedded cinders, pumice and ash. These materials are black, red, yellow, brown and variegated. The particles have jagged edges and a glassy appearance and show little or no sign of soil development. Cinder land commonly supports some grass, but it is not good pasture land because of its loose consistency and poor trafficability. This land is a source of material for surfacing roads.

B. METEOROLOGY, AIR QUALITY AND NOISE

1.0 Meteorology

The island of Hawaii lies well within the belt of northeasterly trade winds generated by the North Pacific high pressure cell located to the northeast of the island. The climate of Hawaii is greatly influenced by the local topography. These terrain influences include large variations in rainfall with elevation, persistent northeasterly winds in exposed trade wind areas, and uniform diurnal and seasonal temperatures in areas near sea level.

Long-term climatological information in the vicinity of the geothermal development subzones can be obtained from data collected at Hilo. Weather data has been compiled by the National Weather Service (NWS) for over 40 years. The site is on the coast approximately 25 kilometers northwest of the proposed geothermal development areas. These data are summarized to give a general overview of the longer term climate in the region. Recent records of site-specific monitoring data are also presented.

a) Regional Climatology

The areas are located in a region on the island of Hawaii where prevailing northeast trade winds are lifted over the island topography, which orographically induces cloudiness causing precipitation to occur throughout the year. Over the island's windward slopes, rainfall occurs mainly in the form of showers within the ascending moist trade winds. Mean annual rainfall, except for the semi-sheltered Hamakua district, increases from 2500 millimeters (mm) or more along the coasts to a maximum of over 7600 mm at elevations of 600 to 900 meters, and then decreases to about 380 mm at the summits of Mauna Kea and Mauna Loa. In general, leeward (southern and western) areas are topographically sheltered from the trade winds, hence from the trade wind showers, and are therefore drier. Sea breezes, created by daytime heating of the land, move onshore and upslope causing afternoon and evening cloudiness and showers. Where mountain slopes are steeper, mean annual rainfall may range from 750 mm along the coast to 3000 mm at elevations of 750 to 900 meters.

Due to the island's proximity to the equator and mid-ocean location, there is little seasonal variation in weather patterns. Winter and spring seasons have slightly more precipitation than the summer and fall months. Approximately 60 percent of the average rainfall of 3300 mm occurs during the six month period between November and April. Within the city of Hilo, average rainfall varies from about 3300 mm per year near the shoreline to as much as 5100 mm in mountain sections. The wettest part of the island, with mean annual rainfall exceeding 7600 mm, lies approximately 10 kilometers upslope from the Hilo city limits. Rain falls about 280 days per year in the Hilo area.

Mean monthly temperatures average about 23.1 degrees C. Hawaii's uniform temperatures are associated with its mid-ocean location and the small annual variation in sun angle and solar energy. At Hilo, the range in average temperature from February and March, the coldest months, to August, the warmest month, is only 2.9 degrees C. The average daily range is 8.6 degrees C. The highest temperature of record at Hilo Airport is 34.4 degrees C with a record low of 11.7 degrees C. Greater temperature variations occur in localities with less precipitation and cloudiness, and temperatures in the mid-30's (degrees C) and less than 10 (degrees C) are uncommon near sea level.

The trade winds prevail throughout the year, although they may be absent for days or even weeks at a time. Most of the western portion of the island is sheltered from the trades by high mountains. The eastern portion of the island, where the geothermal development areas are located, is more directly exposed to the trade winds, although local mountain circulations affect wind patterns significantly. For example, the prevailing winds at Hilo Airport are not the northeasterly trades, but the southwesterly winds that flow downslope off Mauna Loa during the night and early morning hours.

Except for periods of heavy rains, severe weather rarely occurs. Thunderstorms average only 8 per year, and are rarely severe. During the winter, cold fronts or the cyclonic storms of subtropical origin (the so-called Kona storms) may bring blizzards to the upper slopes of Mauna Loa and Mauna Kea, with snow extending at times to elevations of 2700 meters or lower with icing near the summit.

b) Local Meteorology

Meteorological data more representative of the geothermal resource subzones have been collected since March 1981 at the Woods site in the vicinity of the HGP-A well site. This site is shown in Figure III-3 along with other air quality monitoring sites in the region. The Woods data include hourly observations of temperature, wind speed and direction, relative humidity,

Figure III - 3. Air Quality Monitoring Stations precipitation, insolation, and standard deviation of wind direction fluctuation (sigma-theta). From February 1982 through January 1983, observations were recorded every three hours at this site.

Since the Woods data set contains the most complete set of local data, several analyses have been performed on the Woods data for past projects. Recent meteorological data collected at the Woods site is presented in Table 3.1. Annual wind roses for the period of May 1981 to May 1982 are presented in Figures III-4 through III-6. These figures represent wind roses for all hours, daytime hours, and nighttime hours, respectively (Fluor Technology, 1987). The wind rose for all hours, presented in Figure III-4, shows that westerly (nighttime drainage) winds occur with the greatest frequency with the northeast trades occurring with the second greatest frequency. Figure III-5 shows that the northeast trade winds prevail during daylight hours. During the nighttime hours, westerly drainage winds prevail as shown in Figure III-6. A second annual wind rose, prepared for the period of October 1982 through September 1983, is presented in Figure III-7. This wind rose shows a similar wind direction distribution as the wind data discussed above. The annual average wind speed for all hours is 3.3 meters per second (m/sec), while daytime wind speeds average 3.8 m/sec and nighttime wind speeds average 2.8 m/sec (Fluor Technology, 1987). Wind speeds averaged about 2.0 m/sec for all directions, with the strongest winds (3.7 m/sec) infrequently originating from the southwest. On a daily basis, winds were strongest (4.0 m/sec) in mid-afternoon, and the lightest (2.0 m/sec) between the hours of 8 and 11 in the evening.

Atmospheric stability data can be estimated from sigma-theta measurements at the Woods monitor. Stability is a measure of the amount of turbulence present in the atmosphere, and greatly affects the amount of dispersion, or dilution, of any emitted pollutant. Pasquill-Gifford stability classes were derived from sigma-theta measurements according to U.S. Environmental Protection Agency (U.S. EPA) guidelines, with adjustments to nighttime stability classes as recommended by the U.S. EPA. These classes range from class A, the most unstable, to class F, the most stable. Class D indicates neutral stability conditions. Atmospheric mixing, and hence dispersion, is greatest during unstable conditions.

On an annual basis, neutral atmospheric conditions (class D) occurred over 50 percent of the time. Slightly unstable conditions (Class B and C) occurred approximately

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                              TABLE 3-1

                              WOODS SITE
                 MONTHLY METEOROLOGICAL DATA SUMMARY


                                    Wind                      Precipitationa   Relative
      Temperature oC    Prevailing Speed m/sec         mm       mm/day     Humidity
Mo/Yr  Avg    Min    Max  Direction  Avg   Min   Max   Total  Min   Max    Percent

Nov86  22.4   19.8   24.8    N       2.7   1.9   4.2    499    0     94   .   89

Dec 86 20.5   18.7   20.8   NNW      2.4   1.4   4.7     99    0     13       88

Jan87  20.2   18.6   23.3    NW      3.0   1.4   6.1    139    0     52       93

Feb87  20.1   18.4   22.8   NNW      2.7   1.7   4.7     92    0     25       89

Mar87  20.2   19.2   23.5    NW      2.9   1.0   4.6     90    0     36       82

Apr 87 20.6   19.4   23.8   WNW      2.7   2.0   4.5    161    0     42       88

May87  23.0   18.2   24.5    NW      2.7   1.1   4.2    175    0     47       93

Jun87  23.1   22.0   25.2    N       2.5   2.0   3.5    145    0     20       95

Jul 87 23.2   22.7   25.1   NNW      2.4   1.8   2.9    381   0.3   194       96

Aug87  24.4   24.1   26.8    NW      2.5   1.7   3.0     71    0     13       94

Sep87  24.8   23.5   26.2   NNW      2.2   1.4   3.2    103    0     59       95

Oct87  23.5   21.1   24.8    NW      1.8   1.4   2.2    118    0     60       94

Extreme
/Avg.  22.2   21.1   26.8   NNW      2.5   1.0   6.1   2072    0    194       91

Press RETURN for more...

MAIL>

#3                 14-JUN-1988 08:28:15                                          MAIL

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a  Possible malfunction of rain gage during measurement period.  Rain
   gage sensor cable replaced October 23, 1987

(Source: Fluor Technology, Inc., 1987)
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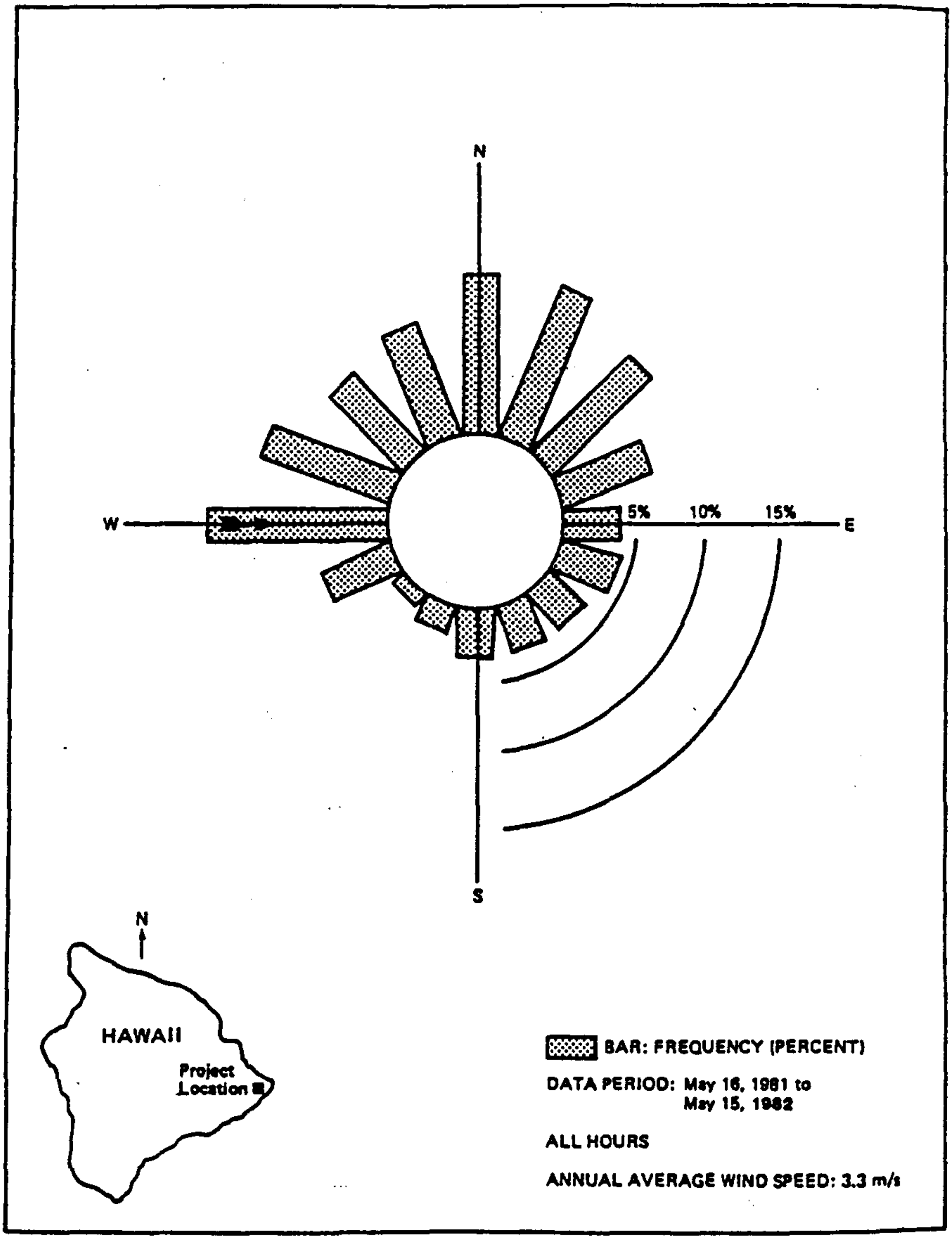

FIGURE ~~3-2~~ III-4 ANNUAL WIND ROSE FOR THE WOODS SITE
MAY 1981 TO MAY 1982
(Source: Fluor Technology, Inc., 1987)

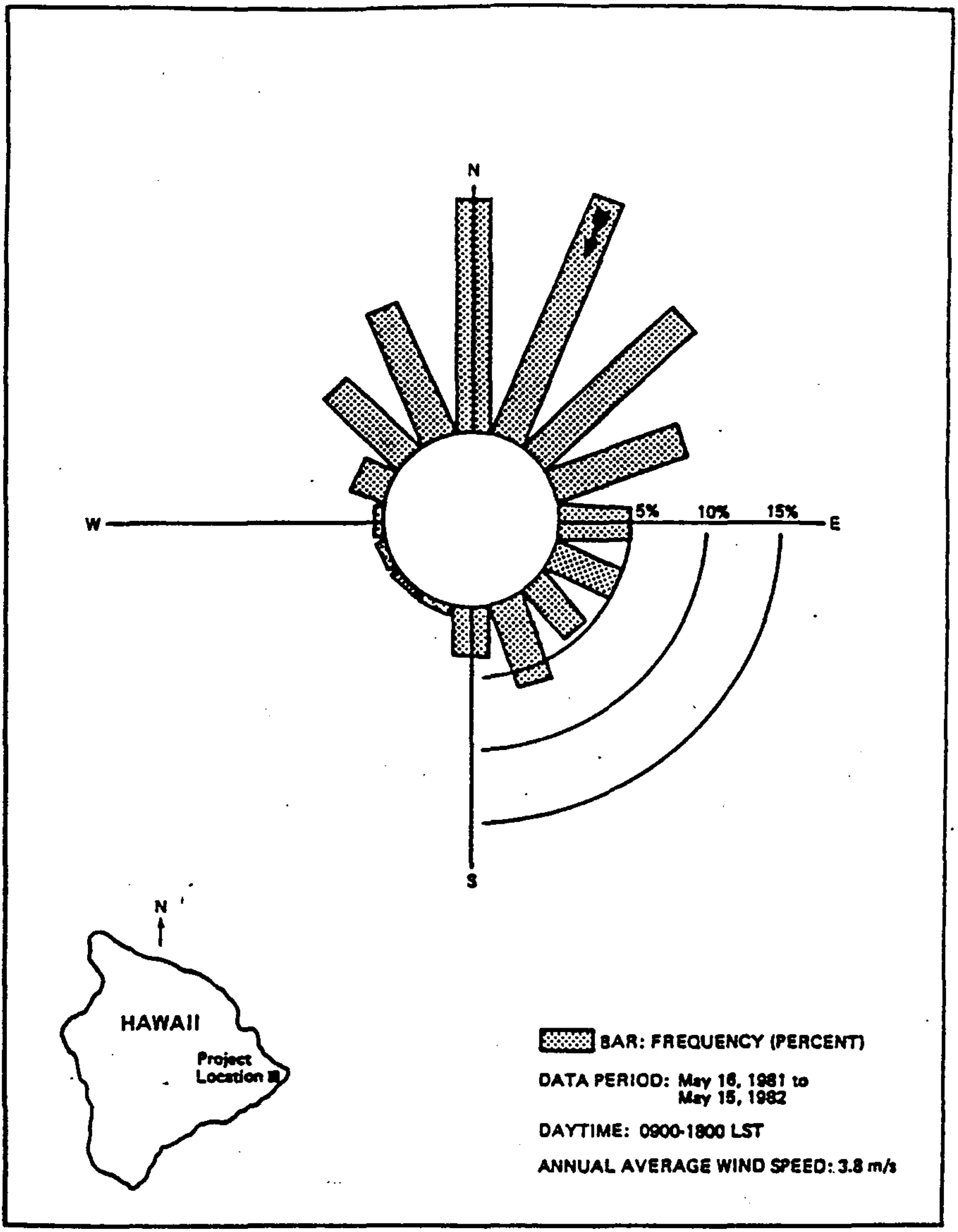

FIGURE ~~3-3~~ III-5 ANNUAL DAYTIME WIND ROSE FOR THE WOODS SITE
MAY 1981 TO MAY 1982
(Source: Fluor Technology, Inc., 1987)

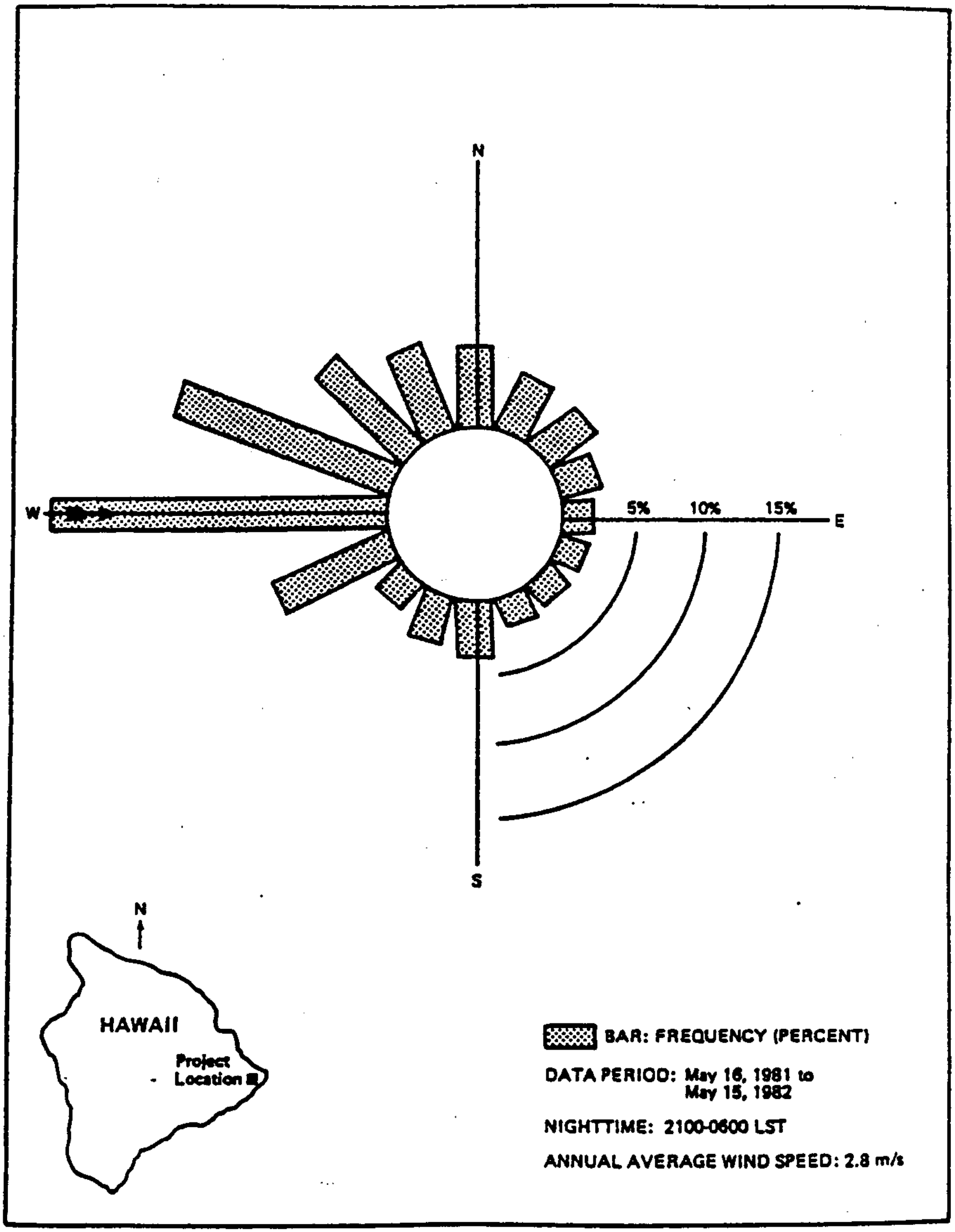

FIGURE ~~3-4~~ III-6 ANNUAL NIGHTTIME WIND ROSE FOR THE WOODS SITE
MAY 1981 TO MAY 1982
(Source: Fluor Technology, Inc., 1987)

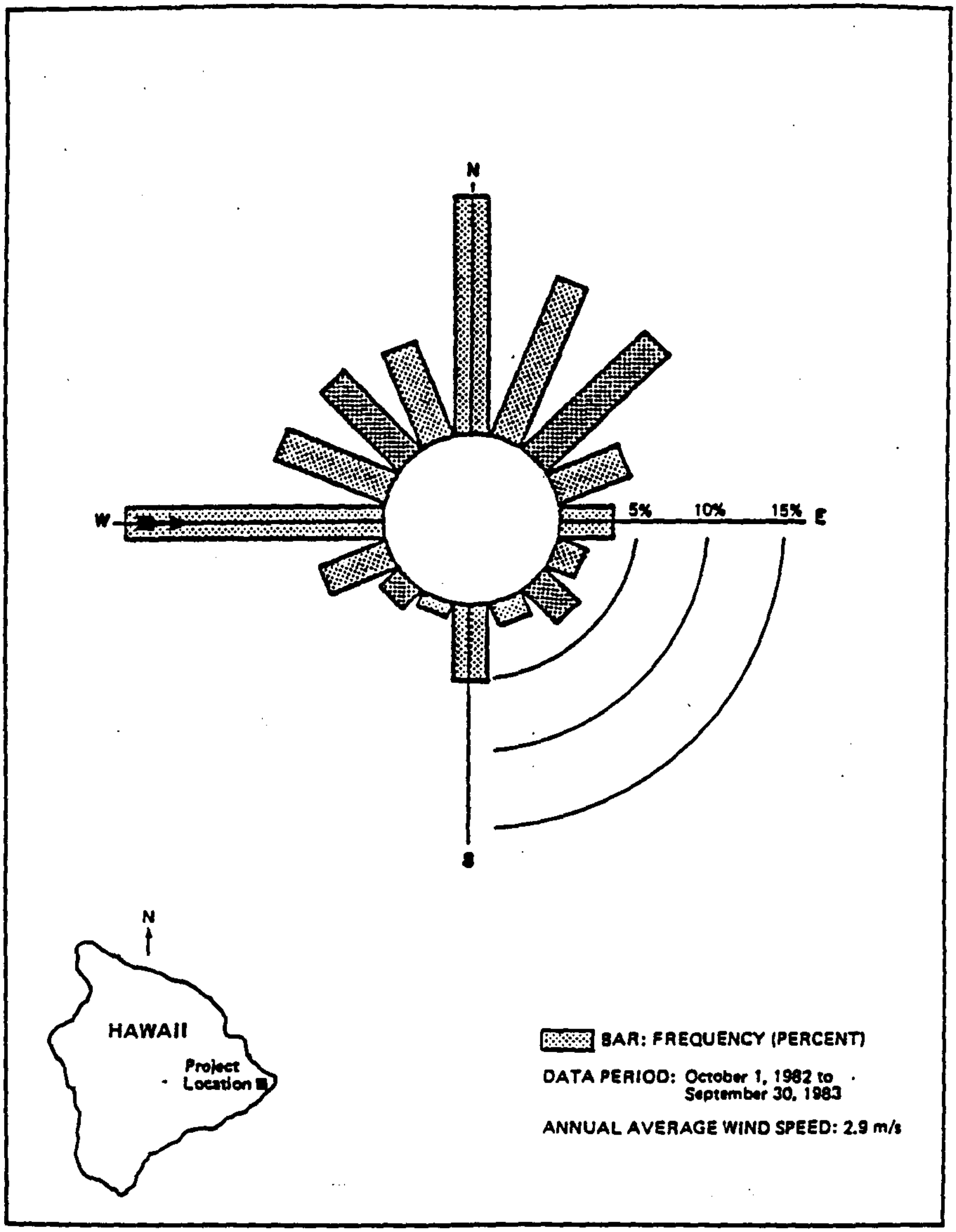

FIGURE ~~3-5~~ III-7 ANNUAL WIND ROSE FOR THE WOODS SITE
OCTOBER 1982 THROUGH SEPTEMBER 1983
(Source: Dames & Moore, 1984)

25 percent of the time. Slightly stable conditions (class E) occurred 20 percent of the time while extremely stable (Class F) or unstable (Class A) conditions occurred less than 4 percent of the time.

Mixing heights in the area can be determined from twice daily upper air soundings taken at Hilo Airport. Daily morning and afternoon mixing heights at Hilo were available from the National Weather Service for 1979. Table 3.2 presents monthly average mixing heights at Hilo based on the 1979 soundings and show that mixing heights in the area are highest in the summer and lowest in the winter. Average morning mixing heights range from 883 meters to 1555 meters. Average afternoon mixing heights range from 909 meters to 1999 meters.

2.0 Air Quality

The State of Hawaii has promulgated air quality standards to protect public health and welfare and to prevent the significant deterioration of air quality. These air quality standards are presented in Table 3.3 and cover Carbon Monoxide (CO), Nitrogen Dioxide (NO_2), Total Suspended Particulate Matter (TSP), Sulfur Dioxide (SO_2), and Ozone (O_3). Standards specified for twelve-month periods or calendar quarters may not be exceeded. Standards for one-hour, three-hour, eight-hour, and twenty-four-hour periods may not be exceeded more than once in any twelve-month period.

The State of Hawaii has also proposed a one-hour hydrogen sulfide (H_2S) standard of one hundred thirty-nine micrograms per cubic meter which may not be exceeded under any circumstance. A one-hour hydrogen sulfide increment of thirty-five micrograms per cubic meter has also been proposed which applies only to geothermal power plants. This increment is the maximun allowable increase of hydrogen sulfide above natural background levels and considers all stationary sources, except for geothermal wells during testing and routine maintenance. This increment may be exceeded once during a twelve month period at any one location.

H_2S has been continuously monitored at several sites in the vicinity of the HGP-A well site (Figure III-3). These sites include:

- o Schroeder Site - located approximately 2 km south-southwest of the HGP-A site. H_2S data collection began in March 1981, and was the first site to be established.

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TABLE 3-2

MONTHLY AVERAGE MIXING HEIGHTS
HILO, HAWAII

Month	Morning Height (m)	Afternoon Height (m)
January	883	1342
February	979	909
March	1039	1664
April	1156	1667
May	1379	1844
June	1555	1999
July	1455	1903
August	1398	1795
September	1437	1880
October	1456	1795
November	1221	1570
December	1199	1456
Annual	1263	1652

Data Period: January 1979 through December 1979
Upper Air Data Source: Hilo Hawaii (Station No. 21504)
Surface Data Source: Barber's Point, Hawaii (Station No. 22514)
(Source: Dames & Moore, 1984)

TABLE 3.3

STATE OF HAWAII AMBIENT AIR QUALITY STANDARDS AND INCREMENTS

POLLUTANT	AVERAGING TIME	AIR QUALITY STANDARD (ug/m^3)
Carbon Monoxide	1-hour	10,000
	8-hour	5,000
Nitrogen Dioxide	Annual	70
Suspended Particulate Matter	24-hour	60
	Annual	150
Sulfur Dioxide	3-hour	1,300
	24-hour	365
	Annual	80
Ozone	1-hour	100
Hydrogen Sulfide[a]	1-hour	139
Hydrogen Sulfide[b]	1-hour	35

---

[a] Proposed ambient air quality standard

[b] The 1-hour H_2S increment applies only to impacts resulting from geothermal power plants under normal operating conditions.

- Hess Site - located approximately 2 km southwest of the HGP-A well site. This station began operation in July 1982.

- Gilman Site - located approximately 1 km west of the HGP-A well site. This station also began operation in July 1982.

- Wood Site - located approximately 2.5 km north of the HGP-A well site. This station began operation in April 1981.

H_2S concentrations for these sites are summarized in Table 3-4. These data show that the maximum 1-hour H_2S in this region was 68.0 micrograms per cubic meter (ug/m^3) at the Schroeder site and was used in the air quality impact analysis as the worst-case ambient background concentration. These maximum concentrations are all well below the proposed state standard of 139 ug/m^3. H_2S has also been monitored at numerous locations for short periods of time. H_2S concentrations were generally found to be lower than the worst-case values reported from the above stations. Therefore, data from these sites will not be presented but a discussion of these sites can be found in NEA, Inc. (1985).

Suspended particulate matter concentrations have also been monitored in the area. Data has been collected on a long-term basis at the Bishop Estates (Upper Leilani) Leasehold (approximately 4 km southwest of the HGP-A site), and at the visitors center of Hawaii Volcanoes National Park (located approximately 20 km east of the HGP-A well site. The U.S. EPA recently established an ambient air quality standard for inhalable particulate matter less than 10 microns (PM_{10}) of 150 ug/m^3 and 50 ug/m^3 for 24-hour and annual averaging periods, respectively. Data from the Upper Leilani site show that the maximum 24-hour PM_{10} concentration measured was 19.0 ug/m^3 on 11 August 1984. The maximum arithmetic mean for the site was 9.5 ug/m^3 during 1984. Data from the Volcanoes National Park site show that the maximum 24-hour PM_{10} concentration measured was 17.8 ug/m^3 on 23 July 1984. The maximum arithmetic mean for the site was 5.2 ug/m^3 during 1984. The maximum PM_{10} concentrations of 19.0 and 9.5 ug/m^3 was be used for the air quality impact analysis for 24-hour and annual average periods, respectively.

3.0 Noise

The potential impact of geothermal development on local noise levels is dependent on several variables including the intensity of the noise source, meteorological conditions, sound propagation conditions, and background noise. This section

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TABLE ~~3-3~~

ONE-HOUR AVERAGE HYDROGEN SULFIDE CONCENTRATIONS
PUNA GEOTHERMAL DEVELOPMENT ZONE

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Site	1981	1982	1983	1984	1985	1986
	Maximum Concentration (ppmv)a,b					
Schroeder	0.045	0.048	0.007	--	--	--
Gilman	--	0.016	0.008	--	--	--
Hess	--	0.014	0.008	--	--	--
Woods	0.013	0.007	0.004	0.013	0.009	0.015
Yearly Maximum	0.045	0.048	0.007	0.013	0.009	0.019

---

a ug/m3 = ppmv * (Molecular Weight / 24.04) * 1000 (ug/mg)
b Molecular Weight of H2S = 34.08

(Sources: Dames & Moore, 1984; Fluor Technology, Inc., 1987)

III - 7a

presents a discussion of background noise conditions in the Puna geothermal development subzone.

a) Existing Site Conditions

Local terrain and vegetation features have a large effect on noise levels since terrain and vegetation can act as noise buffers. The geothermal development subzones exhibit a large variation in terrain features and vegetation. Vegetation varies from light to dense, consisting of papaya orchards, woodlands, other natural vegetation, and barren lava (Fluor Technology, 1987). The terrain in the geothermal development subzones is also quite varied. One feature which would have significant local noise shielding effects consists of several volcanic hills (puu). Each puu in the vicinity of a geothermal power plant or noise receptor would potentially reduce noise impacts.

b) Noise Regulations

There are currently no noise standards with numerical limits in effect. The County of Hawaii Planning Department has developed Geothermal Noise Level Guidelines based on a noise study in the Puna District. There guidelines are based on U.S. Environmental Protection Agency (U.S. EPA) noise criteria and may be applied to projects in the geothermal development subzones.

Noise guidelines are presented in units of average frequency weighted decibels (dBA) to account for human response to a range of sound frequencies. The County of Hawaii Planning Department noise guidelines specify 55 dBA during the daytime (0700 to 1900) and 45 dBA during the nighttime (1900 to 0700) as satisfactory for residential areas. Short duration (less than 1 second) impact noise limits may not be exceeded more than 10 percent of the time in any 20-minute period.

As a reference, the U.S. EPA (1978) has set forth ranges of "well-known" sources of sound. Some of these ranges are:

o quite wilderness area	20 - 30 dBA
o quite suburban residence	48 - 52 dBA
o business office	50 - 60 dBA
o noisy urban area	80 - 90 dBA
o adjacent to freeway	90 dBA
o jet airplane at 100 feet	120 - 130 dBA

Also, the Occupational Safety and Health Administration (OSHA) requirements for the workplace specify that no worker should be exposed to 115 dBA for more than 15 minutes, or to

90 dBA for more than eight hours. The U.S. EPA (1978) recommends that "noise limitations should conform, as an initial minimum, to the regulations issued by the U.S. Geological Survey for geothermal operations on Federal lands; i.e., not to exceed 65 dBA at the lease boundary or one-half mile from the source, whichever is greater."

For the noise impact assessment, the County of Hawaii Planning Department recommended noise levels will be used in determining significant impacts at off-site locations. Noise impacts less than the recommended daytime and nighttime residential levels would be considered insignificant.

c) Existing Noise Levels

Noise measurement data in the Puna geothermal development subzones is limited. An environmental noise survey was conducted by Fluor Technology, Inc. (1987) as part of the Puna Geothermal Venture (PGV) Project Environmental Impact Statement (EIS) noise impact analysis. This data will be used to characterize the typical environmental noise levels expected at suburban areas within the geothermal development subzones.

Noise monitoring stations were located at two residential locations near the PGV site. Background noise levels during the survey ranged from 34.2 dBA (7 p.m.) to 53.2 dBA (5 a.m.), which exceeds the County nighttime noise guidelines of 45 dBA. The high background noise level was due to moderate winds and precipitation in the area during the noise survey. Monitored noise levels from the PGV study are presented in Table 3.5. In general, background noise levels remained well below 45 dBA during most hours of the survey.

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Table ~~3-1~~

NOISE MONITORING DATA

Time Period (hour ending)	Off-Site Residence Brees Station L90a (dBA)	Off-Site Residence Brees Station Leqb (dBA)	Off-Site Residence Gilman Station L90a (dBA)	Off-Site Residence Gilman Station Leqb (dBA)
13:00	36	51.0	--	--
14:00	35	43.9	36	53.3
15:00	35	43.3	34	46.7
16:00	34	42.7	32	40.7
17:00	35	44.6	32	59.2
18:00	33	43.2	35	37.1
19:00	32	34.2	40	43.7
20:00	35	36.7	50	52.1
21:00	34	36.6	39	41.8
22:00	34	35.8	39	41.2
23:00	34	36.0	38	44.8
0:00	35	36.8	41	44.5
1:00	35	37.0	42	44.3
2:00	35	37.2	44	49.4
3:00	35	37.0	48	50.1
4:00	35	37.1	49	51.9
5:00	34	36.6	51	53.2
6:00	34	36.4	50	52.2
7:00	35	46.4	43	47.3
8:00	34	43.9	35	43.8
9:00	34	46.8	36	43.3
10:00	34	48.4	35	42.9
11:00	37	43.6	34	43.8
12:00	40	46.3	33	43.0
13:00	--	--	34	51.2

---

a L90 is the A-weighted sound pressure level that is exceeded 90 percent of the time. The specified time period is one hour. The L90 is commonly used as an indicator of the ambient background noise

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b Leq is the equivalent sound level, which is the energy average of the A-weighted sound pressure level. The specified time period is one hour. The energy average is the constant noise level for an hour [illegible]

C. HYDROLOGY AND WATER QUALITY

1.0 Regional Hydrology

The island of Hawaii has abundant water resources with over 14,000 million gallons per day (mgd) of rainfall. Approximately 25 percent of this volume flows to the ocean as runoff, 31 percent infiltrates as groundwater recharge, and the balance is returned to the atmosphere as evapotranspiration (Feldman and Siegel, 1980).

With its five volcanic systems, a wide variety of hydrogeologic regimes exist on the island. As is typical of the Hawaiian Islands, the greatest volume of precipitation occurs on the windward (northeast) slopes. Most of the island's surface runoff occurs on the older, more weathered volcanoes of Mauna Kea and Kohala Mountain.

The Ghyben-Herzberg lens model can generally be applied to the island of Hawaii. This model indicates that fresh water beneath ocean islands floats on seawater to a depth below sea level which is 40 times the depth above sea level. This general model requires considerable modification due to local meteorologic and geologic conditions.

Extensive dikes, resulting from volcanic activity, effectively restrict groundwater flow and trap precipitation in formations very different from the Ghyben-Herzberg basal lens (Figure III-8). Ash deposits may form impermeable layers resulting in perched groundwater tables. Figure III-9 outlines the general groundwater reservoirs found on the island of Hawaii.

2.0 Local Hydrology

Kilauea, the island's youngest volcano, has only minimal soil development and few interlayed ash beds allowing precipitation to percolate rapidly into the ground. There are no permanent surface streams and only one small lake, Green Lake in Kapoho Crater, which results from a localized ash layer causing a perched water table.

The East Rift Zone of Kilauea Volcano, as with other rift zones of Hawaiian volcanoes, imposes two major modifications on the Ghyben-Herzberg model. First, the extensive system of faults and dikes in the rift zone traps precipitated fresh water, resulting in its occurrence at high elevations and at greater depths than could be attributed to the basal lens. Second, the nearly vertical structure and impermeable nature of

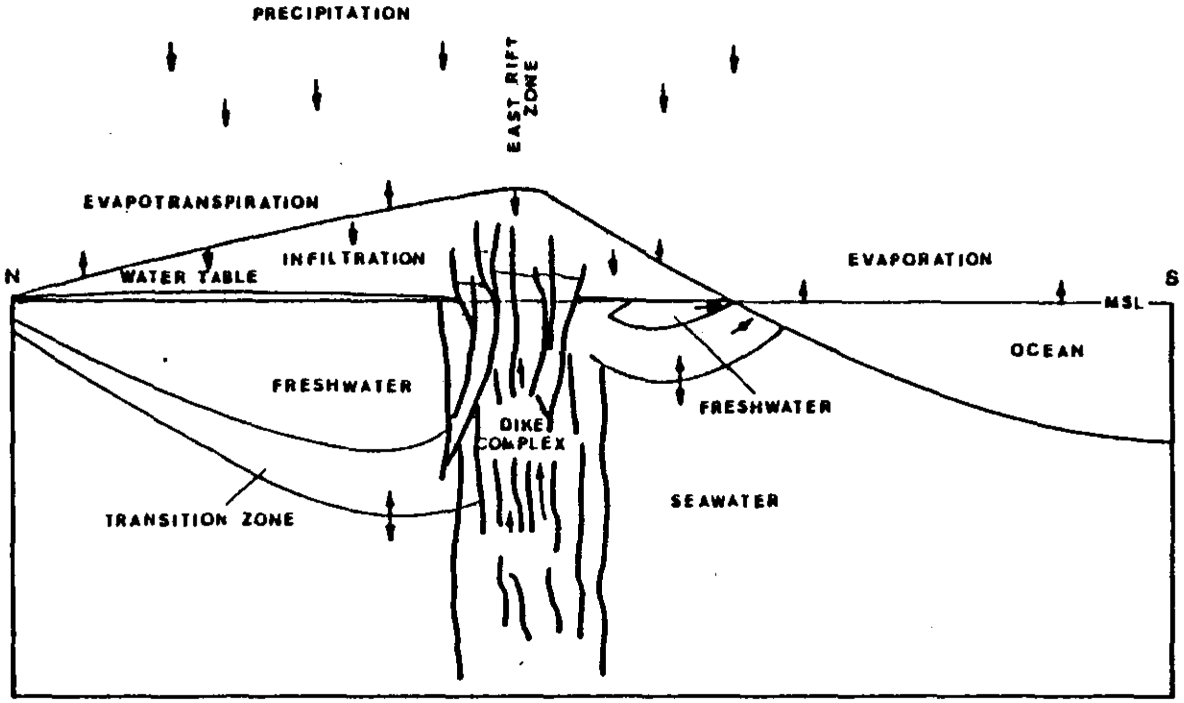
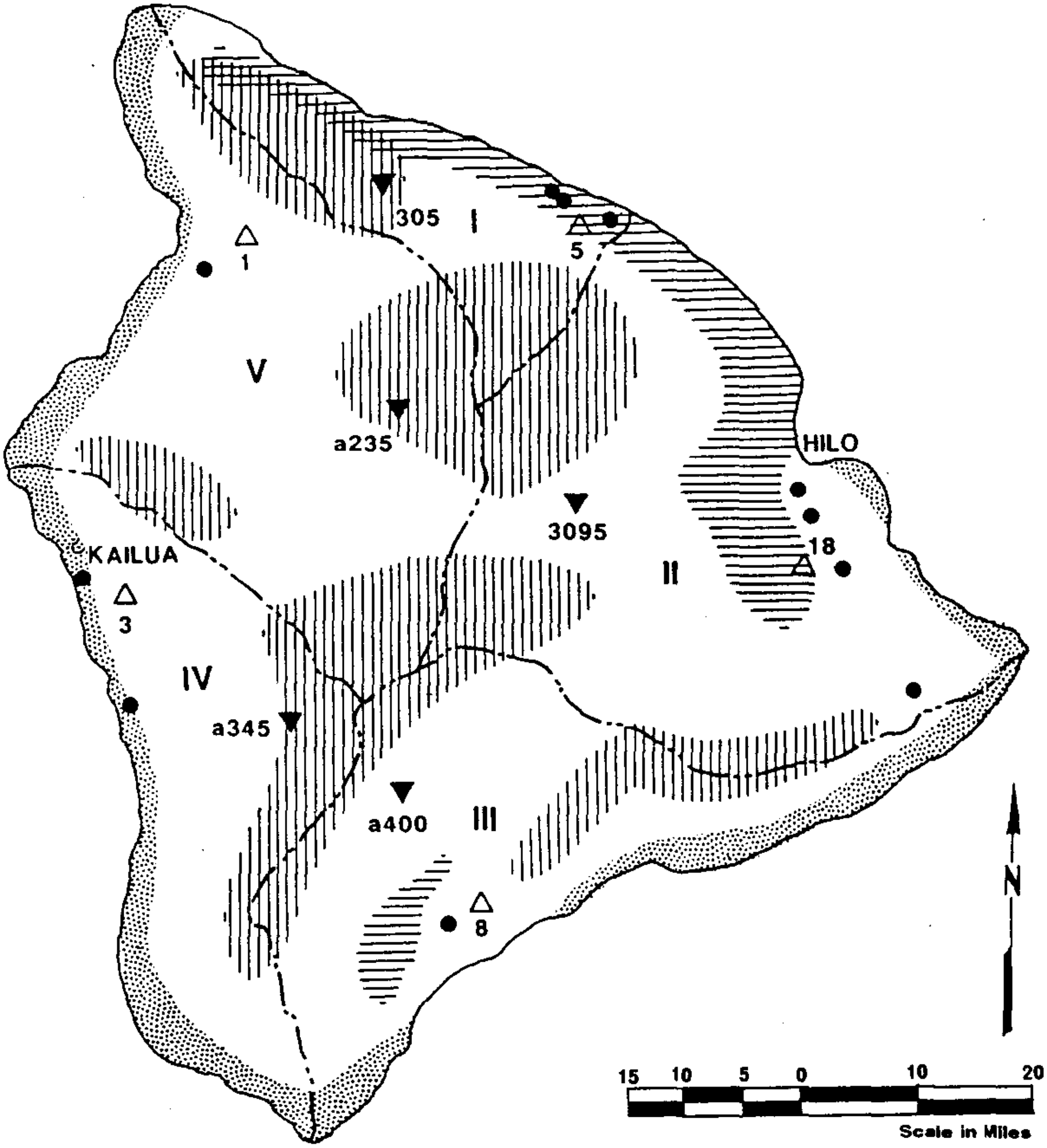


Figure ~~6.~~ III-8 Schematic North-South Cross-Section Through Puna Showing Recharge, Movement, Discharge, Storage, and Subsurface Geology of Groundwater (Druecker and Fan, 1976)



LEGEND:

▼ Ground-water recharge (million gallons per day)
△ Ground-water draft (million gallons per day)
● Principal supply wells
a High recharge rate owing to high capacity of land surface to absorb rainfall.
II Hydrographic area representing major drainage basin
▥ Ground water impounded by dikes
▤ Ground water perched on soil or ash layers overlying basal ground water
☐ Basal ground water floating on saline ground water
▒ Brackish basal ground water

Source: modified from Feldman and Siegel (1980)

Figure III-9
Groundwater Reservoirs

the dike and fault system of the rift zone creates a barrier to groundwater flow.

Precipitation in Puna averages about 100 inches per year. North of the rift, rainfall is about 140 inches annually while the southeast coast is drier with approximately 80 inches per year. Recharge loss due to evapotranspiration is estimated to be from 10 to 30 inches annually (Imada, 1984; Fluor Technology, 1987).

Hydraulic gradients along the northeast coast of Puna range between two and four feet per mile with water table elevations of 12 to 18 feet above sea level five to six miles inland. In contrast, the southeast coast which receives less precipitation and is separated by the East Rift Zone, has gradients ranging between one and two feet per mile with water table elevations of three to four feet above sea level a mile and a half inland (Drucker and Fan, 1976). Circulation within the East Rift Zone itself is probably minimal and is thought to be parallel to the rift (Fluor Technology, 1987).

Tritium concentration and oxygen isotope ratios of groundwater that recharge is primarily local and mean residence time of these ground waters does not exceed a few years (Kroopnick et al., 1978). The basal ground water is discharged along the coasts in the form of diffuse flows and a few large basal springs. Along the northeast coast, the daily groundwater discharge is estimated to be several million gallons. Along the southeast coast, this discharge is much lower (Imada, 1984).

Although permeability of the basal aquifer is high and yields greater than 300 gpm per foot of drawdown are common, discharge of groundwater through wells is low because of limited demand for the water (Imada, 1984). This limited demand is partly the result of the brackish nature of the water south of the rift zone.

3.0 Water Quality

The location of some wells in Puna is shown in Figure III-10. Chemical data from some of these wells is provided in Table 3.6. Pahoa area wells, north of the rift zone, provide an abundance of high quality fresh water from an aquifer estimated to be over 600 feet deep in that area. Geothermal wells, drilled to depths greater than 1800 feet in the rift zone, have indicated the existence of hot (greater than 200 degrees Celcius) geothermal resources at these depths. This deep geothermal reservoir appears to be at least partially separated from the shallower ground water by layers of low permeability (Figure III-2). South of the rift zone, ground water tends to be abnormally warm and saline. Discharge of this water to the ocean results in warm geotheraml springs along a portion of the southeast coast of Puna. This

Figure III-10 Water wells in the Puna Area

3.6
Table ~~I~~ Chemical data for Puna area wells [(a)]

USGS/BWS No.	Name	Date	T (°C)	pH	Na	K	Ca	Mg	Cl	HCO_3	SO_4	SiO_2	T[(d)]
2986-01	Pahoa Station	01-06-75		7.30	36.0	2.72	1.58	2.7	13.5	48	21.1	50.0	9.9
9-5	elev. 705'	07-21-75	23.3	6.65	19.3	2.7	1.6	1.9	9.8	44	27.3		10.6
	pumped												
2487-01	Kalapana Station	01-06-75	28.5	7.68	89.6	5.20	5.30	6.6	132.2	38	37.2	44.5	16.7
9-7	elev. 752'	07-21-75	20.8	7.05	78.8	5.0	5.9	5.6	120	36.8	28.6		18.0
	pumped												
3080-02	Kapoho Shaft	01-06-75	25.5	7.80	85.8	6.60	42.4	37	16.9[(b)]	372	20	53.6	14.1
9	elev. 38'	07-21-75	22.1	7.10	86.5	6.2	23.2	25.7	95.7	328	22.7		10.5
		10-27-75			92.0	5.8	32.0	27.8	105	330	23.0		--
3081-01	Airstrip Well	01-06-75	36.8	7.42	238	13.6	23.0	28	303.5	48	204	71.3	--
9-6	elev. 287'	07-22-75	33.5	7.75	223	16.8	12.5	27.2	316	44	211		11.1
	depth 285'												
2881	Allison Well	01-07-75	37.8	7.35	216	10.8	13.4	15	281	132	69.2	24.1	12.9
	elev. 140'												
	depth 144'												
	Isaac Hale Park	01-07-75	36.0	7.75	2020	86.0	32.4	200	3534	56	507	81.5	8.5
	Spring	10-27-75			2140	87.5	98.0[(b)]	239	3660	61.0	552		--
2783-01	Malama Ki Well	01-07-75	52.2	7.02	2105	109	66.8	210	3811	144	471	100.7	15.6
9-9	elev. 274'	07-22-75		7.45	2890	149	117	293	5120	128	598		8.6
	depth 276'												
G3	Geothermal #3	01-07-75	93.0	6.85	2050	190	76.8	52	3274	30	314	96.6	10.3
	elev. 600'	07-21-75			2000	195	81	59	3410		335		7.3
	depth 550-600'												
G3-T	Geothermal #3[(c)]	07-21-75	74	1.4	1740	158	71	62.5	2980	20	317		9.1
	(Thief)												

(a) All concentrations are in mg/ℓ

(b) Suspect datum

(c) This sample taken 50-60' below water surface

(d) Tritium reported in tritium units

Source: Kroopnick, et al (1978)

suggests that warm water is escaping from deeper geothermal reservoir or dike complexes into the basal rising through the cooler fresher water, reducing the lens effect and increasing the salinity and temperature of the basal water.

4.0 Site Specific Hydrology

The Kilauea Middle East Rift GRS has been grouped with the Kamaili Section of the Kilauea Lower East Rift GRS for purposes of discussing the site specific hydrology. The Kapoho Section of the Kilauea Lower East Rift GRS is geographically separate from the other zones and has distinguishing hydrologic features.

a) Kilauea Middle East Rift GRS and Kilauea Lower East Rift GRS

Very little site specific information is available for this area, primarily because economic necessity has not prompted detailed hydrologic investigations. The nearest wells are the Pahoa wells (2986) just north of the Kamaili Section, and the Keauohana wells (2487) just south of the section (Figure III-10). These wells are similar in depth (740-805 feet) and both are used for domestic supply purposes. The Pahoa wells produce water of excellent quality. It is anticipated that this is generally representative of all areas within these subzones which are northwest of the rift structure. It is thought that ground water north of the rift zone flows to the ocean in a northeasterly direction, generally perpendicular to topographic contours (Fluor Technonogy, 1987).

The Keauohana wells (2487) are somewhat warmer and more saline (Table 3.6). It is anticipated that ground water in and south of the rift zone in this area will be somewhat saline, depending upon the extent of seawater intrusion and geothermal leakage into the aquifer. Discharge to the ocean from this aquifer is expected to be direct in a southeasterly direction.

b) Kapoho Section, Kilauea Lower East Rift GRS

More information is available for this section as a result of the development of HGP-A and other geothermal wells within the section. The hydrology of this area is influenced by the major structural break (transverse fault) of the East Rift Zone at the southwest end of the section. All ground water downgradient of the transverse break appears to be geothermally affected, displaying elevated temperatures and mineral levels (Fluor Technology, 1987).

Ground water within the rift zone flows northeast, parallel to the rift zone, except where structural leakage allows this water to flow southeast. To the north of the rift zone, ground water flows northeast to the ocean, generally perpendicular to topographic contours except where dikes and faults affect the flow. South of the rift zone, ground water flows southwest to the ocean. Permeabilities in the area are high with the exception of the ash layer found near Kapoho Crater.

All water wells within and south of this section display elevated temperatures and relatively high mineral contents suggesting geothermal influence and a poorly developed basal lens. There are no recorded water wells north of the section, but the high quality of water from Pahoa wells suggests that groundwater quality may improve in a northerly direction.

HGP-A, the first successful geothermal well drilled in the East Rift Zone, initially produced much fresher fluids than would be predicted by the Ghyben-Herzberg model. This suggests that the dike system hinders the flow of seawater into the rift zone. The geothermal reservoir tapped by HGP-A differs from shallow well water in several respects. First, it has a high acidity with a pH value of about 3 compared to pH values of 7 or greater for shallow wells. Second, it has a silica content of 440 mg/liter compared to 80 mg/liter for shallow wells. Third, it has a very low tritium content, which indicates a relatively long residence time, possibly exceeding 50 years (R.M. Towill Corporation, 1982). This suggests very limited interaction between the geothermal reservoir and the shallower groundwater aquifers.

The chemical composition of HGP-A fluids has changed considerably since the well was first sampled, as indicated by Table 3.7. This data suggests that the seawater component of the reservoir has been increasing as fluids have been discharged from it.

table 3.7

Chemical Composition of the HGP-A Reservoir Fluids*

Date	Cl	Na	K	Mg	Ca	SiO_2	CO_2	H_2S
1- 8-76	876	480	84.8	0.2	32.8	-	-	-
4-11-77	1220	584	106.4	0.1	30.9	404	-	-
6-12-81	637	322	61.6	0.021	7.4	408	600	450
9- 4-81	2109	1248	143	0.06	41.0	456	538	409
4-19-82	3017	1591	269	0.076	70.1	455	559	387
7-12-82	3445	1881	306	0.041	89.5	466	540	389
2-15-83	4260	2883	373	0.087	142.5	-	-	-
4-18-83	4392	2883	366	0.096	156.	467	538	412.8

Source: Imada (1984)

D. CULTURAL RESOURCES

This review presents the results of a search of archaeological and historical literature for the purpose of assessing possible archaeological impacts of geothermal development of three geothermal resource subzones in the Puna District. The sources consulted include previous archaeological reports within and adjacent to the areas, as well as maps and historical references of the post-European Contact Period. Figures III-11, III-12 and III-13 show known site areas within all three of the geothermal resource subzones.

In addition, a botanical study of the area prepared by the University of Hawaii and maps of dated lava flows prepared by Ms. Tina Neal of the U.S. Geological Survey proved very useful. Figures III-14, III-15 and III-16 show recent lava flows within the subzones. An annotated bibliography of all sources consulted in the preparation of this review is presented with the entire report in Appendix C.

1.0 Historical Review

a) Traditional Accounts

Puna was one of the six ancient districts or moku of the Island of Hawai'i. Traditional accounts relate that Puna was a rich agricultural region, a center of development for religion, and focus for myths concerning Pele.

Traditional references to Puna agriculture, like the legend of Keliikuku in W.D. Westervelt's Hawaiian Legends of Volcanos (1916), and Samuel Kamakau's writings on Imakakoloa in Ruling Chiefs (1961) imply an abundant supply of a wide variety of agricultural goods. "My country is charming. Abundance is found there. Rich, sandy plains are there, where everything grows wonderfully,"(a Boast of Keliikuku)(Westervelt 1916:31). Imakakoloa, a great chief in the district of Puna at the time of Kalani'opu'u (ca 1770) was resisting the "extravagant demands for contributions of all kinds of property" to Kalani'opu'u (D. Barrere 1959). "It was I-maka-koloa, a chief of Puna, who rebelled, I-maka-koloa the choice young 'awa (favorite son) of Puna. He seized the valuable products of his district, which consisted of hogs, gray tapa cloth ('eleuli), tapas made of mamaki bark, fine mats made of young pandanus blossoms (ahu hinalo), mats made of young pandanus leaves ('ahuao), and feathers of the o'o and mamo birds of Puna" (Kamakau 1961:106). Though these references are non specific they are suggestive of the traditional Hawaiian agricultural practice of using a wide range of environmental zones. These would include the coastal zone, the immediate

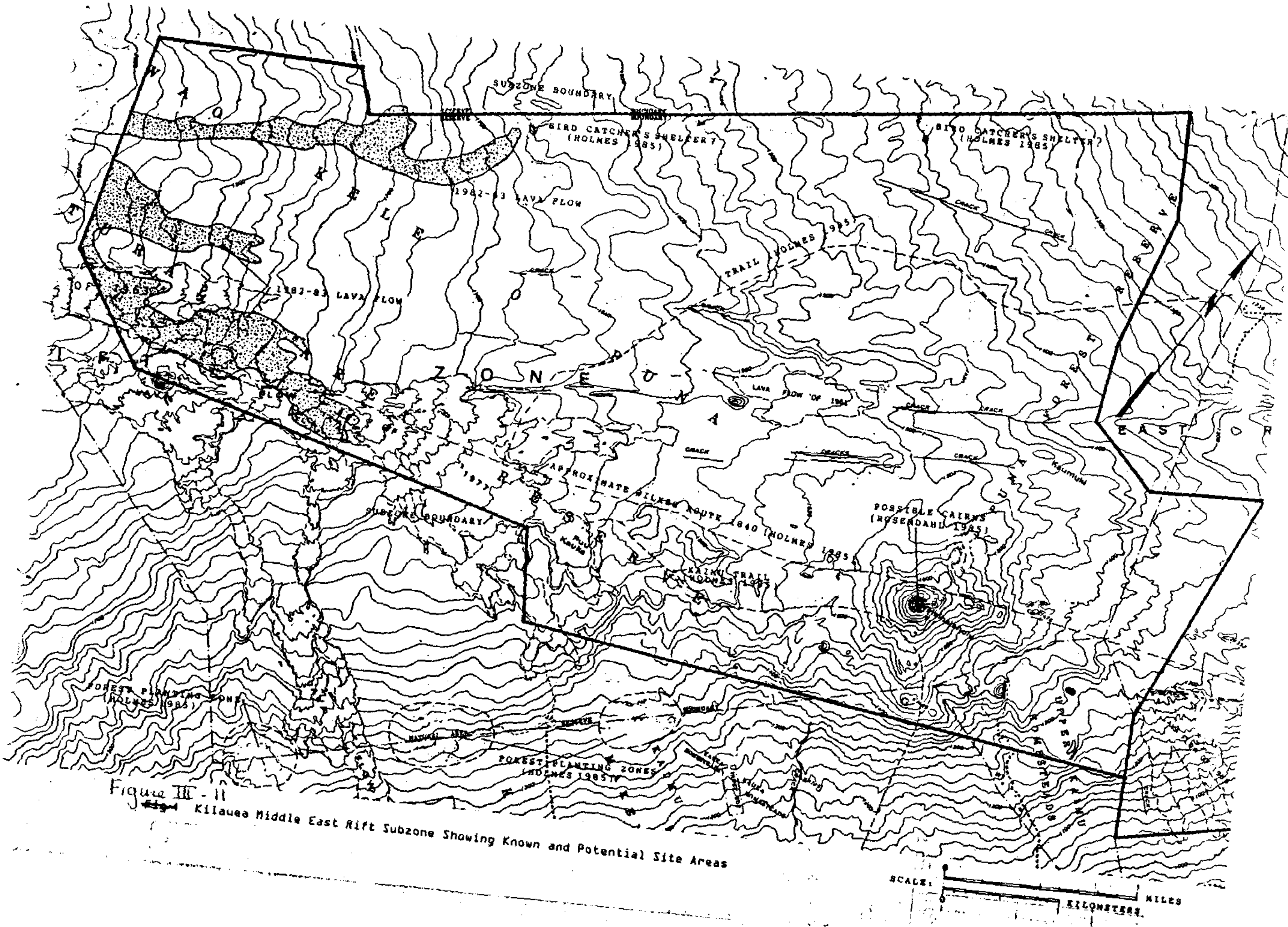


Figure III - 11 ~~Fig.~~ Kilauea Middle East Rift Subzone Showing Known and Potential Site Areas

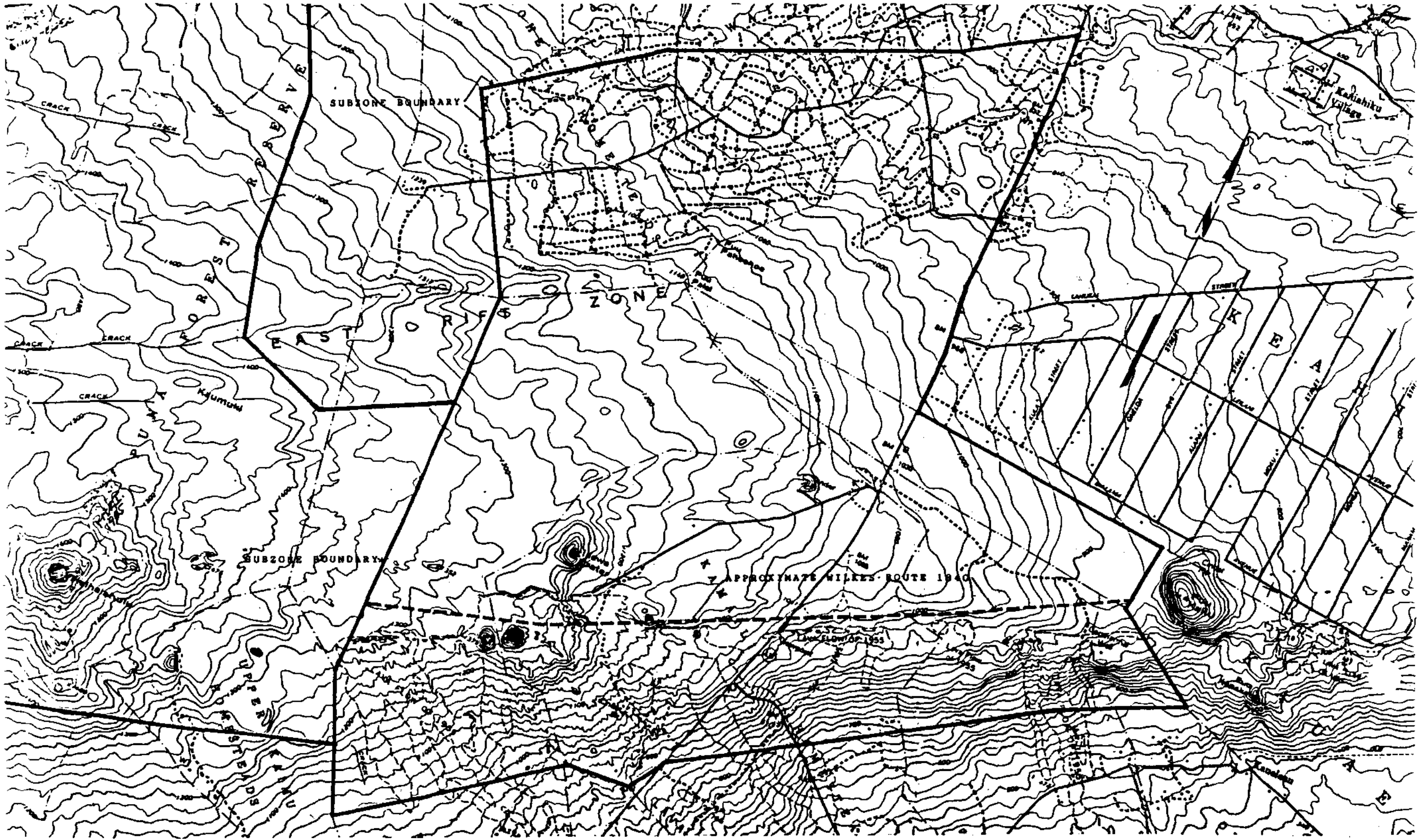


Figure III-12

~~Fig.~~5 Kamaili Subzone Showing Known and Potential Site Areas.

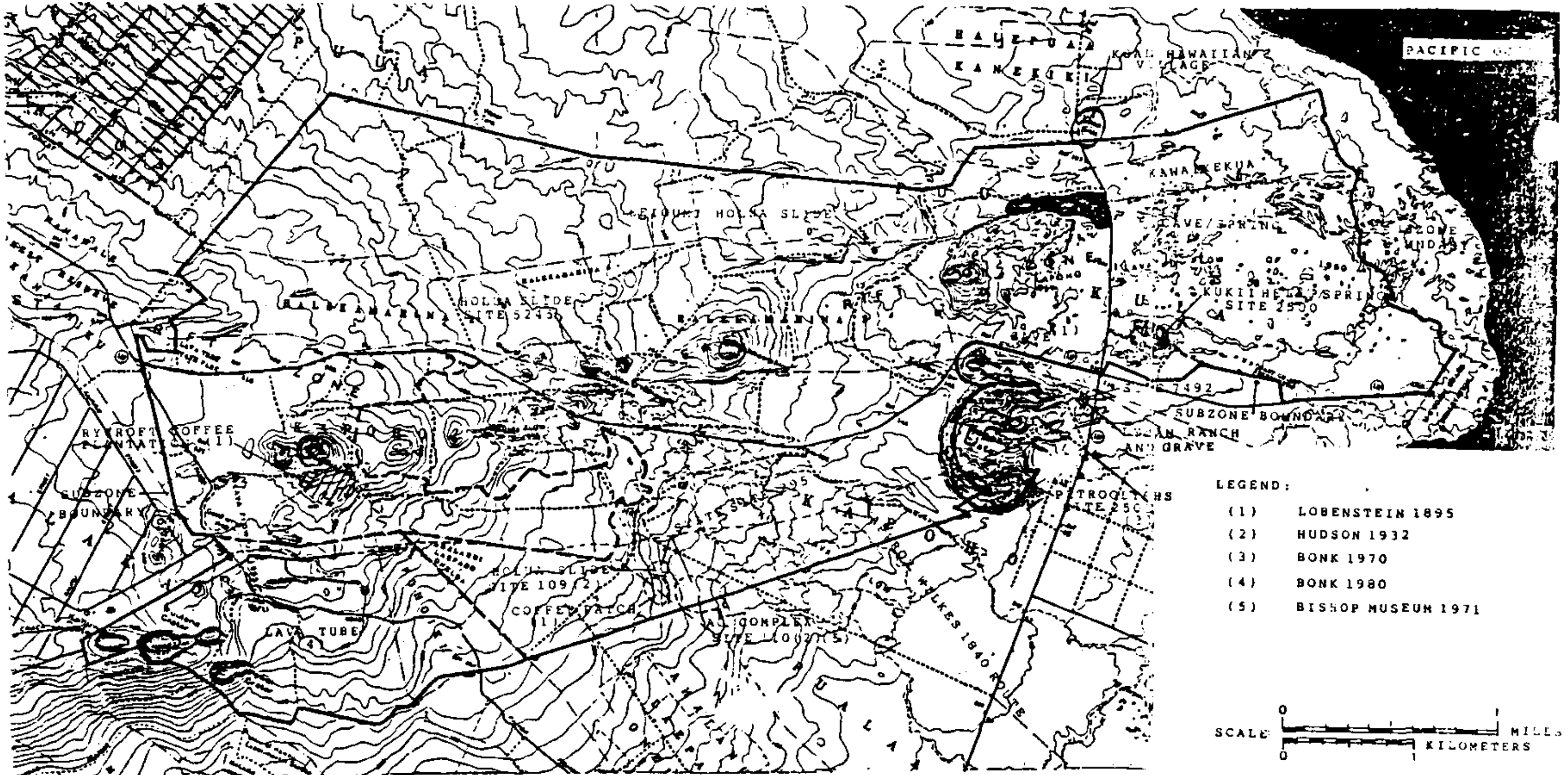
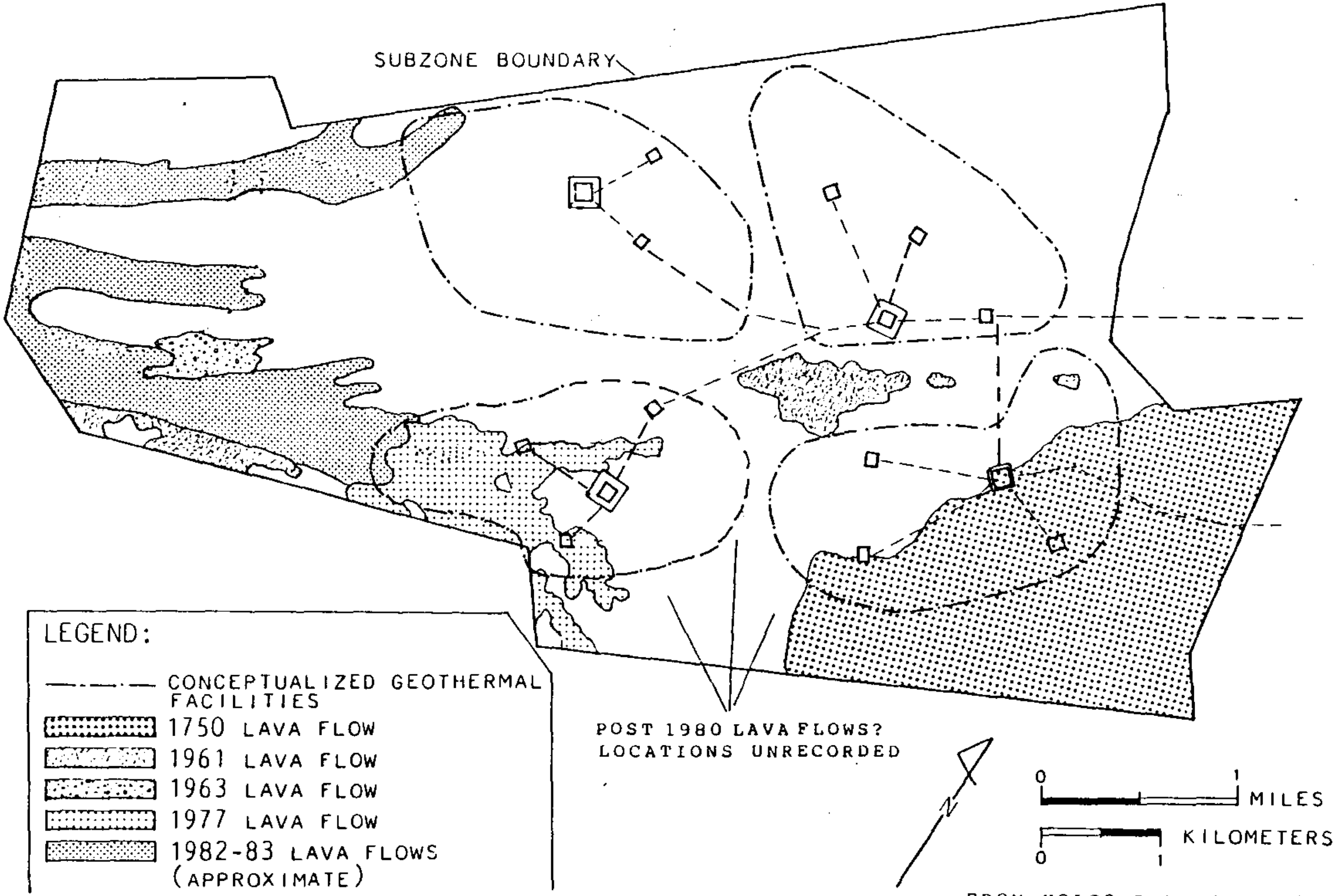


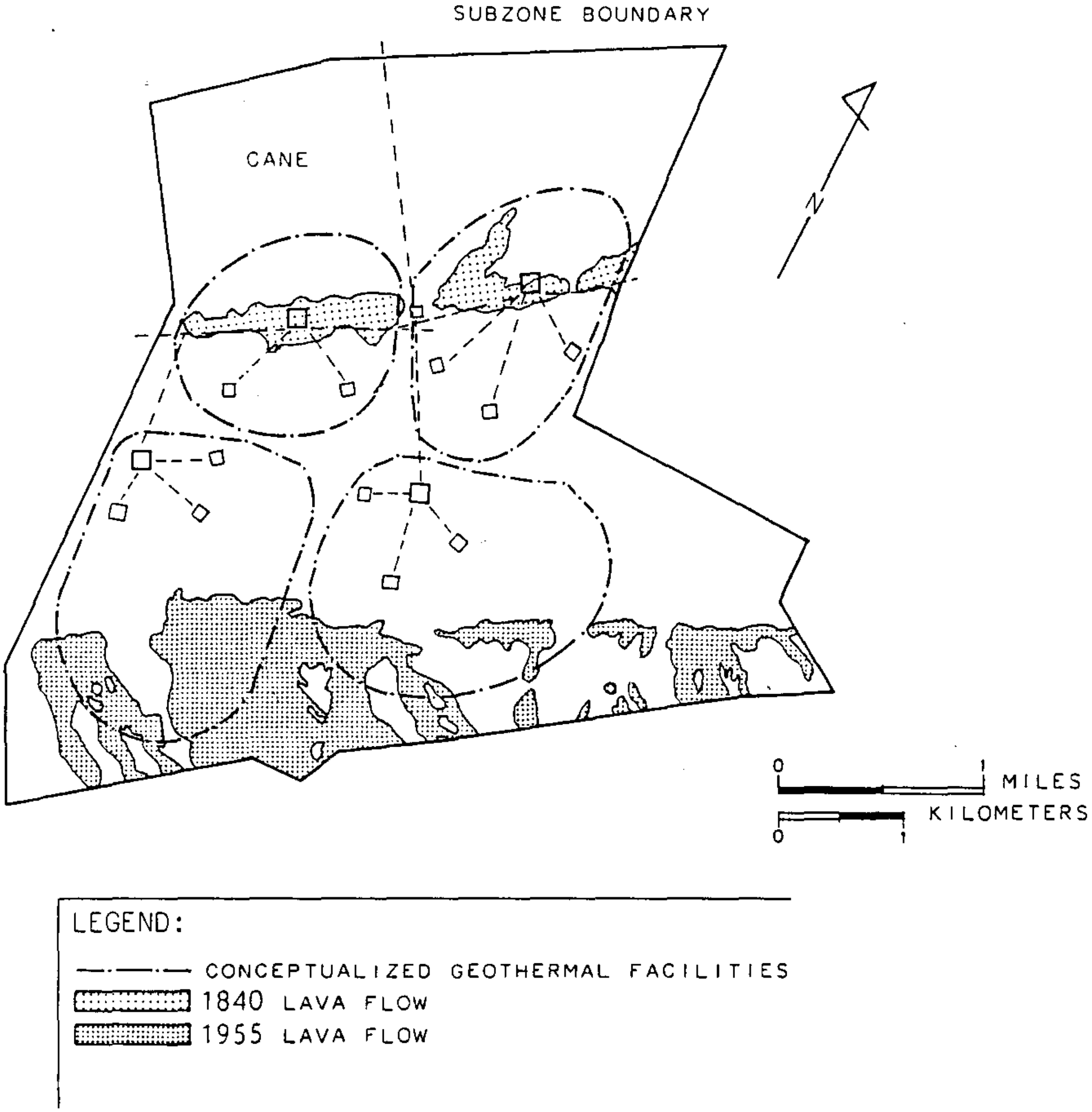
Figure III-13

~~Fig.6.~~ Kapoho Subzone Showing Known and Potential Site Areas.



FROM HOLCOMB, U.S.G.S., 1980.

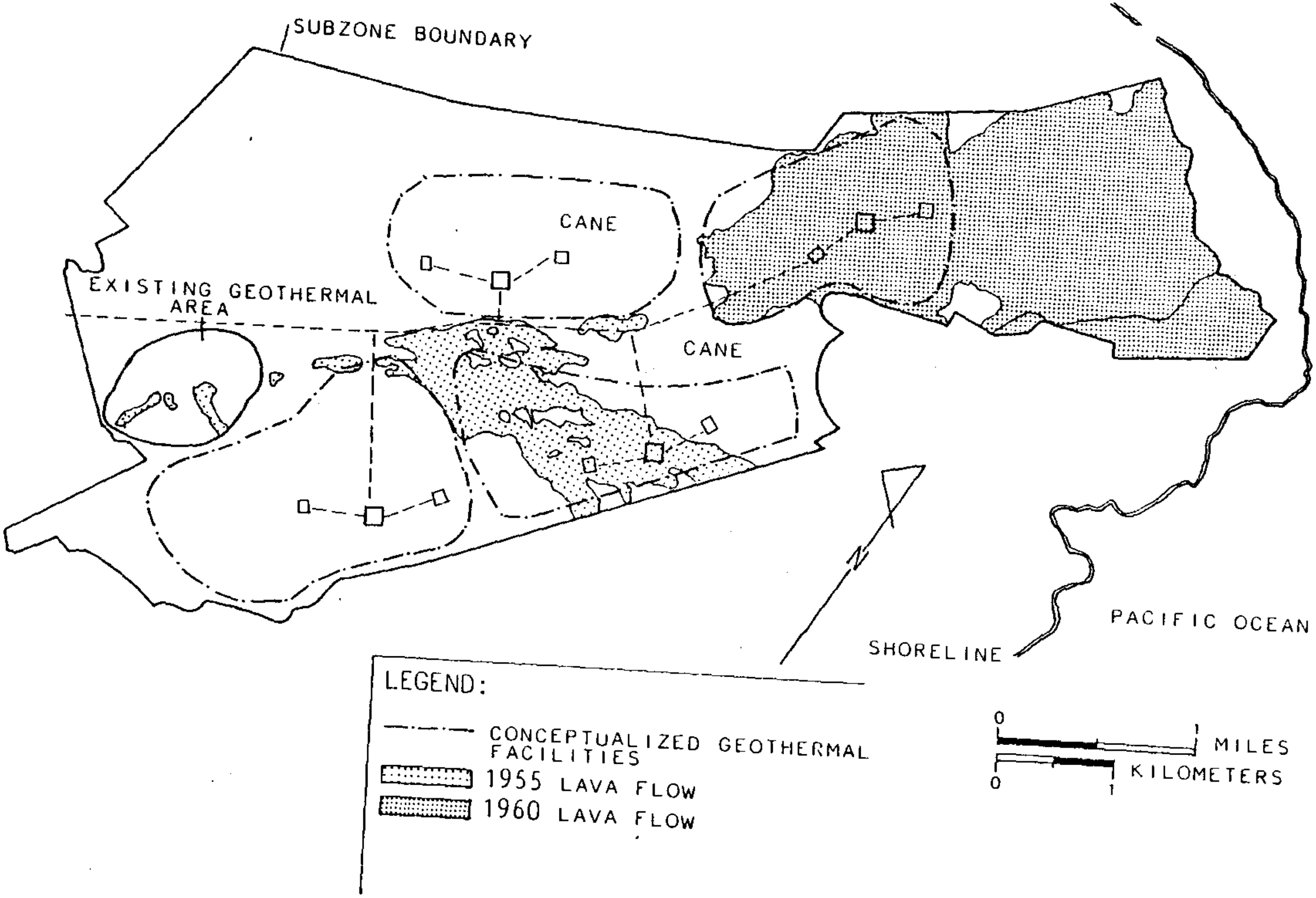
Fig. 7 Kilauea Middle East Rift Subzone Showing Lava Flows Younger Than A.D. 1800



FROM HOLCOMB, U.S.G.S., 1980.

III-15

Fig. ~~8~~. Kamaili Subzone Showing Lava Flows Younger Than A.D. 1800.



FROM HOLCOMB, U.S.G.S., 1980.

III-16

Fig. ~~X~~ Kapoho Subzone Showing Lava Flows Younger Than A.D. 1800.

upland agricultural zone or "the sandy plains where everything grows wonderfully" and the forest zone for such goods as mamaki bark for tapa and the valuable bird feathers for capes (etc.). E.S.C. Handy wrote of Puna saying, "One of the most interesting things about Puna is that Hawaiians believe, and their traditions imply that this was once Hawai'i's richest agricultural region and that it is only in relatively recent time that volcanic eruption has destroyed much of its best land" (Handy and Handy 1972:542).

The references to Puna as a center of religious development has to do with Waha'ula Heiau (Volcanoes National Park). Waha'ula is believed to be the first heiau built by Paao "a priest from Tahiti," around A.D. 1275 (Loo and Bank 1970:47). Paao established a "line of priesthood" that lasted till after the death of Kamehameha I (Beckwith 1979:371). Waha'ula, a "Luakini" class heiau is also known as the last temple in Hawai'i to have had the practice of human sacrifice performed within its walls (Loo and Bank 1970:47). Another major heiau in Puna with a long history is Kukii Heiau (St. Site 2500). Kukii Heiau is located on the top of Kukii Cinder Cone within the proposed geothermal subzone, Kapoho section. Kukii Heiau, according to traditional accounts was built "by Umi (ca ad 1500), a devoutly religious ruler of the island of Hawai'i, after he had taken control of the island....

Kukii was constructed of dressed and hewn stone..." (Fornander 1969:101), a technique rare in pre-European Hawai'i. Though Kukii Heiau has been heavily disturbed by natural events and stone robbings, its location within the project area must be noted.

b) Legends

There are numerous legends concerning Pele and the district of Puna. They generally relate how Pele's anger is characterized by lava covering specific and/or large tracts of land. For example, in the aforementioned legend of Keliikuku, who boasted of his (Puna's) country's abundance, comes home (from O'ahu) to find "his vertical plains covered with black lava...and the remnants of the forest still burning (Westervelt 1916:31-32). One of several legends concerning Cape Kumukahi and Pele has to do with the formation of the point or cape. Kumukahi was a chief in Puna. He was a handsome man who loved the ancient games. He pleased Pele, but when she came to him as an old woman demanding to join the games he ridiculed her. She chased him to the sea, covering him with lava, forming the cape called Kumukahi (Westervelt 1916:27-00).

The sheer volume of traditional accounts relating Pele to Puna is undoubtably due to the very active vulcanism of the area. The overriding theme of these accounts is the power of Pele to transform the landscape. Pele is mentioned in relation to the many cinder cones, formation of Cape Kumukahi, unusual lava formations, and the covering or destroying of large tracts of land.

d) Early History

Though Puna was a rich agricultural region, and the site of Paau's first heiau (Waha'ula) it appears not to have been politically strong during traditional times. Dorothy B. Barrere in "Political History of Puna" states: "We find that Puna, as a political unit played an insignificant part in shaping the course of the history of Hawai'i Island. Unlike the other districts of Hawai'i, no great family arose upon whose support one or another chiefs seeking power had to depend for his success. Puna lands were desirable, and were eagerly sought, but their control did not rest upon the conquering of Puna itself, but rather upon control of the adjacent districts; Ka'u and Hilo" (Barrere 1959).

The review of literature pertaining to the traditional or pre AD 1796 Puna District seemingly indicate a dichotomy of sorts. The Puna District was described as, "once Hawai'i's richest agricultural region" (E.S.C. Handy 1972), and a center for religious development with the construction of Waha'ula Heiau (ca AD 1275) and establishment of a line of priesthood by Paao.

d) Post Contact Period

The historic period (post AD 1776) as it concerns Puna, is characterized as it is throughout Hawai'i by a decline in population, abandonment of traditional villages and agricultural sites, and the move to a market based society.

The early European descriptions of the Puna area generally recount that there was abundant and a wide variety of agricultural lands from different environmental zones. The population was clustered along the shoreline in "villages".

Early descriptions by the Rev. Ellis (1833), Rev. Titus Coan (1835), and the Wilkes Expedition of 1841 are the most revealing. In August of 1823 the Rev. Ellis passed through the Puna district and wrote: "The country had been much more populous than any we had passed since leaving Kona" (Ellis 1963). The Rev. Ellis estimated that in the "vicinity of the village of Kaiau" the population was probably around 2,000. Ellis and his fellow preachers, Artemis Bishop and

Asa Thurston continued on to Hilo, stopping and giving sermons at villages like Kehena and Opihikao which he also called populous. Ellis also mentioned agricultural products such as taro, sweet potatoes and sugar cane cultivated along the coastal strip and breadfruit "in a high state of cultivation" inside Kapoho Crater (in Barrere 1971:12).

The Rev. Titus Coan came to the Hilo Mission Station in 1835 and became the "district's" (includes Puna) appointed preacher. Titus Coan was a major force in the Puna area for nearly 50 years. He was the prime mover of a great religious revival that lasted from 1837 to around 1840. The revival was centered at Hilo and accelerated the "permanent or temporary abandonment of entire villages in outlying areas" (McEldowney 1979:36). During Coan's tenure he made numerous field trips to preach and in 1841 made a census for Puna. Coan noted that most of the inhabitants of Puna lived along the shore, though hundreds lived inland and the population was 4,371 of which none were foreigners (Holmes1985:7, from Missionary Herald extracts). In 1846 Chester Lyman, a professor from Yale, accompanied Coan on a tour of Puna and observed scattered agricultural activity in the upland forest, the breadfruit trees and taro patches in Kapoho Crater, and melons and gourds at Koae (Lyman 1924).

The Wilkes Expedition (1840-1841) follows the Kilauea East Rift Zone from Kilauea to Kapoho Crater then on back to Hilo. The descriptions again generally recount earlier descriptions. The expedition did encounter an "extensive upland taro patch" which Tommy Holmes approximated to be between 2,000 and 2,200' elevation within the ahupua'a of Kahauale'a (i.e. west of the project area). Wilkes commented on the sweet potatoes "growing among heaps of stones and pieces of lava" (Wilkes 1845:v.4:188) and also observed the banana, taro, and breadfruit growing in Kapoho Crater.

The mid-1800's (1840-1860) were a time of major change for all of Hawai'i including Puna. Though subsistence agriculture still dominated life in Puna, it was on a much reduced scale. The measle epidemic of 1848 began in Hilo and spread throughout the island, killing an estimated one-third of the population(McEldowney 1979:37). This was followed by the smallpox epidemic of 1853 with a further reduction of population.

The disruption of life styles due to the epidemics was coupled with an economy increasingly based on foreign trade, to whalers and California Gold Rush population explosion. Also the traditional land tenure policies changed with the "Great Mahele"(1840's-1850's) which allowed for private ownership of land.

In all of Puna there were only two small kuleana (lots to the actual persons living and working the land) awarded which is very unusual. Instead, the "sons and heirs of Kamehameha I's supporters became actual owners of the lands given to their fathers in recognition of the services to him (Barrere 1970:46). There were eleven ali'i who received title to virtually all of Puna as "absentee owners". By the end of the 1850's" in most back country ahupua'a the old subsistence-level life style was no more" (Ibid.:18).

e) The Nineteenth Century

The late 1800's saw the beginnings of large-scale commercial ventures in Puna. Cattle ranching became formalized with the Shipmans and Eldarts leasing portions of Puna from Keeau to Pu'ala'a in 1878. By 1890 W. H. Shipman controlled most of the grazing lands of Puna. In the 1890's coffee was grown and milled by R. Rycroft and was shipped out of Pohoiki. The "Lyman Ranch" near Kapoho Crater and the "Coffee Plantation" and mill of Rycroft are both located on the 1895 Loebenstein map.

The most important commercial venture began in 1899 with the incorporation of 'ola'a Sugar Plantation, the first in Puna (M. Kelly 1981:144). In 1900 the Puna Sugar Company was established but was essentially run as a subsidiary of 'ola'a Plantation from 1905 to 1936 when 'ola'a bought Puna Sugar Co. The Puna Sugar Co. eventually had some 6,500 acres in and around Kapoho.

In conjunction with the sugar industry, were rock and lumber industries which were all tied in with the expansion of the railroad into Puna. The railroad began in 1899 as the Hilo Railroad Company with Benjamin F. Dillingham and Lorrin A. Thurston as the original promoters. The railroad first hauled ohia logs from the forest clearing for the cane fields. In 1901 the rail line was extended into Kapoho with a 5-mile branch to Pahoa.

The Hawaiian Mahogany Lumber Company was started in 1907 with a mill in Pahoa. The company had gotten a contract with the Santa Fe Railway System to supply Ohia wood ties. In 1910 the lumber company "secured the right to lumber the forest on a tract of unleased government forest land in Puna, adjoining the Kaohe Homesteads at Pahoa, and having an approximate area of 12,000 acres" (Conde and Best 1975:103). The company, later known as the Hawaii Hardwood Company, went out of business around 1918.

Rock quarrying at Kapoho was conducted from 1908 to 1925 with rocks hauled on the Hilo Railroad Company lines. The bulk of the quarried rocks were utilized in the construction of the Hilo breakwater. The Kapoho quarries delivered some 88,657 tons of rock for the breakwater from 1922 to 1925 (Kelly 1981:193).

Sugar remained the single most important economic factor in Puna with much of the Kamalii and Kapoho sections under cultivation. In 1922 there were some 2,000 acres in the Kapoho area under cultivation. The Puna Sugar Co. operations continued to expand adding more acreage to cane cultivation. However, the 1955 Kapoho eruption was said to have eliminated some 1,400 acres of cane area (Kelly 1981:132). In 1979 Puna Sugar Co. harvested nearly 7,000 acres of cane out of their 16,000 acre total (_Ibid_.: 119).

f) The Kilauea Middle East Rift Zone subzone (Figure III-11)

The review of historical literature indicates that the Kilauea Middle East Rift Geothermal Subzone (approximately 9,000 acres) as a portion of the Puna Natural Area Reserve was not used extensively during pre-historic or historic times. During prehistoric times there were probably forest planting areas, specifically on the southern fringe. The forest was exploited for such things as wood, bird feathers, tree bark for tapa, and olona for cordage. This forest area or _wao_ (upland jungle) would also have been an important food resource area for such items as wild taro and bananas during times of famine. During historic times olona was still being extracted from the forest area until the late 1800's. In the early part of the 20th Century commercial logging of Ohia was undertaken in conjunction with the beginning of the sugar industry and its railway system. The area became a forest reserve starting in 1911 with 19,850 acres and was expanded upon to 25,738 acres in 1928. In 1981 a portion of the reserve, 16,847 acres was given Natural Area Reserve status (Holmes 1985:4)

g) Kamaili Subzone (Figure III-12)

The Kamaili subzone section (approximately 5,400 acres) appears to have been only marginally used for agriculture during pre-historic times, but more than the Puna Reserve area. No specific references to this area were found but general remarks by early historic visitors indicate that at least the southern and northern fringes were somewhat utilized as "upland planting areas." Historically there has been extensive sugar cane cultivation, especially in the northern portion, excepting the central area which is rocky lava lands.

h) The Kapoho Subzone (Figure III-13)

The Kapoho subzone section (approximately 6,800 acres) was, of the three subzones, the most intensively utilized during the pre-historic and historic times. One of the major differences is that the Kapoho section extends to the coast (near Cape Kumukahi) and the entire southern boundary is also considerably closer to the coast than the other two geothermal subzones.

Evidence of pre-historic land use include an agricultural complex and destroyed holua slide in Upper pu'ala'a ahupua'a (Hudson Sites 109, 110, St. Site 4295), Petroglyphs at Kapoho Crater (St. Site 2501) and Kukii Heiau (St. Site 2500). Traditional and early historic accounts are also indicative of pre-historic usage. These include references to Kaholua O Kahawali (St. Site 5245), a cinder cone in a Pele legend, utilized as a holua slide, the formation of Cape Kumukahi as related in another Pele legend. The early historical accounts include references by Wm. Ellis, Titus Coan, Wilkes, and Chester Lyman to the populous shoreline habitation and agricultural zone with extensive upland agricultural areas. These references include specific mention of the "plantation" within Kapoho Crater and Koae Village and though both are just outside the project area (abutting the southern and northern boundaries respectively) their location is suggestive of similar land usage within the project area. The 1895 Loebenstein map also shows "ancient cultivating grounds" in Upper Pu'ala'a and near Pu'uhonua'ula "kalo" is referenced further evidence of the agricultural usage of the Kapoho section.

During historic times the area came under increasing pressure by wide-scale commercial activities. This began with cattle ranching in the 1870's and included the short lived coffee industry in the 1890's. The greatest and longest lasting venture was the sugar industry which began around 1900. The sugar industry also was a catalyst for the railroad system, lumbering, and rock quarrying. The Kapoho area eventually had well over 2,000 acres in cane cultivation under the Puna Sugar Co. However, the eruptions of 1955 and 1960 took over a large portion of this acreage.

2.0 Archaeological Review

a) Introduction

Archaeological research, concerning Puna in general, was first initiated in the early 1900's. These early investigations (Stokes 1906, Thrum 1907) were almost exclusively concerned with major stone structures (i.e. heiau). In the 1930's A.E. Hudson conducted a more comprehensive archaeological survey which involved mostly coastal areas from Waipi'o Valley (Hamakua) to Punalu'u (Ka'u). In the 40's and 50's K.P. Emory and other Bishop Museum staff members conducted surveys in two different Puna locations. Emory, in 1945 conducted an exploration of "Shipman's Cave" in Keaau, Puna. In 1959 the Bishop Museum did research on the "Kalapana Extension of Hawai'i Volcanoes National park" which included a section of the "Political History of Puna" by Dorothy Barrere. The 1960's through 1980's saw the advent of contract archaeology which has produced numerous reports concerning the Puna area.

b) The Three Major Occupation Zones

The majority of research has been conducted along the coast, but a few reports have dealt with inland areas also. The general pattern that has emerged from the archaeological research indicates that the highest concentration of sites (habitation, religious, and agricultural) occurs within the "coastal zone" areas.

The next highest concentration of sites would be the adjacent "upland agricultural zone." Sites in this zone would include agricultural complexes in suitable arable land and dispersed habitational features.

Beyond the upland agricultural zone would be the "forest zone." The forest zone activities would include procuring of wood products, fibrous materials such as olona for cordage, bird catching for valuable feathers, and foraging for food products, especially during times of famine. The references to habitational features in the forest zone indicate that they would have been of a temporary nature and built out of bio-degradable materials (i.e. ti leaves, etc.) leaving virtually no clue of the former locations. Other archaeological features within the forest zone would include trails and associated features (i.e. ahu) and possibly burials associated with cinder cones.

One type of sites that could be found in any of these "zones" is the lava tube. There have been a number of major tube systems, as well as isolated lava tubes, found throughout the Puna area. Tubes have been utilized for everything from temporary habitational features to refuge and religious sites (including burials and heiau).

The zones referred to (coastal, upland agricultural, and forest), for the general pattern of traditional Hawaiian land use, as indicated by archaeological investigations are variable in nature. The zones have been variously described in terms of elevation, distance from the shoreline, and vegetation. Holly McEldowney (1979) presented a settlement pattern "based on analysis of archaeological data...and literature from the early historic period" concerning the area from Cape Kumukahi to Hilo in which she describes five zones (I-V in terms of elevation). These included the Coastal Zone I (0-50 ft), II Upland Agriculture (50-1,500 ft), III Lower Forest (1,500 - 2,500 ft), IV Rain Forest (2,500 - 5,500 ft.), V Sub-Alpine (5,500 - 9,500+ ft). Clearly, the elevations of the zones are dependent on the variability in physiography of the specific study area(s). However, the conclusions by McEldowney concerning these zones are that "Substantial pre-historic-type settlements were found to have occurred on the coast, with extensive agricultural fields located in areas of Zone II. The higher elevation areas of Zones III, IV, and V were utilized for exploitation of a large variety of forest resources, such as trees, fiber, birds, etc. and trails" (Komori 1987:8, from McEldowney 1979:15-33).

A similar settlement pattern has been noted in other archaeological reports pertaining to Puna though in some cases the zones are referred to in distance from the shore line (i.e. 0-1 mi, coastal zone, etc.). N. Crozier and D. Barrere characterize the coastal zone (1971) in Pu'ala'a, Puna as follows: "From the standpoint of sheer number of archaeological features in a relatively small areas, this is a very important archaeological zone...it is safe to assume that this coastal section was fairly important before European contact" (Crozier 1971:42). This same report also included a portion in the upland agricultural zone, where mounds and a "small complex" (agricultural) were located. These upland features are within the southwestern boundary of the Kapoho Subzone Section.

Ross Cordy in a "field check" of the ahupua'a of Keauohana (Cordy 1987) observed a similar pattern of a high density of sites near the coast, including a possibly pre-historic cemetery "as impressive a cemetery as I have seen, including the large Kaloko cemetery in North Kona" (Cordy 1987:16). Cordy also observed agricultural features that became more formalized inland, "These sites (agricultural) are less formal terraces and irregular low-walled areas in the seaward depression. But formal walled plots and perhaps kuaiwi walls are present inland" (Ibid.:16). Cordy also mentions that a local informant suggested "that intact remains may well continue inland to the Keauohana Forest Reserve" (Ibid.), which would be at the southwestern boundary of the Kamaili subzone section.

The upland agricultural zone has been briefly discussed in relation to Pu'ala'a and Keauohana. Other reports discussing this zone include Yent and Ota (1982) and Komori and Peterson (1987). Yent and Ota as staff members of DLNR "evaluated the archaeological cultural resources of the Halepua'a sections of the Nanawale Forest Reserve in Puna." This reconnaissance located "a remnant of the native agricultural system"...which "consists of mounds and depressions for the planting of such food plants as sweet potato, breadfruit, banana, and possibly taro" (Yent and Ota 1982:16). This "remnant" of an agricultural complex is within the 100 to 200 ft elevation with the authors further stating: "The remnant at Halepua'a is also important in the context of the Kahuwai Village Complex (Site 4278) located just north of Halepua'a. The Kahuwai Village complex site is coastal and includes canoe landing sites and structures while Halepua'a is just mauka and is an example of an agricultural complex. Thus, the two site areas considered together incorporate both marine and agricultural resources being utilized in the traditional Hawaiian pattern for the Puna vicinity" (Ibid.:18).

There are three recent archaeological reports (Hommon 1982, Holmes 1985, Haun/Rosendahl 1985) concerning the forest zone of Puna. The Hommon and Rosendahl projects included actual reconnaissance surveys in Upper Kahauale'a and the Waokele O Puna Natural Area Reserve respectively. The Holmes report was a "documentary literature search" on the "Puna Forest Reserve/Wao Kele O Puna Natural Area Reserve."

These reports detail the virtual absence of archaeological sites and the low probability of finding sites. Hommon found "only two indications of past human activity", one "evidently an abandoned jeep road," the other "a small (5 by 4 feet or c. 1.5 by 1.2 meters) isolated area of Kahili ginger plant" (Hommon 1982:15).

Though the Holmes report did not include on the ground survey, the documentary research indicated that "while there was apparently episodic, and perhaps occasionally even sustained use or activity in the area, such activity apparently did not result in any significant structures/sites. None, at this point, are known" (Holmes 1985). Rosendahl's project included ground and aerial (helicopter) reconnaissance. "One site, a cluster of possible pre-historic Hawaiian burial structures, at the summit of (Pu'u) Heiheiaholo (Haun 1985:8) was located (Figure III-11). No other sites historic or pre-historic were observed in either the ground or aerial surveys.

Though there was a general lack of known or newly located sites all three reports suggest that there should be sites within the forest reserve. However, concerning the existence and probability of locating archaeological sites Rosendahl states: "The negative results support the indication of the previously completed limited ground reconnaissance that most archaeological remains to be found within the project area will probably be relatively sparse in density, tenuous in nature, and difficult to recognize with certainty" (Rosendahl 1985:13).

Archaeological reports concerning lava tubes within the Puna District include: Emory (1945), Ewart and Luscomb (1974), Bonk (1980), Yent (1983), Olson (1984), and Komori (1987). Generally, the lava tubes are not well-documented in either traditional or early historical accounts. The one major exception, as reported by L. Olson, is State Site No. 10001 (Puna Cave Complex) which he correlated to traditional accounts concerning Pele. Lava tubes and tube systems can be found from the coastal zone to the upland forest zone. However, the only confirmed lava tube cove site within the project area is in Bonk (1980) (Figure III-13). This cave "formed when a section of an old lava tube collapsed" was not explored by Bonk because of the "20 to 25 foot sharp drop" to the cave floor. The cave is in the Kapoho subzone section in an area of heavy growth of Pandanus and other trees...." However, I noted quite a few ti plants growing around the rim area...and I can easily infer that this cave may well have served a cultural function such as that for burial purposes" (Bonk 1980:2).

Archaeological investigations of lava tubes in Puna and elsewhere, have proven to be quite productive. Though lava tubes have not been well documented within the project area it can be assumed that with more systematic survey coverage lava tubes and/or tube features (i.e. sinks, blisters) will be found.

c) Summary

In general this archaeological record for Puna has correlated well with traditional and early historic accounts. Higher concentrations of sites (habitation, etc.) and the more impressive structures and complexes are associated with the coastal zone. Immediately inland and up to the forest margin the "upland agricultural zone is dominated by agricultural features that in some places are a formalized system including, "Formal walled plots and perhaps <u>kuaiwi</u> walls" (Cordy 1987). The forest zone has not been extensively surveyed archaeologically. The work done has found little evidence of pre-historic usage. However, this is somewhat to be expected, according to the early historical accounts of only specialized and sporadic use of the forest zone.

Historical land use is also evident in the archaeological record. The Puna area and particularly portions of the Kamaili and Kapoho subzones have been utilized for sugar cane cultivation. Cane cultivation has been most prevalent in the "upland agricultural zone" and the existence of pre-historic surface sites in these areas is unlikely. The railway bed (Hilo Railroad Co.) associated with cane transportation (pre 1946), is still in existence, in certain locations and portions have been recommended for preservation (Komori 1987:34).

The archaeological and historical records indicate that the Kapoho Geothermal Subzone section (Figure III-13) was, of the three geothermal subzones, the most extensively used. The Kapoho section would include both the coastal and upland agricultural zones which were of the greatest importance to the traditional Hawaiian settlement pattern. The Kamaili Geothermal Subzone (Figure II-12) probably contained pre-historic agricultural sites, especially the northern and southern boundaries, as well as associated habitation, lava tubes and trail sites. The Middle East Rift Zone Geothermal Subzone (Figure III-11) (Wao Kele O Puna Natural Area Reserve) probably contained very few sites other than temporary shelters, trails, and forest planting areas.

3.0 Summary

Although it is clear from historical records and 19th Century Maps that the upland of Puna within the three Geothermal subzones were utilized by ancient Hawaiians and utilized into the historic era, the actual number of recorded and potential site areas are limited. This could be a result of the lack of systematic survey in the areas and a number of sites may be present, but are as yet undiscovered. However, it is certain that large areas of the lava lands are devoid of archaeological remains, particularly in the more inland sections. Most of the areas that would have been within the upland planting zone have been inundated by recent lava or saw long-term use in sugar cultivation.

a) The Three Subzones within the Kilauea Middle East Rift Subzone

Rosendahl recorded some possible cairns at Heiheiahulu (under cane in 1985) and Holmes (1985) recorded a trail (the Kaimu Trail) and some possible bird catching shelters

(Figure III-11). It is probable that portions of the Kaimu Trail have been covered by post-1982 lavas in the south central portion of the subzone. The western portion has been covered by lavas post dating 1961 (Figure III-14).

Within the Kamaili Subzone there are no recorded archaeological sites (Figure III-12) and the southern and north central areas have been covered by the 1955 and 1840 flows respectively (Figure III-15). The northern portion was planted in sugar cane.

The Kapoho section contains the largest number of sites or potential site areas (Figure III-13). Most of these are at or near cinder cones. At the northeast end of the Kuukii Cinder Pit a *heiau* (Kukii Heiau) and spring have been recorded. Kaholuao-kahawai to the west is a possible *holua* slide with mythological connections to the goddess Pele. In the south central portion is a *holua* slide and an agricultural complex recorded by Hudson (1932). These sites lie to the west of the 1955 lava flow. Further to the west a lava tube was recorded by Bonk (1980) and the Rycroft Coffee Plantation appears on Lobenstein's 1895 map. The two caves reported by Loebenstein in the east part of the Kapoho Subzone were almost certainly inundated by the 1960 lava flow (Figure III-16). The entire eastern section of the subzone, except for the higher cinder cones and small *kipukas*, has been inundated by the 1960 lava flow. Because kukii Heiau is on higher ground it has survived this flow. The 1955 lava eruption has inundated large areas in the east central portion and lands between the 1955 and 1960 lavas are cane fields.

b) Archaeological Potential

The following general observations apply to the potential for impact of geothermal development on tangible archaeological resources:

1. The major concentration of known archaeological site areas is in the Kapoho Subzone, of which only one site area appears to be close to the conceptualized facility locatio - *Holua* slide and agricultural sites first recorded by Hudson in 19332 (Figure III-13).

location

2. Within the Kamaili and Kilauea Middle East Rift Zones there are no known archaeological site areas near proposed geothermal facilities.
3. All areas covered by lavas postdating 1800, particularly those areas covered by very recent flows have no archaeological potential (Figures III-14, III-15 and III-16). There are, however,

small kipuka areas within many of these flows which have the potential for containing archaeological sites.

4. There have been major lava tube sites recorded in the Puna District in general (Emory 1945, Olson 1984). Lava tubes were preferred dwelling places and sources for fresh water in ancient Hawai'i. These features are difficult to identify in ground survey and there could be many undiscovered tubes on the older flow surfaces, including cane lands within all three subzones.
5. Review of historical and archaeological records shows that early travellers and archaeologists have visited areas within all three subzones. However, systematic transect survey has been very limited and mostly confined to the southwest portion of the Kapoho Subzone (Bonk 1980, 1984, Rogers-Jourdane, and Nakamura 1984, Cordy 1986). Many sites within older flow surfaces may be as yet undiscovered. As a general archaeological rule the older the flow surface, the more likely sites are to be present. Similarly the older the flow surface, the heavier the vegetation and the greater the difficulty in finding archaeological sites either from the air or the ground.

E. FLORA AND FAUNA

The primary objectives of the flora assessment were to (1) identify, describe, and map the major vegetation types within the GRS; (2) provide a checklist of plants inventoried from the GRS; and (3) identify Federal and/or State officially listed, proposed, and candidate threatened or endangered plant species within the GRS. The primary objectives of the fauna assessment were to (1) prepare a generalized description of the vertebrate and invertebrate communities within the GRS; (2) provide an annotated checklist of the vertebrate species within the GRS; and (3) identify Federal and/or State listed endangered species within the GRS.

1.0 Methods

The information presented in this report is drawn largely from the existing literature. The primary sources for the biological information presented are the Puna Geothermal Area Biotic Assessment report prepared for DPED by Char and Lamoureux (1985a) and Jacobi's (1985) summary of biological information gathered during the U. S. Fish and Wildlife Service's Forest Bird Survey in Puna.

Other literature sources include biological surveys prepared for a number of Environmental Impact Statements and environmental assessments for geothermal projects and various other studies within the Puna area (Clarke *et al*. 1981; Ecotropics 1981a, 1981b, 1981c, 1982; Conant 1982; Lamoureux and Williams 1982; Williams and Lamoureux 1982; Towill 1982a, 1982b; Char and Kjargaard 1984; Char and Lamoureux 1985b).

In addition, various government and private agencies, such as The Nature Conservancy, Hawaii (TNCH), U. S. Fish and Wildlife Service (USFWS), and the State Department of Land and Natural Resources' Division of Forestry and Wildlife (DOFAW), and individuals were consulted and provided additional information.

2.0 Flora Assessment

a) Major Vegetation Types

Six major vegetation types occur on the lands which have been designated as Geothermal Resource Subzones. The distribution of these vegetation types is presented in

Figures III-17, III-18, III-19. Of the six vegetation types the 'ohi'a forest is further divided into four subtypes based on associated plant species, structure, disturbance, and the presence of introduced species. The 'ohi'a forests which have been less disturbed support a number of rare or endangered native plant and animal species.

o <u>Lava</u>

Kilauea Volcano, a broad shield volcano lying against the southeastern slope of Mauna Loa, dominates the Puna landscape. Two rift zones extend southwestward and eastward from the caldera; most flank eruptions have taken place along these two rift zones, particularly along the later (Macdonald and Abbott 1970).

The east rift zone runs the length of the study area and trends southeastward from the caldera for five miles but then bends sharply and extends east-northeastward to Cape Kumukahi and onward along the ocean floor (Macdonald and Abbott 1970). Lava flows, pit craters, and spatter and cinder cones of different ages mark the east rift zone.

Lava flows of different ages can be observed within each of the different subzones. In wet areas such as Puna the development of vegetation is much more rapid than drier areas such as Kona. The whitish-gray lichen, <u>Stereocaulon vulcani</u>, often appears first on some lava flows; however, such plants as 'ohi'a (<u>Metrosideros collina</u>) and ferns such as sword fern (<u>Nephrolepis multiflora</u>) may also appear at the same time. 'Ohi'a is the most common pioneer among the flowering plants and may even appear before the lichens. On pahoehoe flows colonization by plants takes place mainly along joint cracks and fissures; on 'a'a flows plants are found scattered over the flow.

On the 1977 flow near the 1660 ft elevation U.S.G.S. benchmark, plant cover on the 'a'a is very low, 1 to 2%. A few small 'ohi'a plants and sword fern may be found scattered here and there. Lichen cover is also low with <u>Stereocaulon</u> covering 30 to 40% of the rocky surface. Scattered throughout the flow are pockets of vegetation (kipukas) left more or less intact by the lava. These kipukas are of varying sizes. The larger kipukas usually survive

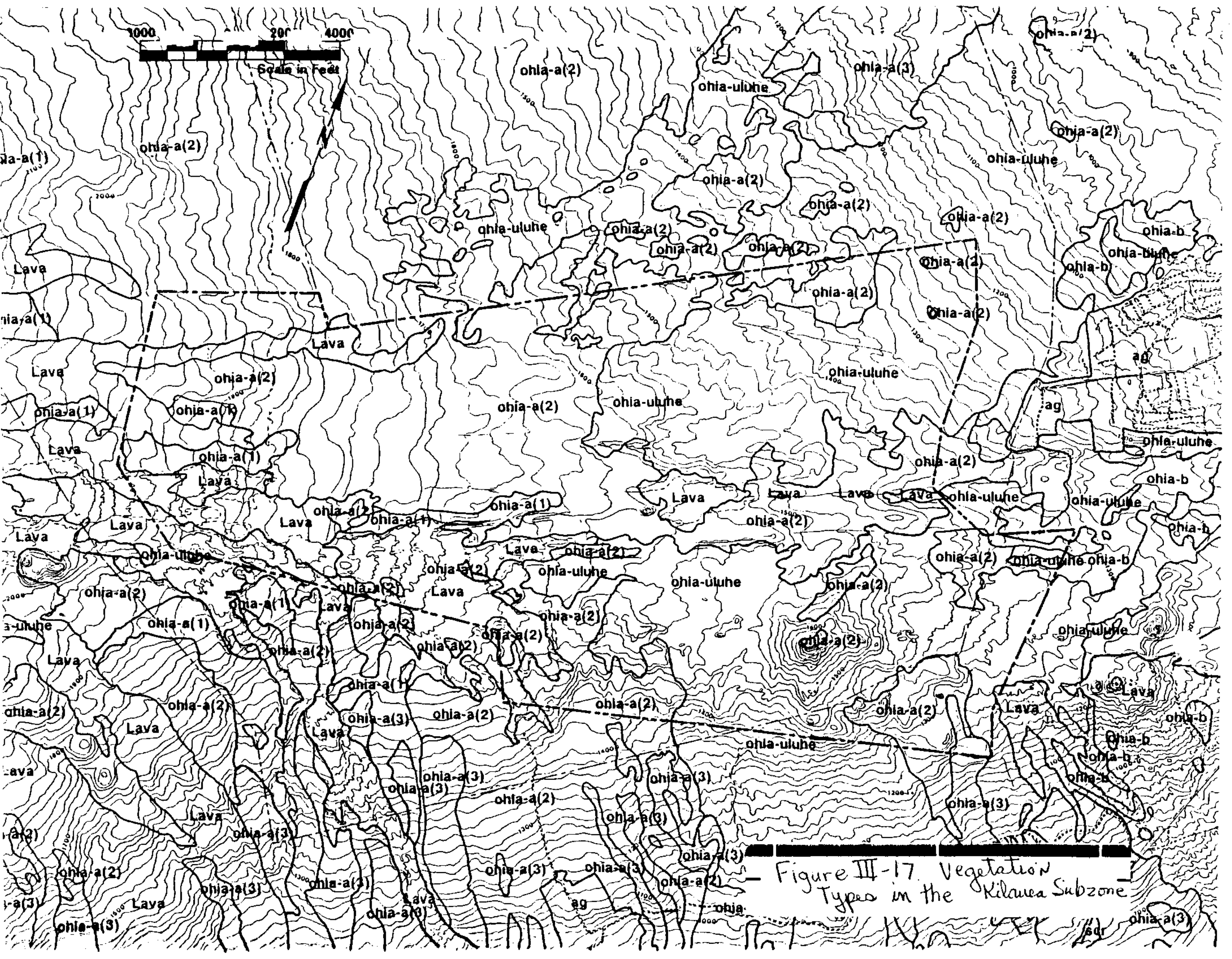


Figure III-17 Vegetation Types in the Kilauea Subzone

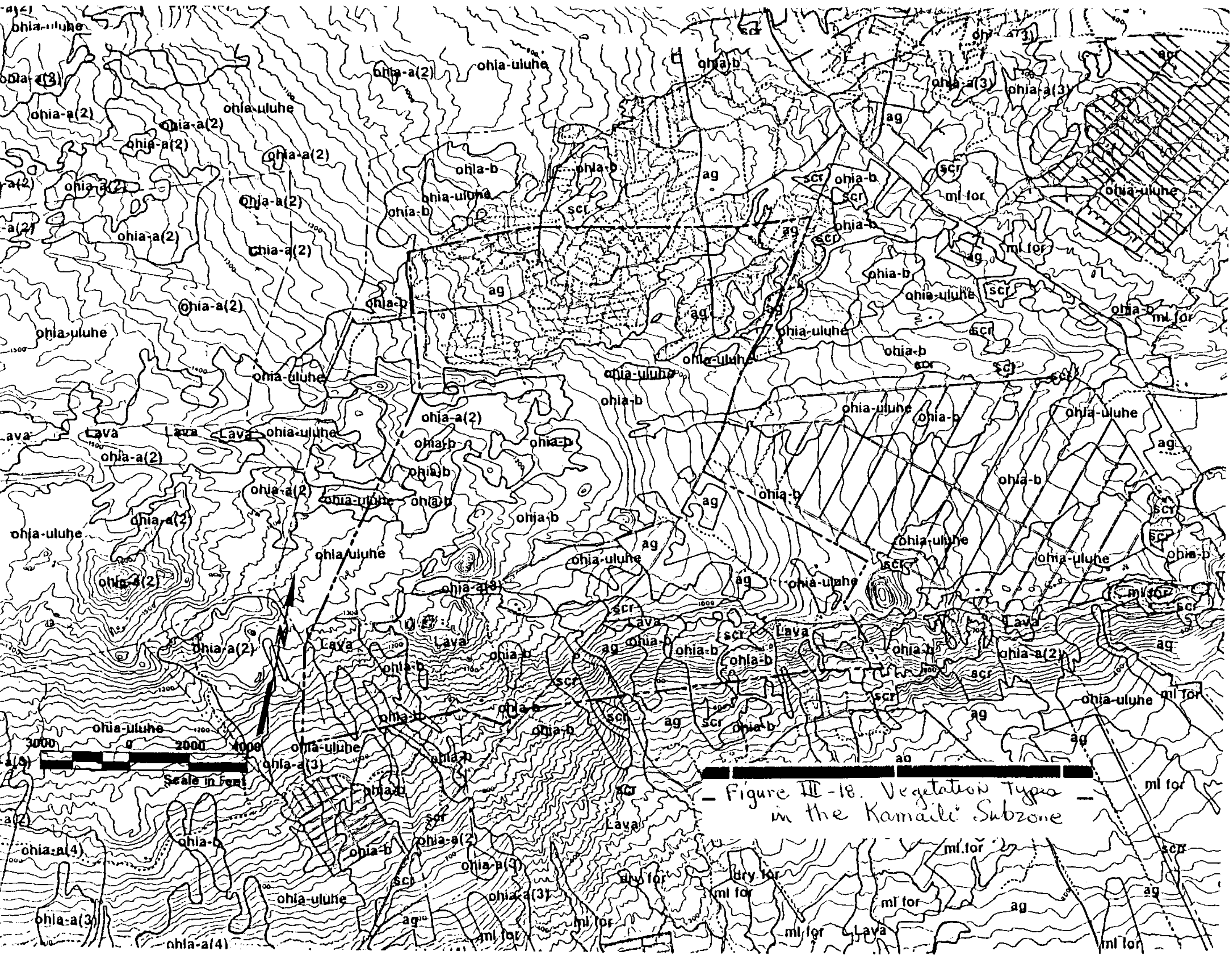
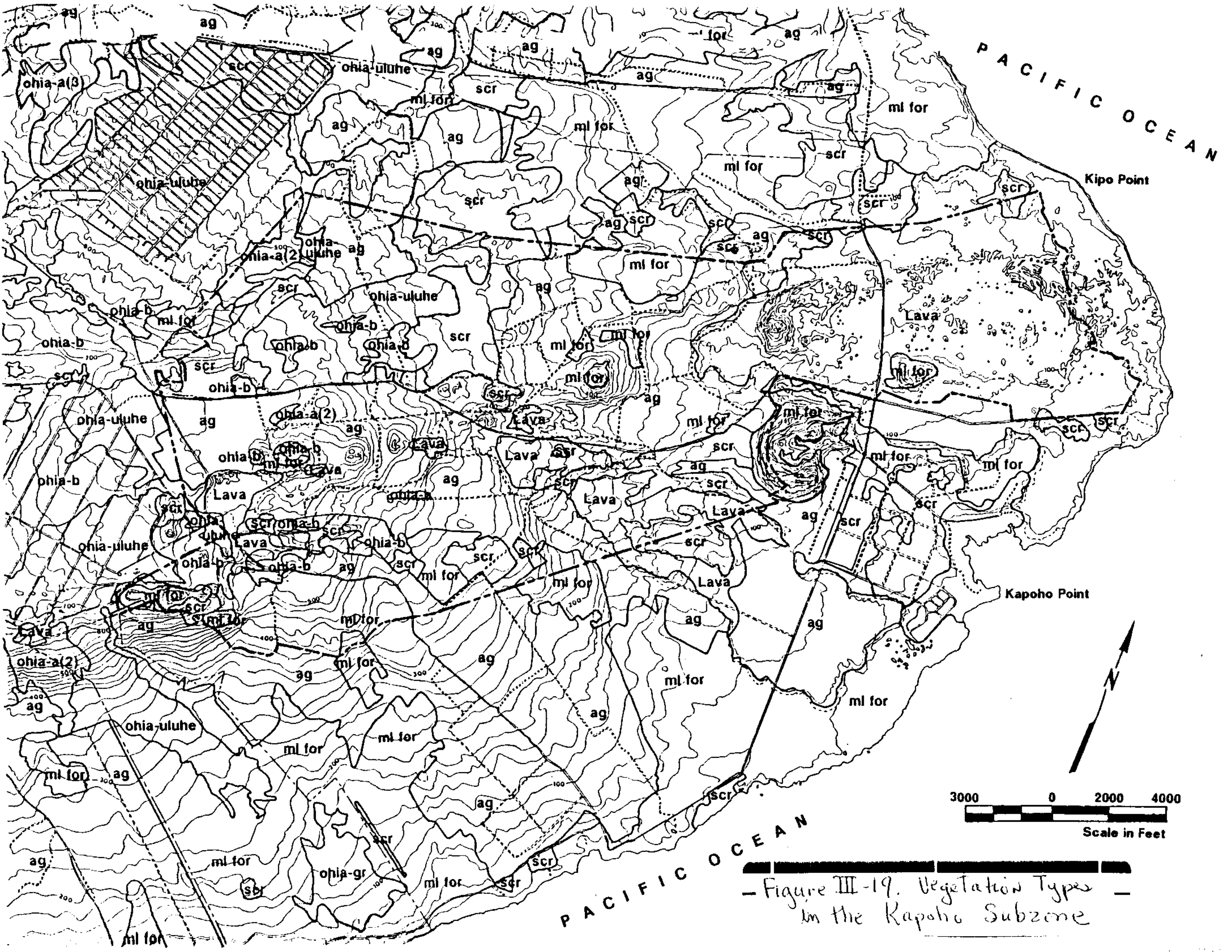


Figure III-18. Vegetation Types in the Kamaili Subzone



- Figure III-19. Vegetation Types in the Kapoho Subzone -

with most of their components intact. The smaller kipukas usually have many of their 'ohi'a trees killed but still standing. Ferns such as uluhe (Dicranopteris spp.) and flowering plants such as mamaki (Pipturus hawaiiensis), Buddleja asiatica, and 'ohi'a often take root at the bases of these trees because these standing dead trees act as interceptors during driving rains, causing water to run down the trunks (Smathers and Mueller-Dombois 1974). Tree molds scattered throughout the flow also provide shady, damp crevices where young plants may grow.

The 1955 flow between Keauohana Forest Reserve and 'I'ilewa Crater consists of 'a'a which is densely covered with Stereocaulon. Higher plant cover is 10 to 20%. Vegetation consists of 2 to 4 m tall 'ohi'a with many smaller individuals 15 to 30 cm tall and the introduced sword fern. Other species occasionally seen on the flow include bamboo orchid (Arundina bambusaefolia), broomsedge (Andropogon virginicus), moa (Psilotum nudum), and Buddleja. As one approaches the edge of the flow where it meets the forest, the percentage of plant cover and the number of species increases. Plants from the surrounding forests such as huehue (Cocculus ferrandianus), mamaki, uluhe, and 'uki (Machaerina spp.) slowly invade the flow from the forests.

- 'Ohi'a-Uluhe woodland

This vegetation type covers large areas of Puna, especially on the relatively young lava flows below 1000 ft elevation near Pahoa.

The 'ohi'a-uluhe woodland is interpreted as one of several stages in the normal succession leading to 'ohi'a forest on relatively wet 'a'a and pahoehoe flows. This vegetation type is often not uniform. Atkinson (1970) observed that even on the same flow there is a wide variation in the proportions of uluhe and 'ohi'a. It may vary from an uluhe "fernland" with few 'ohi'a trees to an 'ohi'a/uluhe "treeland"; gradations from "fernland" to "treeland" are not uncommon. Jacobi (1985) noted that the rate of vegetation development may be significantly influenced by the type of lava flow the plants have to grow on. In wet habitats the fastest rate of development towards an 'ohi'a forest is found on broken lava substrates--'a'a or "shelly" pahoehoe.

In places the 'ohi'a-uluhe woodlands have been burned at some time or another (Atkinson 1970) or logged (Char and Lamoureux 1985b). These disturbed woodlands have large patches of broomsedge (Andropogon virginicus) scattered throughout; clumps or thickets of Malabar melastome (Melastoma malabathricum) and waiawi (Psidium cattleianum) are also common.

The dense fern cover prevents the establishment of many seedlings and as a result only a few scattered plants such as kopiko (Psychotria hawaiiensis), 'uki (Machaerina spp.), Malabar melastome, and bamboo orchid (Arundina bambusaefolia) are found in the thick uluhe mats. The uluhe may be up to 3 m tall in some places. This vegetation type is difficult (and dangerous) to botanize as the thick carpet of matted ferns often obscures the large earth cracks, fissures, and tree molds beneath.

o 'Ohi'a forest

This vegetation type covers extensive portions of the Island of Hawai'i and is the principal vegetation type found within the Geothermal Resource Subzones. The dominant tree in this forest is 'ohi'a or 'ohi'a lehua (Metrosideros collina); all three varieties of Metrosideros occur in these forests. However, on older substrates large trees of Metrosideros collina var. macrophylla are often dominant (Stemmermann 1983).

The 'ohi'a forest, especially the least disturbed portions, is the principal habitat for large numbers and kinds of native birds. Many rare native plant species are also found in this vegetation type.

Four different kinds of 'ohi'a forest are recognized in this study and are described in the following sections. Where different kinds of 'ohi'a forests meet, there is very often no sharp boundary delineation and one kind may grade into the other.

- Wet 'ohi'a forest with native species. This kind of 'ohi'a forest occurs within the Kilauea Middle East Rift Subzone. At these lower elevations (1900 to 1000 ft) these wet forests are fragmented by recent lava flows and 'ohi'a forests which have been disturbed to some extent.

The wet 'ohi'a forest with native species is the least disturbed vegetation type within the study area and is the best example of a more or less intact wet native forest community. Exotic (or introduced) plant species are confined primarily to the trailsides and within the forest (away from trails) and are relatively rare or uncommon except where pigs have rooted or wallowed. Most of these exotic plants are grasses, sedges or herbs and include such species as Hilo grass (Paspalum conjugatum), broomsedge (Andropogon virginicus), Vaseygrass (Paspalum urvillei), Cyperus haspan, water purselane (Ludwigia palustris), Hypericum spp., Drymaria cordata and fireweed (Erechtites valerianaefolia). A few scattered shrubs of strawberry guava (Psidium cattleianum) may sometimes be encountered.

These wet 'ohi'a forests with native species are closed canopy forests (>60% cover) and are composed largely of mature, tall statured (>10 m) 'ohi'a trees. Trees with trunks 1 to 1.5 m in diameter are not uncommon.

Beneath the 'ohi'a trees is a subcanopy layer of native trees, 8 to 10 m tall which includes kawa'u (Ilex anomala), olapa (Cheirodendron trigynum), alani (Pelea clusiaefolia), and kopiko (Psychotria hawaiiensis). Trees of 'ohe (Tetraplasandra hawaiensis) may sometimes be found, usually in the more open areas. Tree ferns (Cibotium spp.) form a third layer (3 to 5 m tall) which may be dense in places. A number of shrubs and smaller trees are found scattered among the tree ferns. These commonly include kanawao (Broussaisia arguta), pilo (Coprosma spp.), several Cyrtandra species, Clermontia parviflora, and 'akia (Wikstroemia sandwicensis). Patches of uluhe (Dicranopteris spp.) are found scattered throughout the forest, especially in areas where the canopy cover is more open. A large number of terrestrial and epiphytic ferns is found in this type of forest. Liverworts and mosses are abundant and form thick cushions on the trunks of trees.

At the lower elevations the composition of the subcanopy layer begins to change. Lama (Diospyros ferrea) and kopiko become the common elements of this layer while the tree fern layer begins to thin out. Only small portions of these lower elevation forests now remain intact. These forests are an important biological resource in understanding the dynamics of our native forests (Stemmermann 1983; Mueller-Dombois 1985).

- Wet 'ohi'a forest with native species and exotic shrubs. This forest type is found primarily in the Kilauea Middle East Rift Subzone. The ohia-a(2) forest is more or less similar in composition and structure to the less disturbed ohia-a(1) forest discussed previously. It may have a closed or open canopy. Exotic shrubs, primarily strawberry guava and Malabar melastome (Melastoma malabathricum) are found throughout the forest but are most abundant in areas which have been disturbed. Patches of uluhe and exotic grasses are also more frequently encountered. The tree fern layer is usually not as well-developed as in the ohia-a(1) forest.

Signs of pig activity are often found; feral cattle damage to 'ie'ie (Freycinetia arborea), 'uki (Machaerina angustifolia), and olapa may also be observed in these forests.

Parts of the ohia-a(1) and ohia-a(2) forests bordering the recent Pu'u O'o flows have suffered damage from heat, fire, and volcanic fumes and debris (tephra and ash). As a result, there is often a strip of vegetation, 5 to 10 m wide, of standing dead 'ohi'a trees bordering the lava flows. These areas are invaded by an assortment of weedy species such as sword fern (Nephrolepis multiflora), pluchea (Pluchea odorata), Hilo grass, Buddleja asiatica, and broomsedge. Clidemia hirta, a noxious weed, can be found in such areas in the Kilauea Middle East Rift Subzone.

Jacobi (1985) notes that this habitat contains a number of plants which have their distributions restricted to, or attain their greatest abundance, below 2,500 ft elevation. Unique features of the lowland forests include the incorporation of such subcanopy and shrub species as 'ahakea (Bobea timonioides), mehamehame (Antidesma platyphylla), and olomea (Perrottetia sandwicensis). Certain of the Cyanea and Cyrtandra species are only found in these lowland forests.

Unfortunately, these lowland habitats have generally been heavily impacted by human activities in Hawai'i. Direct impacts include logging and clearing of forests; indirect impacts include habitat degradation by introduced animals such as pigs and cattle and introduced plants such as strawberry guava, Malabar melastome, and Clidemia.

It has been estimated that less than 10% of the original area of lowland 'ohi'a rain forest remains in the State today, and most of it contains at least a minor complement of introduced species (Jacobi 1985).

- 'Ohi'a-kukui forest with mixed native and exotic shrubs. This forest type is similar to the ohia-a(2) forest but contains a certain admixture of kukui (Aleurites moluccana) trees and other exotic tree and shrub species (Mueller-Dombois 1985). The wet 'ohi'a-kukui forest units are easily recognized on aerial photographs. The rounded, silvery-green colored kukui canopy appears as whitish, mottled areas on black-and-white photographs.

Kukui is a Polynesian introduction, and the Hawaiians most likely cultivated some parts of this forest. The 'ohi'a-kukui forests examined during the various botanical surveys contained plants of 'awa (Piper methysticum), 'awapuhi-kua-hiwi (Zingiber zerumbet), pi'ia (Dioscorea pentaphylla), Hawaiian bamboo (Schizostachyum glaucifolium), and ti (Cordyline terminalis). More recently introduced plants such as jackfruit (Artocarpus heterophyllus), avocado (Persea americana), and Philodendron sp. are also found in these forests. Strawberry guava and Malabar melastome shrubs may form a dense understory in these forests.

- 'Ohi'a forest with exotic subcanopy and shrub layers. Within the three geothermal subzones large areas are covered by 'ohi'a forests dominated by exotic subcanopy and shrub layers. The forests may consist of medium to tall stature trees with open or closed canopies. This type of forest is often hard to distinguish from the ohia-a(2) forests on the aerial photographs, especially if the canopy is closed. The understory layers of this type of forest have, at some time in the past, been more or less greatly disturbed as exotic species dominate.

Tall strawberry guava forms a dense subcanopy layer, 6 to 7 m tall, while smaller guava plants, 1 to 3 m tall, make up the shrub layer. Malabar melastome is usually a common component of the shrub layer. The ground beneath is usually heavily shaded and groundcover often consists of basketgrass, thimbleberry (Rubus rosaefolius), downy woodfern (Christella dentata), 'awapuhi-kua-hiwi, and strawberry guava seedlings of all sizes. Other exotics found in this type of 'ohi'a forest include honohono (Commelina diffusa), Spathoglottis plicata, fireweed, ti, pi'ia, a number of ginger species (Hedychium spp.), Hilo grass, and rose apple.

Native species such as lama, tree ferns, 'ie'ie, and kopiko are occasional to common. The more open areas of these forests are usually filled with tangled mats of uluhe.

o Mixed lowland forest

The mixed lowland forests are found on the lower elevations of the Kapoho subzone and are common throughout the lower Puna area. This vegetation type presents a varied mosaic of plant associations rather than an integrated entity. It is fragmented by villages, subdivisions, cultivated lands and lava flows.

The lowland forest contains many species found in the moist mesophytic 'ohi'a forest in addition to hala (Pandanus spp.), hau (Hibiscus tiliaceus), and other lowland species. Its inland boundaries are difficult to delineate as it overlaps other inland ecosystem types (Fosberg 1972).

The lowland forests have been strongly modified by man. The Polynesians introduced trees such as niu (Cocos nucifera), kukui (Aleurites moluccana), kamani (Calophyllum inophyllum), 'ulu (Artocarpus altilis), milo (Thespesia populnea), and 'ohi'a-'ai (Syzygium malaccense). They also brought with them ohe (Schizostachyum glaucifolium), mai'a (Musa spp.), yams (Dioscorea spp.), taro (Colocasia esculenta var. antiquorum), 'ape (Alocasia macorrhiza), noni (Morinda citrifolia) and 'awa (Piper methysticum). These plants are frequently found associated with old Hawaiian house sites and agricultural terraces in Puna.

Later post-Cook introductions include trees and shrubs of Java plum (Syzygium cumini), mango (Mangifera indica), avocado (Persea americana), rose apple (Syzygium jambos), guava (Psidium guajava), strawberry guava (Psidium cattleianum), Christmas berry (Schinus terebinthifolius) and monkeypod (Samanea saman). Forestry plantings of trees such as albizia (Albizia spp.), ironwood (Casuarina spp.), gunpowder tree (Trema orientalis), Ceara' rubber (Manihot glaziovii), macaranga (Macaranga spp.), Melochia umbellata, and guarumo (Cecropia spp.) were also made. Many of these introduced species have naturalized and spread.

The mixed lowland forests in Puna today are composed most frequently of a mixture of native trees--'ohi'a, lama (Diospyros ferrea ssp. sandwicensis), hala--and the introduced trees mentioned above. The heights of these forests vary greatly from low stature, almost scrub-like, disturbed forests to medium or tall stature older forests. The understory varies considerably depending upon the nature of past disturbances and the amount of canopy cover. The shrub layer may consist of the two guava species, Pluchea odorata, Malabar melastome (Melastoma malabathricum), Christmas berry, and the native shrubs kopiko (Psychotria hawaiiensis), mamaki (Pipturus hawaiiensis), and 'akia (Wikstroemia sandwicensis). Noni and hapu'u i'i (Cibotium chamissoi) are occasionally found. Where the understory has been greatly disturbed guava and/or strawberry guava may form a dense shrub layer.

Ground-cover is sparse when the canopy is dense. Basketgrass (Oplismenus hirtellus), 'awapuhi kua hiwi (Zingiber zerumbet), downy woodfern (Christella dentata), sword fern ((Nephrolepis multiflora), and smaller shrubs of thimbleberry (Rubus rosaefolius) and Stachytarpheta spp. are commonly observed. Seedlings of the tree and shrub species are numerous. Where canopy cover is less dense such as in disturbed areas, along roadsides, and the peripheries of the forest, the ground cover is dense and may consist of Californiagrass (Brachiaria mutica), molassesgrass (Melinis minutiflora), napiergrass (Pennisetum purpureum), honohono (Commelina diffusa), and sensitive plant (Mimosa pudica var. unijuga). The vines maile pilau (Paederia foetida), ka'e'e (Mucuna gigantea), and white thunbergia (Thunbergia fragrans) are also common in these more open areas.

o Scrub

This vegetation type is found in areas which have been frequently disturbed or previously cleared. It is usually dominated by exotic species. Scrub vegetation occurs primarily in the Kapoho subzone where there has been much more disturbance and agricultural activities.

The structure of this vegetation type may vary from open, grassy areas with scattered shrubs and trees to dense, closed scrub. Broomsedge (Andropogon virginicus), molassesgrass (Melinis minutiflora), or Californiagrass (Brachiaria mutica) are usually the dominant grass species in the open scrub. Napiergrass(Pennisetum purpureum), bush beardgrass (Andropogon glomeratus), and Hilo grass (Paspalum conjugatum) may be locally common in some areas. The most abundant shrub species are Malabar melastome (Melastoma malabathricum) and the two guava species (Psidium guajava, Psidium cattleianum). Other shrubs commonly observed are lantana (Lantana camara), pluchea (Pluchea odorata), butterfly bush (Buddleja asiatica), and Desmodium cajanifolium. Scattered patches of uluhe (Dicranopteris spp.) may also be found in the scrub vegetation.

Very scattered low (<5 m) to medium (5 to 10 m) statured 'ohi'a trees may occasionally be found in some open scrub. Exotic trees frequently observed in the open scrub include Trema orientalis, albizia (Albizia spp.), Cecropia spp. and Melochia umbellata.

Solid stands of dense, almost impenetrable scrub composed most often of guava (Psidium guajava) and/or strawberry guava (Psidium cattleianum) are found wherever the land has been disturbed. Psidium reproduces and spreads rapidly from root sprouts. In some places this scrub can become as tall as 10 m or more and develop into a forest. Malabar melastome may also form dense scrub; however, this type of scrub does not get as tall as the Psidium scrub.

The density and diversity of the ground cover varies with the amount of light able to penetrate the scrub. The herb layer is poorly developed where the scrub is dense. Much of the ground isbare or covered with litter from the shrubs above. Shade tolerant plants such as basketgrass (Oplismenus hirtellus) and downy woodfern (Christella dentata) are found here. Where the scrub is less dense Glenwoodgrass (Sacciolepis indica), sword fern (Nephrolepis multiflora), thimbleberry (Rubus rosaefolius), Stachytarpheta spp., honohono (Commelina diffusa), as well as basketgrass and downy woodfern, are present.

Few native species are found in this vegetation type, and then these species tend to be found in the more open scrub. Besides 'ohi'a and uluhe, other natives sometimes found in the scrub include 'akia (Wikstroemia sandwicensis), lama (Diospyros ferrea ssp. sandwicensis), and sedges such as Fimbristylis dichotoma, 'uki (Machaerina angustifolia), kuolohia (Rhynchospora lavarum), Pycreus polystachyos, and Scleria testacea.

o Agricultural lands

Much of Puna, especially the lower Puna area, has been cultivated since pre-historic and historic times. All cultivated lands including sugar cane and papaya fields, orchards, anthurium and orchid farms, fallow fields, etc., as well as abandoned fields, pastures, and the network of roads associated with farming activities were designated "Agricultural lands" in the Char and Lamoureux study (1985a). Agricultural lands are found on the Kamaili and Kapoho subzones.

These agricultural lands present a mosaic of different patterns on the aerial photographs and are in a constant state of change from year to year. Different crops, stages of cultivation, fallow fields, crop rotation, and expansion of existing fields all contribute to the general dynamics of agricultural lands.

Sugar cane (Saccharum officinarum) and papaya (Carica papaya) have been the primary crops grown in the Puna region. However, with the closing of the sugar mill, many of these fields have been abandoned or turned over to papaya cultivation. These abandoned fields are in various stages of weedy succession.

Papaya fields in various stages of cultivation from newly transplanted seedlings to mature, bearing plants, 2 to 4 m tall, cover fairly large acreages, mostly in the Kapoho subzone. Abandoned papaya fields are also frequently found. Like the sugar fields, these abandoned papaya fields are in various stages of weedy succession. Melochia umbellata will often quickly invade these fields.

Long abandoned fields with their networks of roads and other evidences of human activities can still be delineated on the aerial photographs if they have not been obscured by the vegetation. Ground check of these areas reveals remnants of the former crops or the weedy tree and shrub species associated with abandoned fields.

Other crops grown in the Kamaili and Kapoho subzones include bananas (Musa hybrids), passion fruit (Passiflora edulis), guavas (Psidium guajava cultivars), and various cut flowers and foliage.

A number of weedy species are commonly associated with all these cultivated areas. These include several Euphorbia spp., false pimpernel (Lindernia crustacea), Ageratum conyzoides, Polygala paniculata, comb hyptis, and kyllinga. Many fields are periodically treated with herbicides to control these weeds.

Pasture lands are also included in this ecosystem type. They vary in structure and are very diverse in species compositions. For example, some pastures may be open savannahs with tall 'ohi'a trees on lands cleared of native forests or they may be scrubby if overgrazed. Most of the pasture grasses and herbs were deliberately introduced and specifically planted or sown to improve the pasture (Fosberg 1972). Pasture grasses commonly seen in the study site include pangolagrass (Digitaria decumbens), narrow-leaved carpetgrass (Axonopus affinis), and Hilo grass (Paspalum conjugatum).

b) Plant Species List

The plant species list is drawn primarily from Char and Lamoureux (1985a) and from later surveys of lands in the Middle East Rift Zone (Char and Lamoureux 1985b; Lamoureux 1988) and is included in Appendix D.

3.0 Fauna Assessment

a) Vertebrate Resources

Information on the fauna resources is drawn from a number of different studies and reports. Avifauna occurrences are primarily from Berger's (1985) discussion of the avian resources presented in Char and Lamoureaux (1985a), Jacobi's (1985) summary of bird species found during the USFWS Forest Bird Survey, Conant's (1982b) baseline survey of the birds in the Keahialaka-Pohoiki-Kapoho-Kula areas, Char and Kjargaard's (1984) survey report for Puna Geothermal Venture, and the EIS prepared for the Kahauale'a Geothermal Project (Towill 1982a).

Information on mammal distribution within the GRS was also extracted from the last three references mentioned above.

o Avifauna

Twenty-one bird species have been recorded from the Geothermal Resource Subzones. Of the six endemic species, the Hawaiian Hawk or 'I'o (Buteo solitarius) is the only listed endangered species. The endangered 'O'u (Psittorostra psittacea), considered to be the rarest of the surviving honeycreepers on the island of Hawai'i by the USFWS Forest Bird Survey team, has been observed on the adjacent Kahauale'a lands and the upper elevation portions (plus or minus 2,260 ft.) of the Puna Forest Reserve.

In general, the endemic species are associated with the less disturbed vegetation types found primarily on the Kilauea Middle East Rift Zone, although Conant (1982b) has observed a few 'Elepaio (Chasiempis sandwichensis), 'Amakihi (Hemingnathus virens), 'Apapane (Himatione sanguinea), and one 'I'iwi (Vestiaria coccinea) in forested areas of Kamaili and nearby Pahoa. The endangered Hawaiian Hawk occurs widely throughout the Puna District and over the GRS.

Table 3.8 summarizes the species present and their distribution within the GRS. An annotated species list is presented in Appendix D.

b) Invertebrate Resources

Unfortunately, inventories of the invertebrate resources have not been included in the biological studies conducted for the various EISs and EAs for geothermal projects. Literature on these resources is scattered in various taxonomic treatments (Sharp 1899-1913; Cooke 1921; Caum 1928; Zimmerman 1948 et seq.; Cookeand Kondo 1960; etc.).

Limited field surveys have been conducted in the areas adjacent to the Kilauea Middle East Rift GRS. The areas surveyed support similar forest types and habitats as those found in the Kilauea Middle East Rift GRS. A fairly rich complement of native invertebrates, including relatively diverse arthropod communities, can be expected in the less disturbed vegetation types within the GRS.

TABLE 3.8. LIST OF BIRDS RECORDED FROM THE GEOTHERMAL RESOURCE SUBZONES, PUNA DISTRICT, HAWAI'I

SPECIES	STATUS+	1*	2	3
Buteo solitarius Hawaiian Hawk, 'I'o	N,E	+	+	+
Phaeornis obscurus Hawaiian Thrush, 'Oma'o	N	+	-	-
Chasiempis sandwichensis 'Elepaio	N	+	+	-
Hemingnathus virens 'Amakihi	N	+	+	-
Vestiaria coccinea 'I'iwi	N	+	+	-
Himatione sanguinea 'Apapane	N	+	+	-
Pluvialis dominica Lesser Golden Plover, Kolea	M	-	+	+
Callipepla californica California Quail	F	-	+	-
Phasianus colchicus Ring-necked Pheasant	F	-	+	+
Lophura leucomelana Kalij Pheasant	F	-	+	-
Tyto alba Barn owl	F	-	+	+
Streptopelia chinensis Spotted Dove	F	+	+	+
Geopelia striata Barred Dove	F	-	+	+
Colomba livia Rock Dove	F	-	+	+
Garrulax caronus Melodious Laughing-thrush	F	+	+	+
Zosterops japonicus Japanese White-eye	F	+	+	+
Acridotheres tristis Common Myna	F	-	+	+
Lonchura punctulata Spotted Munia	F	+	+	+
Passer domesticus House Sparrow	F	-	+	+
Cardinalis cardinalis Northern Cardinal	F	+	+	+
Carpodacus mexicanus House Finch	F	+	+	+

+STATUS: N = native, endemic to the Hawaiian Island
M = regular migrant visitor
F = foreign introduced species
E = endangered
*Recorded (+) or absent (-) from
1 = Kilauea Middle East Rift GRS
2 = Kilauea Lower East Rift GRS: Kamaili Section
3 = Kilauea Lower East Rift GRS: Kapoho Section

Even in areas subject to frequent volcanic gassing there may be a generally rich component of native invertebrates (S. Gon III, pers. comm.). Indicator taxa which may be expected in intact native vegetation are presented in Table 3.9.

Non-native invertebrates include ants, Vespula (yellow-jacket wasps), slugs, Oxychilus (garlic snails), as well as a good complement of other non-native insects, spiders, centipedes, crustacea and snails.

Lava tubes may support cave invertebrates (some of which are candidates for endangered status). The Hawaiian aeolian ecosystems on recent lava flows are poorly understood and have only recently been studied in detail, but these are invertebrate dominated and include several endemic species of Lycosid spiders, flightless crickets, springtails and centipedes that are not represented in surrounding vegetated systems (S. Gon III, pers. comm.).

On the Kapoho and Kamaili Sections of the Kilauea Lower East Rift GRS, the majority of the vegetation has been disturbed to some degree and introduced species often form the dominant vegetation types. In such areas, native invertebrate diversity is likely to be lower.

Where there are remnant pockets of native vegetation as in pit craters, in cracks and on pu'us, there may be remnant native invertebrates. Surprisingly, even in some 'ohi'a forests where the understory has been severely disturbed, Gon (pers. comm.) has found an assortment of native arthropods in the forest canopy above.

The barren lava flows in the Kapoho Section may still support a native aeolian system in places, but non-native invertebrates, especially ants, may have displaced them.

TABLE 3.9

INVERTEBRATES WHICH MAY BE EXPECTED IN NATIVE VEGETATION

Native Spiders:	Vernacular
Theridion grallator	Hawaiian Happy-face spider
Theridiid spp.	cobweb spiders
Salticid spp.	jumping spiders
Tetragnathid spp.	4-fanged orb spiders
Thomisid spp.	crab spiders

Native Insects:	Vernacular
Lispocephala spp.	predatory muscid flies
Dolichopodid spp.	NA
Drosophilid spp.	Hawaiian pomace flies
Tipulidae spp.	Hawaiian crane flies
Microlepidopteran spp.	small-bodied moths
Macrolepidopteran spp.	large-bodied moths
Eupithecia spp.	Hawaiian predatory caterpillars
Collembolan spp.	springtails
(many other species in several orders and families)	

Native Crustacea:	Vernacular
Amphipod spp.	NA

Native Snails:	Vernacular
Succinid spp.	Hawaiian amber snails
Tornatellinid spp.	Minute land snails

PART IV: ECONOMICS AND SOCIO-ECONOMIC SETTING

A. ASSUMPTIONS

In the following analysis, delivered capacity is assumed to be 500 MW based upon 10 50-MW (net) power plants. In order to account for line losses and maintenance downtime, generating capacity would be about 55 MW per plant or more. This differs from the conceptual development illustrated in Figures II-2, II-3 and II-4 and evaluated in air quality and other environmental areas. Please refer to Part II, Basic Assumptions for a discussion of this difference.

The following development schedule, cost and employment estimates are based on the "Undersea Cable to Transmit Geothermal-Generated Electrical Energy from the Island of Hawaii to Oahu: Economic Feasibility," (DAHI, 1988). However, appropriate adjustments were made to the quantities given in the DAHI report to reflect the fact that larger but fewer power plants are assumed. Additional information on employment estimates was obtained from Pacific Gas and Electric Company, based on their geothermal operations at the Geysers north of San Francisco.

The schedule for completion of operational geothermal plants, which is consistent with that given in the DAHI report, is:

Month	Year	Unit	Cumulative Capacity (MW delivered)
Jan	1995	1	50
Mar	1996	2	100
May	1997	3	150
Aug	1998	4	200
Oct	1999	5	250
Jan	2001	6	300
Mar	2002	7	350
May	2003	8	400
Aug	2004	9	450
Oct	2005	10	500

Development would begin about three years before the first plant becomes operational. Consequently, construction would span a 14-year period.

B. ECONOMIC CHARACTERISTICS

1.0 Construction Activity

a) Development Costs (1986 dollars)

It is estimated that 15 production wells would be required for each 50-MW power plant. At 4 MW per well, this would provide sufficient capacity for 55 MW of power, with one well being a backup in case of an outage. In addition, three injection wells would be required for each power plant. In order to provide these 18 usable wells, it is further estimated that an average of four unusable wells would be drilled-wells which must be abandoned because they are unusable for production or disposal of the condensed steam. The entire well field for 10 power plants would total about 226 wells: 150 production wells, 30 injection wells, and 40 unusable wells. The total development cost for these wells, assuming $2.5 million for each production well and $2 million for each injection and unusable wells, would be $515 million.

For the steam-gathering system the estimated cost is $10.8 million per power plant, or $108.8 million for ten plants.

The cost of a 50-MW power plant is estimated to be $52.6 million (based on DAHI's estimate for a 25-MW plant and scaled up appropriately) (DAHI, 1988); for ten plants, the cost would be $526 million.

For the complete 500-MW geothermal power generating system - including the well fields, steam gathering system, and power plants-the estimated development cost is $1,149 million. Over the 14-year construction period, the construction expenditures would average about $82.1 million per year.

b) Construction Employment

In order to drill the required number of wells, seven 12-man drilling crews, with each crew drilling about three wells per year, are expected. Total employment for drilling would be about 85 jobs. Construction employment required to build ten power plants and associated piping for the system-gathering system is estimated to average 155 jobs. Thus, total construction employment for wells, the steam-gathering system, and power plants is expected to average about 240 jobs over the 14-year construction period.

c) Construction Wages

Construction wages would total about $8 million per year over the construction period (an average of 240 jobs at $33,426 per job (DBED DATA BOOK, 1987, p. 367).

2.0 Operations

a) Energy Sales

Accounting for line losses, 500 MW of "baseload" geothermal power would result in the sale of about 4.38 million kilowatt hours (kWh) of energy to Oahu, and reduce oil imports to Hawaii by over 6.6 million barrels annually. Assuming an average fuel-oil cost of about $35 per barrel as the basis for determining the value of geothermal energy, geothermal energy sales would amount to over $230 million annually. Fuel oil at $35 per barrel corresponds to a crude-oil price of about $30.43 per barrel; this is regarded as a conservative estimate of the price of crude oil during the late 1990s and into the twenty-first century.

b) Operations and Maintenance (O&M) Costs

It is expected that many production wells would have to be replaced over time because of a loss of steam pressure. The useful life of a well is expected to be random, with many of the early wells having a relatively short life. However, during the first 5 years of operation, replacement wells are not anticipated because of the reserve capacity that would be available. However, starting in the 2000, it is anticipated that approximately six replacement wells would be required annually. This translates into an annual cost of $15 million, based on $2.5 million per well.

As indicated above, each power plant is expected to have fifteen producing wells and three injection wells per plant. For 10 power plants, there would be 180 usable wells. At an estimated cost of $58,000 per well, the total annual O&M costs at full development would be $10.4 million.

Annual O&M costs for the 10 power plants are expected to total $3.3 million for operational labor and $24.1 million for chemicals, waste disposal, and contracted maintenance.

Therefore, at full development, the total cost for well replacement, well-field O&M, and power-plant operational labor and O&M is estimated to be about $52.8 million per year.

c) Employment

After construction is completed, employment is projected to total 200 jobs:

		Jobs
Well Replacement (2 crews of 12)		24
Power Plant and Well Field:		
Supervisors	2	
Engineers	2	
Operators	50	
Electricians	5	
Instrument Technicians	5	
Secretary	2	
Other (support staff)	5	
Subtotal		71
Contracted Maintenance:		
General Crew	30	
Overhaul Crew	75	
Subtotal		105
TOTAL JOBS		200

Contracted maintenance would include crews which move from plant to plant to perform general maintenance and to overhaul the power plants. The general maintenance crew would include unskilled laborers for cleanup, painting and repair; the overhaul crew would include electrical, mechanical, and instrument engineers and technicians.

These employment figures assume highly automated plant operations; with less automation, operational employment could be double the figures used in this report.

d) Wages

O&M wages are estimated to total $7.1 million per year at full development, excluding benefits. This is based on average annual wages of $33,426 for construction workers (see above), $38,000 for power-plant and well-field personnel, $20,000 for the general maintenance crew, and $40,000 for the overhaul crew.

3.0 Total Economic Impact

Direct and total annual sales, employment, and annual wages which would be generated by the construction and operation of geothermal power are estimated as follows:

	Direct	Multiplier	Total
Construction:			
Average Annual Sales	$82.1 million	2.77	$227. million
Average Employment	240 jobs	2.48	595 jobs
Average Annual Wages	$8. million	2.23	$17.8 million
Operations:			
Annual Sales	$230. million	2.07	$475. million
Employment:			
Well Drilling	24 jobs	2.48	60 jobs
Plant Operations	176 jobs	3.38	595 jobs
Total	200 jobs		655 jobs
Annual Wages	$7.1 million	2.24	$15.9 million

The direct economic impacts summarize the previous discussion. The total impacts include direct economic impacts, indirect impacts generated by business expenditures, and induced impacts generated by employee expenditures. These total impacts are based on multipliers provided by DBED's State Economic Model.

As indicated, construction activity is expected to generate $227 million in total annual sales, support 595 total jobs, and generate $17.8 million in total annual wages. Operations would generate an estimated $475 million in total annual sales, support 655 jobs, and generate $15.9 million in total annual wages.

4.0 Population and Housing Supported

Based on the employment which would be provided, the construction of geothermal facilities and their operation would support the following number of people and homes:

	Direct	Total
Construction:		
Average Employment (jobs)	240	595
People Supported	575	1,430
Homes Supported	215	530
Operations:		
Average Employment (jobs)	200	655
People Supported	480	1,570
Homes Supported	180	580

These estimates are based on 2.4 people per job and 2.7 people per home, respectively; the multipliers reflect Big Island conditions (derived from DBED Data Book, 1986).

As indicated, during construction, geothermal power is expected to directly support 575 people and 215 homes, and directly and indirectly support a total of 1,430 people and 530 homes. Upon full operations, 480 people and 180 homes would be directly supported, and 1,570 people and 580 homes directly and indirectly supported.

C. SOCIO-ECONOMIC SETTING

1.0 Definition of Study Area

The Puna District is located on the island of Hawaii's east coast; it is adjacent to the South Hilo District which contains the government, business and commercial center of Hilo. The district has a land area of approximately 500 square miles. Often characterized as rural/agricultural, the Puna area is, in fact, comprised primarily of vast expanses of open space. Large open recreation areas such as Hawaii Volcanoes National Park, unvegetated recent lava flows and a widely dispersed population contribute to the impression that much of the district is barren and undeveloped.

The Puna district is comprised of U.S. census tracts 211 (here referred to as "lower Puna") and 210 ("upper Puna"). In this report, lower Puna will be viewed as the primary study area. Attention will also be given to the rest of Puna, to the city of Hilo when appropriate, and to Hawaii County generally.

Upper Puna extends along Route 11 (or Mamalahoa Highway, the principal belt road circling the island), from the outskirts of Hilo, in a generally southwesterly direction through Keaau, Mountain View, and Glenwood, to Volcano.

Lower Puna is linked at the north to upper Puna and to the rest of Hawaii County by Route 130, which runs southeast and south from Keaau to the lower Puna communities of Pahoa and Kalapana. Other roads link smaller residential communities (primarily subdivisions) to Pahoa and to the sparse cluster of homes in the coastal community of Kalapana. At the south end of the district, the Chain of Craters Road through the Hawaii Volcanoes National Park has connected Kalapana to the Volcano area in the past, and presumably will again when cleared of recent lava flows. However, the frequency with which the road is blocked by lava and the distances from major shopping areas do not make the Chain of Craters Road a major thoroughfare for Puna residents. Thus, for most practical purposes, lower Puna represents something of a cul-de-sac in the island's transportation system.

The proposed development would be located in lower Puna along the Kilauea East Rift Zone, in the Kapoho/Pohoiki area and parts of the Puna Forest Reserve. The communities closest to the project sites include several subdivisions and the town of Pahoa.

2.0 Hawaii County Overview

2.1 Economic Activities

On the island of Hawaii (coterminous with Hawaii County), agriculture overshadowed all other economic ventures for much of this century. However, tourism has now become the largest single source of income for the county. Visitor expenditures amounted to $344 million in 1986. In that year, sugar production was valued at $74 million, and the total above-board agricultural production of the county was valued at $166 million (State of Hawaii, Department of Business and Economic Development, 1987b). The Hawaii Island visitor industry grew rapidly during the 1970's, but its growth slowed in the early 1980's. Occupancy rates have increased of late, although they remain lower than on the other major islands. The 1986 annual average occupancy was 62.8 percent, compared to the statewide average of 81.7 percent (State of Hawaii, Department of Business and Economic Development, 1987a, p. 40).

While the number of hotel rooms on the island has been fairly stable, there is now the possibility of major tourism expansion on the island's west coast. The Hyatt Regency Waikoloa Hotel -- slated to become the Neighbor Islands' single largest hotel, with some 1,750 rooms -- is now under construction in South Kohala and is scheduled to open in late 1988. Several thousand other hotel and resort condominium units have been either approved or recently proposed for development in West Hawaii, and two major resort complexes (one of them already holding partial government approvals) have been proposed for the island's southernmost district, Ka'u.

The Big Island's agricultural situation is more mixed. With the closing of Puna Sugar Company in 1984, Hawaii County's sugar production dropped by 18 percent. Diversified agricultural activities have been extensively explored. The 1986 production value for diversified agriculture in Hawaii County, $91.8 million, amounted to an increase of 35 percent over the 1984 value. Among the crops contributing to that value are macadamia nuts, coffee, papayas, and flowers. Livestock produced $22 million in income in 1986 (State of Hawaii, Department of Business and Economic Development, 1987b). A food irradiation facility has been proposed to reduce past obstacles to successful exportation of papaya and other food products.

High technology investments also figure in the Big Island economy. These include astronomical observatories on the peaks of Mauna Kea and Mauna Loa, as well as ocean energy research and related aquaculture activities in Kona. The new Hawaii Ocean Science Technology (HOST) Park is intended to support aquaculture and related ventures. Geothermal energy is now being tapped on a small scale in Puna, and various forms of space-related development -- including a possible satellite launch facility in Ka'u -- are under exploration by the State and County governments.

2.2 Demographic Background

The island of Hawaii is the largest of the Hawaiian chain, with an area exceeding 4,000 square miles, but it is the least densely populated county in the state, with fewer than 30 people per square mile. The majority of the population lives on the eastern side of the island, although the West Hawaii population has been growing at a generally faster overall rate.

According to the U.S. Census Bureau, the island's population increased by an average 3.8 percent per year from 1970 (when the population stood at 63,468) to 1980 (official population of 92,053). In mid-1986, the population reached an estimated 111,755 (personal communication, Robert Stanfield, Research Statistician, Hawaii State Data Center, October 13, 1987), suggesting an annualized average 3.15 percent growth for the first part of the 1980's.

Tables not included

In addition to simple population growth, the island underwent various demographic changes from 1970 to 1980, as shown in Tables 4.1 to 4.4. Some of the more significant of these include:

- The ethnic composition changed. The proportion of residents of Japanese ancestry declined from 38 to 27 percent of the population (Table 4.1). Hawaiians and part-Hawaiians increased from 12 to 19 percent. Caucasians, who had amounted to 29 percent, came to be 35 percent of the population.

- Education levels increased (Table 4.1). The percentage of adults with post-high-school education doubled.

- The civilian labor force increased by 58 percent, with the addition of 15,000 workers (Table 4.2). The industrial profile of workers shifted somewhat away from agriculture and manufacturing, toward retail and professional activities.

- There was a sharp jump in the percentage of families (particularly families with children) headed by females, and the percentage of families below the federally-defined "poverty level" increased slightly from 1970 to 1980 (Table 4.3).

- The resident housing stock increased by 79 percent (Table 4.4). Occupied units increased by 69 percent, while the average household size dropped 14 percent. The proportion of occupied homes that were owner- occupied increased, while the proportion of substandard units declined markedly. However, rentals increased as a proportion of median family income.

3.0 The Puna Study Area

3.1 Economic Activities

Puna's economy is distinctive for the Big Island in that it lacks major tourism investment and no longer produces sugar. Tourists usually travel through upper Puna, along Route 11, between Hilo and Volcanoes National Park (site of the 37-unit Volcano House hotel). In lower Puna, Kalapana Black Sand Beach attracts some sight-seers, but past proposals to construct resorts there have been defeated.

Amfac's Puna Sugar Company ended its sugar operations in 1984. With the closing of the plantation, about 15,000 acres were taken out of sugar production. About 485 jobs were lost by the end of the shutdown. While many of the Puna Sugar workers lived in Keaau and Hilo, about one-fifth lived in Lower Puna (State of Hawaii, Department of Labor and Industrial Relations, 1982).

Another background factor of import to Puna's economy and society was the development of extensive subdivisions in the 1950's and early 1960's. Many of these "agricultural" subdivisions were actually constructed on recent lava flows. Most lack County-standard roads, water, and sewer lines; some portions are not served by electricity or telephone lines. Local government originally encouraged the subdivisions as a welcome addition to the County's tax base. However, in recent years, the cheap land has resulted in rapid but widely-scattered single- family home development, with consequent increased taxpayer demand for government services.

Puna today is a mixture of bedroom communities for people who work in Hilo, small-scale specialized agriculture, subsistence activities, and illegal marijuana cultivation.

With the end of sugar operations in Puna and the consequent release of acreage for other purposes, diversified agriculture has taken on increased importance. No single crop grows well in the varied areas once planted in sugar; an Amfac representative estimates that at least ten years will be needed to find effective uses for the vacated land (personal communication, J. Melrose, Land Planner, Amfac Properties Land Administration, November 3, 1987).

Papayas, macadamia nuts, bananas, flowers, and foliage are among the agricultural products of Puna. Much of the district's papaya and macadamia nut acreage is in lower Puna. Papayas are mainly grown by small producers. Puna currently has the large majority of Hawaii County's 241 farms with 2178 acres in papayas in 1986 (Hawaii Agricultural Statistics Service, 1987, p. 34).

The cultivation of flowers and nursery products, particularly anthuriums and potted foliage, is largely done by small entrepreneurs. These independent growers often depend on family members' labor rather than hired employees.

Plans to test the commercial feasibility of cocoa production in Puna have been announced by Amfac and others involved in a joint venture. Amfac has dedicated a 56-acre parcel in Puna for cocoa, and is considering the use of its Puna lands for cocoa farming by independent small farmers, should tests yield positive results.

Puna is considered a major marijuana growing area. One indication of the crop's importance statewide comes from a 1984 estimate that its production and distribution contributed $360 million in unreported personal income (Kephart, 1984). Police reports of plants confiscated and destroyed suggest that the majority of plants in the state are located in Hawaii County (State of Hawaii, Department of Planning and Economic Development, 1984, 1986). Major efforts to curb marijuana production in 1986 and 1987 have led to increased arrest levels in Puna. Indirect evidence suggests that some marijuana growers have become discouraged as a result of police efforts, and a smaller crop is being marketed (personal communication, Captain Newton Lyman, Hawaii County Police Department, November 3, 1987).

Commercial and retail activities are found in Keaau, Kurtistown, Mountain View, Glenwood, Volcano, Pahoa, and Kalapana. A regional shopping center has opened in Keaau. The majority of commercial operations in the district are still family-operated enterprises serving the nearby communities. However, Puna residents mostly shop in Hilo and a regional shopping center on Route 11 south of Hilo. In a 1983 survey, Puna residents' most common answer to a question about the distance they traveled to do their food shopping was 11 to 20 miles. That distance was less than the distance mentioned by most Ka'u and Hamakua residents, but greater than the distance for Hilo, Kona and Kohala residents (Hawaii Opinion, 1983, p. 47).

Industrial activities in Puna have included the processing of agricultural products and the production of energy from bagasse. Until recently, the Puna Sugar mill supplied Hawaii Electric Light Company (HELCO) with power generated by burning wood chips and bagasse. Amfac stopped tree harvesting for this purpose in March 1988, and has agreed to sell its Puna Biomass power plant to HELCO for a nominal sum. Amfac has withdrawn from power-generating activities in Hawaii County, selling its biomass plant and interest in a geothermal venture (Harada-Stone, 1988a, 1988b).

Amfac Tropical Products' Keaau plant processes papayas and guavas. C. Brewer's Mauna Loa macadamia processing plant is also in Keaau.

W. H. Shipman, Ltd. has developed a light industrial park in Keaau. Nearly all lots in the first increment of 19 lots were sold at the park's opening in January, 1988 (Hawaii Tribune- Herald, January 29, 1988). The park includes space for some 300 lots (personal communication, Bob Cooper, Development Manager, W.H. Shipman, Ltd., November 3, 1987).

Currently, small-scale geothermal installations are in place or under construction in the Kapoho-Pohoiki area.

In the lower Puna areas near the existing geothermal sites, major economic uses of the land include diversified agriculture, subsistence agriculture, hunting, and livestock raising. Marijuana cultivation is believed to be common in both lower and upper Puna. Pahoa is the primary retail center for lower Puna, although it lacks the larger shopping facilities to be found in Keaau or Hilo.

3.2 Demographic Indicators

3.2.1 Population

According to U.S. Census data, Puna's overall population was 5,154 in 1970 and 11,751 in 1980 -- implying an annualized average growth rate of 8.6 percent per year, more than twice the islandwide rate for the 1970's and proportionately greater than growth in any other Big Island district, except for North Kona. The State has estimated Puna's mid-1986 population at 18,400 -- suggesting a "slower" average growth rate of 7.4 percent per year. Still, Puna's estimated growth in the period 1980-1986 was faster than that of all other districts in the state during the same period, except for Hanalei on Kauai (State of Hawaii, Department of Business and Economic Development, 1987a, p. 2).

Much of the Puna district's recent growth has been taking place in lower Puna (Census Tract 211), which increased its share of the overall Puna population from 26 percent in 1970 to 40 percent in 1980. Data in Table 4.1 also indicate a number of changes in the demographic composition of lower Puna's population, many of which are similar to -- but even more pronounced than -- demographic changes for the island as a whole:

- Caucasians had formed the fourth largest ethnic group in the district in 1970; by 1980, they were the largest. The ethnic Japanese formed a much smaller part of the 1980 population than of the 1970 population.
- The educational level of the population rose substantially.
- The Puna population expectably took on more transient characteristics. The proportion of the population living in the same house five years earlier dropped sharply, while the proportion of residents born outside Hawaii increased.
- Lower Puna became younger on average. The percentage of the population over 65 years of age decreased by nearly eight points, and there was an increase in the proportion of people aged less than five years.

Pahoa is the Census Defined Place (CDP) nearest to the geothermal project site. (The other communities listed in Tables 1 to 4 are all in Upper Puna.) Pahoa showed no population increase during the 1970's. In lower Puna, the subdivisions, rather than the town, have attracted new residents. Pahoa residents were also exceptional in that they include relatively more ethnic Japanese (43 percent) and more foreign-born persons (22 percent) than in the Census Tract as a whole. Pahoa residents in 1980 were less likely to have completed high school than others in lower Puna, and far less likely to have lived off-island.

No separate census data for the subdivisions adjacent to the geothermal project sites are available. A door-to-door survey in 1984 found 152 households in the Leilani Estates subdivision, with a population approaching 400 (Anderson and Oyama, 1987). The only available indication of (actual or potential) population in the nearby subdivisions is the number of lots into which they are divided (on tax maps):

Hawaiian Holiday Estates	88 lots
Lanipuna Gardens	110 lots
Leilani Estates	2,266 lots
Nanawale Estates	4,289 lots.

In Leilani Estates, then, there were about 15 lots for every house standing at the time of the survey. This underscores the point that much land remains undeveloped and unoccupied in the subdivisions.

3.2.2 Labor Force

In both 1970 and 1980, the Puna unemployment rate was higher than the county average, and the labor force participation rate was lower (Table 4.2). By 1980, the Puna unemployment rate was 1.75 times the county rate. More recently, the county unemployment rate has increased, but Puna rates remain higher than the county average. While the State of Hawaii Department of Labor and Industrial Relations estimated the county's 1986 unemployment rate as 7.6 percent, the comparable figures for lower and upper Puna were 12.8 and 13.5 percent respectively (unpublished data, provided by Francisco Corpuz, Research Statistician, Research and Statistics Office, Hawaii State Department of Labor and Industrial Relations.)

The 1980 Census provided gender-specific information on the civilian labor force for both lower and upper Puna. Table 4.5 shows that women in Puna -- especially lower Puna -- were less likely than women elsewhere on the island both to seek and to find employment. Male unemployment in Puna was only slightly higher than male unemployment elsewhere in the county. (After the closing of Puna Sugar, that may no longer be so.)

The Puna Community Survey, a State- and County-sponsored study conducted in 1982, provided information on the major work activity of household heads (SMS Research, 1982, Vol. II, pp. 29- 31). Some of the major categories were:

retired	23%
unemployed/doesn't work	8%
construction	12%
sugar	8%
other agriculture	13%
government	8%

The Puna Community Survey also yielded data on household heads' job location:

at home/doesn't work	30%
Puna	32%
Hilo area	27%
Ka'u area	1%
other Big Island area	7%
other reply	2%
don't know/refused	1%

3.2.3 Family Characteristics and Income

In 1980, the Hawaii County median family income was just 84 percent of the state median figure. Puna District appeared to have even more grave income and poverty problems than did the county as a whole (Table 4.3). The median family income for lower Puna ($13,842) was only 72 percent of the 1980 county median ($19,132). The percentage of families below the poverty line in both Puna census tracts was above the county average, but the lower Puna percentage was notably higher than the upper Puna figure.

The Pahoa CDP showed a particularly high percentage of families below the poverty level in 1980. Yet, this area also had a high percentage of families in upper-income brackets, indicating a wide range of incomes.

Compared to both upper Puna and the county as a whole, lower Puna's family structure in 1980 was slightly more weighted toward female-headed households, especially in families with children present.

3.2.4 Housing Stock

General improvements in the availability and quality of housing are clearly visible in the rise in owner-occupied housing and the decrease in substandard housing shown in Table 4.4 (although the proportion of units in Puna lacking plumbing or with relatively few rooms still remained above the county figure).

The 1980 U.S. Census showed the percentage of owner- occupied housing to be higher in Puna than in the county as a whole (Table 4.4). The median value of housing in the district was, however, well below the county median. In lower Puna, the 1980 median value was only two-thirds the county median. Rents, on the other hand, were higher in Puna than in the county as a whole in 1980.

3.3 Lifestyle and Values

This section offers an overview of data on values and lifestyle in Puna. Puna residents often stress that they like the relatively undeveloped character of the district. Nonetheless, many express concern over the availability of jobs and the limited infrastructure of the district.

3.3.1 Valued Aspects of Life

A 1982 survey sponsored by the State and County showed that residents found that the "best things" about life in Puna were: (1) the area's undeveloped character; (2) the weather; (3) the scenery; and (4) lack of pollution (SMS Research, 1982, Vol. I, p. 22). Puna respondents to a 1983 survey mentioned both environmental and interpersonal aspects of the district when asked their opinion about the "two best things about living on the Big Island" (Hawaii Opinion, Inc., 1983, p. 4). Puna residents mentioned "nice, friendly people" more often than any other category, and more often than did people from other districts.

Puna residents sometimes describe themselves as rural, or as persons who have chosen a rural lifestyle. A "Puna lifestyle" can involve various ideals and practices: an emphasis on family life, an appreciation for the friendliness and slow pace of life in small communities, the ability of residents with agricultural resources to "live off the land," or to "live in harmony with the land," achieving self-sufficency. Residents' sense of themselves as independent pioneers is in some cases bolstered by the notion that Puna is "the last frontier" (Fluor Technology, Inc., 1987, p. 10-28).

3.3.2 Further Aspects of Puna Lifestyles

The foregoing suggests that Puna residents value easy personal relations and the rural nature of their district. However, their lives and attitudes are more complex than this may suggest.

First, Puna is not as isolated as some other areas on the island. Most residents shop, and many are employed, in Hilo (SMS Research, 1982, Vol. I, p. 15). Second, many residents report substantial concerns over limited economic opportunities in Puna, and want improvements in roads and government services.

Next, social change and problems are part of life in Puna. Residents' geographic mobility is high. School populations include many new arrivals; in 1986-87, about 600 new students came to the Pahoa schools, and 453 left, while the total enrollment was about 1,700 (personal communication, Ed Matsushiga, Research Statistician, Information System Services Branch, Department of Education, October 6, 1987). A government fact- finding group cited local social service providers as finding child abuse, child neglect, and sexual abuse "not uncommon" in lower Puna (State of Hawaii, Progressive Neighborhoods Program Task Force, 1984). Some of these social service informants feared to make personal household visits in the area.

Finally, an illegal economy encourages behaviors that do not fit well with the ties among friendly people that Puna residents value (see above, 3.3.1). It may be presumed that marijuana growing involves interpersonal tensions and suspicion, rather than generalized friendliness. Growers have been singled out as likely to have attack dogs (Clark, 1987).

3.3.3 Native Hawaiians' Values and Lifestyle

Native Hawaiians, although comprising less than a quarter of lower Puna's 1980 population (by Census ethnic definitions), arguably represent a social group of particular significance. This is because many Native Hawaiian families have resided in the region for generations, and because of the reputed spiritual bond between Native Hawaiians and the volcanic activity at Kilauea Volcano, considered home to the volcano goddess Pele.

A consortium of Hawaiian organizations, the Puna Hui Ohana (1982), identified 1,334 residents of Puna as "aboriginal Hawaiians," of whom 1,001 lived in lower Puna. The average age of the persons in those families was 25.4 years. The Puna Hui Ohana reported that the Hawaiians of Puna are largely content with the prevailing lifestyle in the district.

The Puna Hui 'Ohana study described the activities and concerns of Hawaiians in Puna. It drew on interviews with key informants in the community and on a survey of most adult Hawaiians in lower Puna.

Most of the Hawaiians surveyed lived some miles from the subzones, in Hawaiian Beaches (42.5 percent), Pahoa (21.9 percent) or Kalapana (18.8 percent). Although many lived in relatively new subdivisions, they usually had lived a long time in Puna. The average length of residence in Puna was 22.4 years (for the entire sample).

Most respondents did not report extensive use of the Hawaiian language or involvement in <u>hula</u>. A majority said they consumed traditional Hawaiian foods and used traditional medicines. Most respondents reported involvement in traditional subsistence activities -- fishing, shoreline food collecting, and food gathering. The gathering of medicinal plants and maile was practiced by many, as was hunting. Commercial involvement in these activities was rare.

4.0 Attitudes Toward Economic Development in General

4.1 Hawaii County Attitudes

Residents of the Big Island have consistently favored economic development because of a need for jobs.

Big Island respondents were more in favor of growth (68 percent favoring) than others in the state (53 percent favoring, statewide) when asked in a recent survey whether they supported economic growth for Hawaii (B. Sunderland and Associates, 1987, presented to Patti Cook and Associates, Inc., p. 14).

Nearly all Hawaii County respondents to the 1984 State Plan Survey (SMS Research, 1984, p. 11), thought that Hawaii needs more jobs and industry. (For 67 percent of the Hawaii County sample, this issue is "<u>extremely</u> important" -- compared to 55 percent of the respondents statewide.)

An earlier survey on tourism found that Big Island residents valued tourism because of the money it brings to the island and because the industry provides needed jobs (Ward Research, 1982, p. 7).

A concern qualifying Big Islanders' support for economic development is local control. Only 36 percent of the Big Island respondents to the Sunderland survey mentioned above favored state-level decision making on projects affecting one island. Residents of the other Neighbor Island counties were similarly unwilling to support centralized control.

4.2 Puna Attitudes

In recent opinion surveys, Puna residents have expressed strong support for economic development. Like others on the Big Island, they favor the creation of new jobs. The closing of the Puna Sugar Company in 1984 and the relatively high level of unemployment in Puna underline this concern. Yet, many oppose industrialization on the grounds that it could change the area into a densely populated, polluted zone. Puna residents have favored diversified agriculture and light industries related to agriculture over other types of economic development (Table 4.6).

The County's planning survey (Hawaii Opinion, Inc., 1983) included questions about economic development "on the Big Island." Puna residents voiced support for diversified agriculture, tourism, and aquaculture. Only about a quarter of those polled in Puna supported either geothermal development or heavy industry.

In the Puna Community Survey (SMS Research, 1982) upper Puna residents tended to support economic development. Residents of the Kapoho-Kalapana area were more apt to be skeptical or opposed to development. Pahoa residents were more concerned than others with social problems (SMS Research, 1982).

5.0 Attitudes Toward Geothermal Development

5.1 Hawaii County Attitudes

Various opinion surveys indicate that, like other Hawaii residents, people on the Big Island recognize Hawaii is heavily dependent on outside sources of energy. Many favor developing alternate sources of energy. Geothermal development is widely supported, although survey respondents are less in favor when it is linked with heavy industrial development in Puna or elsewhere on the Big Island.

In a recent survey (SMS Research, 1987), people were asked to give their opinion of programs to build an undersea cable to send geothermal electricity from the Big Island to Hawaii. The idea of exporting energy to other islands was favored by a large majority of respondents statewide. Big Island respondents were also supportive:

Very favorable	48.5%
Somewhat favorable	22.8%
Somewhat unfavorable	12.9%
Very unfavorable	6.9%
Don't know	8.9%

In an earlier survey (SMS Research, 1986), a plurality of those asked about a geothermal export scenario supported the idea (Table 4.7). Big Island residents' reasons for supporting or opposing the export of geothermal energy were similar to those of Puna residents (see Sections 5.4.1 and 5.4.2). Supporters looked for economic benefits from geothermal development and liked the idea of sharing energy with other islands. Some wanted assurance that the impact of geothermal projects on the environment and on residents' health and lifestyles will be limited.

In another survey (Barbara Sunderland and Associates, 1987, p. 14), people were asked whether they generally favored geothermal energy, the resorts of West Hawaii, a spaceport and a papaya irradiation plant. A majority of the 400 Big Island respondents supported geothermal development (77 percent), resorts (74 percent), and the space launch facility (54 percent). Residents of East and West Hawaii alike were similarly in favor of geothermal development.

Respondents to the 1983 County planning survey (Hawaii Opinion, 1983) were asked to rank their support for various industries by indicating how, "If you had ten million dollars to help industries on the Big Island," that money should be divided. Geothermal development ranked sixth (after diversified agriculture, tourism, aquaculture, construction and sugar) for respondents islandwide. Islandwide, 41 percent of respondents supported "geothermal-related" development. In Puna, only 24 percent of the 117 respondents did so, the same proportion as supported heavy industry.

5.2 Puna Attitudes

Although residents of Puna are more likely than others in Hawaii to be critical of geothermal energy development, supporters of geothermal projects have typically outnumbered opponents in surveys. Residents have responded more positively when the idea of geothermal energy development was separated from industrial development in Puna. Many question the need for extensive geothermal development in their district. Yet, many of those who criticize particular projects state their support for geothermal development in principle (e.g., Leilani Community Association, 1978; K. Kirkendall, Public Hearing on Proposed Kilauea Middle East Rift Geothermal Subzone, Pahoa, September 26, 1985).

A 1986 survey (SMS Research, 1986) asked respondents to evaluate three geothermal energy scenarios: (1) plants near the existing Kapoho facility, producing about 25 megawatts for use by Big Island consumers; (2) plants in Kapoho and the Puna Forest Reserve, producing about 100 megawatts to generate all the power used by Big Island consumers; and (3) plants in Kapoho and the Puna Forest Reserve, occupying a larger area than the plants described previously, producing up to 500 megawatts for export to Oahu. Of the 227 Big Island respondents, 103 were from Puna. Table 4.7 indicates both the Puna responses and the responses of the entire Big Island sample.

4.8

In this survey, Puna supporters and opponents of exported energy were about equal in numbers. Economic and environmental factors were mentioned as concerns, but the major issue discussed by both sides was the sharing of resources with outsiders (see section 5.4.2). While energy export could allow the use of resources without promoting widespread industrial development, this argument was not developed by Puna residents.

Residents of other districts were somewhat more favorable towards the second and third scenarios than were people from Puna. While scenarios involving a "large-scale" geothermal development did not win the support of a majority of Puna respondents, a few more supported those scenarios than categorically opposed them. For some on the Big Island, energy export is welcome because the sharing of resources is seen as a value. Puna respondents were likely instead to be unwilling to share, arguing that others should solve their own energy problems.

A 1984 health study in Leilani Estates included questions about attitudes toward geothermal development. Leilani Estates is adjacent to the first successful geothermal well. Residents reported some annoyance due to noise (18 percent of respondents) or smells (14 percent) in the previous year (Anderson and Oyama, 1987, p. 9). Still, 44 percent favored geothermal development in Puna, while only 20 percent opposed it (Memorandum, B. Anderson to D. Thomas, February 12, 1986).

In 1982, Puna residents were asked their opinions of (1) geothermal energy development alone, (2) energy development with light industrialization, and (3) energy development with heavy industry. The combination of geothermal with light industry gained the strongest support (66 percent of those responding in favor). Twice as many respondents opposed heavy industry (44 percent) as supported this option (21 percent) (SMS Research, 1982, Vol. I, p. 34).

5.3 Impacts Anticipated by Hawaiians in Puna

The Puna Hui 'Ohana survey respondents saw geothermal development as having large-scale consequences. Some impacts were expected by many respondents to be good or bad. In other cases, the response was mixed, with many respondents expecting negative impacts, and a few more respondents expecting positive ones:

GOOD	NEITHER GOOD NOR BAD	BAD
Economy	Social Conditions	Hawaiian Culture
	Community Closeness	Historical Sites
	Employment	Traditional Religion
		Hunting, Fishing, Gathering
		Traffic
		Agricultural Land
		Land Taxes
		Physical Environment
		Quakes, Eruptions
		Plants, Animals

Some 40.2 percent of the respondents viewed the overall impact of geothermal development as bad, and 32.5 percent judged it as good (Puna Hui 'Ohana, 1982, p. 130).

Geothermal development was seen as a possible source of jobs, but many Puna Hawaiians doubted whether Hawaiians would get such jobs. One theme in their comments was that it was unlikely that a high technology field such as geothermal would have room for relatively unsophisticated Puna residents of Hawaiian ancestry.

Both the authors of the Puna study and many of their informants stressed the importance of the land for Puna residents of Hawaiian ancestry. The long list of anticipated negative impacts, most of which have to do with the occupation of the land by a new development, underlines the importance for Hawaiians in Puna of respect for the land.

5.4 The Pele Practitioners

Since the Puna Hui Ohana 1982 survey was published, several Hawaiians have argued that development, especially geothermal development is improper in a region belonging to the goddess Pele (Pele is associated with volcanic activity). These persons, who recognize relationships to Pele based on family ties or worship, became known as the Pele practitioners.

In a submission to the Board of Land and Natural Resources, Aluli and Dedman (1985) view geothermal development as "an obvious and profound affront to Pele." They argue that Pele is a living goddess. They oppose geothermal development on the grounds that it threatens:

- Pele, and Hawaiians' relationship to the goddess;
- Hawaiians' relationship with the land; and
- Hawaiian identity.

These points were linked in testimony presented by a Big Island <u>hula</u> teacher, who submitted that geothermal development would be an invasion of Pele's domain, leading to a loss of belief, a loss of a sense of belonging to the land and the deity, and hence a loss of identity (Pualani Kanahele, in Board of Land and Natural Resources, 1986a). Another expectation is that by tapping geothermal steam, wells would be drawing from Pele's substance, thereby depleting her vitality (Aluli, in Ibid.).

The Board of Land and Natural Resources (1986b, 1986c) accepts that Pele is owed respect, but finds that respect for Pele does not bar geothermal development.

When the Pele practitioners asked the the Hawaii Supreme Court to stop geothermal development on religious grounds, the Court turned down their petition. The Court found that the plaintiffs did not show that development would do significant harm to the exercise of their religion (Glauberman, 1988). The U.S. Supreme Court has refused to review the Hawaii decision.

More recently, about 40 Hawaiians have formed the Pele Defense Fund which carries out legal and public relations work (Hosek, 1988). The Pele Defense Fund has filed a challenge to a land exchange between the State and Campbell Estate and the subsequent creation of the Kilauea Middle East Rift Geothermal Subzone as infringing on "ceded lands" rights (Glauberman, 1988; Harada-Stone, 1988). The Hawaii Supreme Court has denied certification to this challenge.

The point of contention between Pele practitioners and the State was, until 1988, whether respect for Pele ruled out geothermal development. The religious question has been succeeded by a broad opposition to technological development on the Big Island, not just to geothermal projects.

In newspaper advertisements appearing in early 1988, the Defense Fund presented 12 points in opposition to development. Pele was mentioned in only one of the 12 numbered paragraphs (Pele Defense Fund, 1988). According to the head of the company that created the advertisement, "the ad goes beyond the religious into the environmental" (Hosek, 1988).

5.5 Identity and Beliefs for Other Hawaiians

Attitudes towards Pele vary greatly:

- The Pele practitioners assert that Pele deserves great respect (Hosek, 1988);
- Some Hawaiians view themselves as traditionally connected to other gods or powers, and as little involved with Pele (Piianaia, in Board of Land and Natural Resources, 1986a);
- Many Hawaii residents view respect for Pele as appropriate and prudent, especially on the Big Island (Thompson, 1987, Hartwell, 1987) -- yet they may support geothermal development and other projects the Pele practitioners oppose; and
- For some Christians, respect for Pele violates the First Commandment (Thompson, 1987). Kapi'olani's defiance of Pele in 1824 has long been seen as one of the heroic moments of Hawaiian religious activity (Bingham, 1848), and is still celebrated in hula (Hartwell, 1987).

The vast majority of Hawaiian survey respondents are interested in making a living in the existing economy, and report little interest in Hawaiian religion (Office of Hawaiian Affairs, 1986).

When Hawaiian respondents were asked about their attitudes towards the program to send geothermal energy to Oahu by an undersea cable, 67.4 percent favored the program, and only 19.7 percent viewed it unfavorably (SMS Research, 1987).

The issue of respect for Pele may be of concern to many Hawaiians who do not practice Hawaiian religion or oppose all geothermal development. Respect for Pele may be seen as respect for the Hawaiian people and for an aspect of Hawaiian tradition.

Prominent members of the Pele practitioners have spoken out for Hawaiian rights and groups on several islands of Hawaii (Uprichard, 1988). Also, groups opposed to geothermal development have claim to be protecting the land -- for example, the Citizens for Responsible Energy Development with Aloha 'Aina. In so doing, they link themselves with Hawaiian political groups, which have expressed deep reverence and concern for the land (Linnekin, 1983, 1985; Kirkpatrick, 1987).

Debates over geothermal development hence involve more than technical questions, and can touch on matters that are sensitive for some Hawaiian persons and groups. Disagreements and dissension among Hawaiians are a likely consequence of debates over development in Hawaii, but not of any specific project in particular. This impact may limited in strength and duration, due to mechanisms in Hawaii's culture to overcome interpersonal divisions (Shook 1985).

5.6 Assessment of Community Concerns and Issues

Community concerns and issues deserve study because (1) if controversy and polarization occur in the process of planning a project, these are social impacts of the proposed project; (2) certain issues are difficult to quantify, and the aim of identifying impacts may be served by noting these concerns in the environmental assessment.

Information on community concerns and issues comes mainly from surveys and testimony at public hearings. Surveys can show whether a concern is widespread at a given time. Testimony can provide a detailed account of one speaker's views of an issue. Both sources of information have limitations. The viewpoints expressed at hearings need not be widely shared. Surveys provide a snapshot of opinions that may change over time. Also, different issues have emerged as important for residents when different geothermal futures are discussed. In the Section 5.6.1, the various concerns that have emerged over nearly a decade of debate are grouped under five general headings. Section 5.6.2 assesses their relative importance to the production of geothermal energy for export.

5.6.1 Types of Issues and Concerns

Puna residents' concerns in relation to geothermal development can be grouped under five headings for analytical purposes:

(1) Economic Benefits: Many in Puna recognize a need for new jobs (Table 4.6). Geothermal development is sometimes supported as a source of employment (SMS Research, 1987). The cost of electricity is also a concern of residents; some favor geothermal energy as leading to reduced costs for electricity. Several survey respondents see a present and future need for electrical energy in Hawaii. Some mention that residents of some Puna areas do not now have electricity; others support geothermal energy as supplying the power necessary for economic growth (SMS Research, 1986, pp. 50, 57).

(2) Sharing of Local Resources: The idea of energy self- sufficiency is widely supported in Puna and elsewhere on the Big Island (SMS Research, 1986). Geothermal energy is sometimes viewed as a Hawaiian resource to be shared among Hawaii's people. Some Puna residents, however, are unwilling to share with other islands, and see urban institutions -- the State government and energy companies -- as threatening their lifestyle. For some, then, geothermal energy development and export could bring Hawaii's people together; for others, proposed developments threaten a valued isolation.

(3) Environmental Issues: Survey responses show a widespread concern for the ecology. Consequently, many respondents are willing to support geothermal energy if assured that environmental issues will be carefully addressed. Some residents argue, however, that geothermal development will exhaust natural resources. The possible impact of geothermal sites on forest vegetation and wildlife, particularly the 'io Hawaiian Hawk, has been viewed critically. Opponents of geothermal developments have repeatedly expressed concerns that, in the case of an earthquake or similar catastrophe, environmental damage might occur which energy developers could not control or repair (Edmunds, 1987 p. 91). While many persons are concerned with the environment, there is no evidence that they share all the ecological concerns mentioned by speakers at hearings on geothermal sites.

(4) Impact on Residents: Many residents have questions about possible impact of geothermal development on their own lives.

- Neighbors ask whether their catchment water will be affected by fumes. Some think that their livestock will be harmed by noises or fumes. Often a buffer of a mile is requested between project sites and residences.

- Puna subdivision residents, living near proposed electrical transmission lines, have raised questions about potential impacts. One resident, chairman of the Transmission Line Committee of the Orchidland Community Association, mentions as his concerns (1) health and safety; (2) property values; (3) visual impacts; (4) TV and radio reception; (5) the possibility that additional lines will be strung once an easement for power lines is obtained (Laine, 1987). In his letter, he speaks in favor of "responsible development" that minimizes impacts on residents and existing homes.

- <u>Other Puna residents</u> have expressed uncertainty or concern over several potential impacts. Noises and smells associated with geothermal production are sometimes thought to affect wide areas. Residents question whether their health may be affected by fumes. One issue is that geothermal development could bring population increases. Some note that area residents supplement their diets by hunting in forest areas that will be affected by geothermal development.

(5) Hawaiian Religion: In surveys (SMS Research, 1982, 1986), Puna residents rarely mentioned religious reasons for their attitudes toward geothermal development. In public hearings, though, some Hawaiians have testified to their worship of Pele and their sense that any geothermal development in Puna amounts to sacrilege. The Puna Hui Ohana report (1982) further proposed that geothermal development could change Hawaiians' attitudes towards persons, nature, and the supernatural.

In February 1988, advertisements urging people to oppose geothermal development on the Big Island appeared in Hawaii and mainland newspapers. The Pele Defense Fund opposed geothermal drilling partly as violating Hawaiians' religious beliefs and as a step towards industrializing the Big Island.

5.6.2 Relative Importance of Different Concerns to Geothermal Development

The relative importance of different concerns for members of the community at large has been indicated in two surveys (SMS Research, 1982, 1986).

The 1982 survey asked Puna residents' opinions of three geothermal futures (electricity production alone, with light industry, and with heavy industry). The survey also probed for the <u>reasons</u> behind residents' opinions. Those reasons can be roughly grouped as economic, environmental, social, and other.

Overall, Puna survey respondents mentioned economic issues most often, then environmental issues, and finally social and other issues about equally often. Kapoho-Kalapana residents were much more likely to mention environmental and economic issues than social and other issues. Keaau residents -- in an area relatively far from the geothermal sites, where development has depended on sugar production and proximity to Hilo -- placed far more weight on economic issues than any other factors. (These findings were reached by combining data from tables in SMS Research, 1982, Vol. II, pp. 99-130.)

The 1986 survey also asked people's opinion of three scenarios and the reasons for their opinions. However, the three scenarios were not the same as in the 1982 study, which lacked an "export to Oahu" scenario. Instead, they were the scenarios listed in Table 7: (1) small-scale, local use; (2) larger-scale, local use; and (3) larger-scale, export.

Respondents' reasons for their opinions -- whether those opinions were positive, negative, or "it depends" -- can be grouped as:

- concern with <u>shared use of local resources</u> (e.g., for opponents, an unwillingness to share local geothermal resources with outside areas, or, for supporters, a sense of duty or desire to share) -- a category of concern which did not emerge so strongly in the 1982 survey;
- concern with <u>energy</u> itself (e.g., interest in alternate energy, wish to minimize oil dependence);
- <u>economic/cost</u> concerns (e.g., jobs, or the cost of electricity);
- <u>environmental</u> concerns (e.g., with forest resources, or concern about fumes and health impacts);
- <u>other</u> reasons (e.g., vague or general ones).

(It may be noted that some of the issues which were frequently discussed in public hearings -- see Section 5.4.1 -- rarely emerged in surveys of the general public. A listing of verbatim comments in the original survey report shows that even the miscellaneous "other" category rarely included any discussion of issues such as religious concerns or property values.)

Table 4.8 summarizes the most frequent reasons expressed by respondents in both Puna and the rest of the island for the opinions they expressed about all three geothermal scenarios. It may be seen that -- for the two non-export scenarios -- geothermal development supporters in both Puna and the rest of the island focused primarily on energy needs and secondarily on economic/cost factors. However, both opponents and the undecided focused primarily on environmental (and health) concerns.

However, for the export scenario, the issue of whether or not to share local resources emerged as a much greater consideration. The minority of Puna respondents supporting energy export to Oahu stressed a desire to share resources as the second most frequently stated reason. However, opponents of export in both Puna and the rest of the island were likely to specify their unwillingness to share local resources (and/or their preference to let Oahu solve its own energy problems) as a major rationale for their positions.

The SMS analysis of the findings, however, suggested that apparent unwillingness to share resources with Oahu was still actually rooted in environmental concerns, in that opponents objected to paying environmental costs for Oahu's energy benefits. This analysis would fit with observations about energy production controversies around the country, in that conflict typically involves perceptions of localized costs borne by relatively few people around the production site vs. widely dispersed benefits for residents far from the site.

5.7 Hawaiians's Claims to Land and Mineral Rights

The question of who is to profit from geothermal development also affects Hawaiians. Legal rights to the new resource must be defined. These rights raise political issues, since the State's position on "ceded lands" is perceived by some Hawaiians as an indication of the extent to which the State recognizes or denies Hawaiians' rights (Ward, 1988).

The ownership of geothermal resources was clarified by the Legislature in 1974 (Act 241, Hawaii Session Laws), when it held that geothermal resources are minerals. Mineral rights on most of the land in Hawaii are reserved for the State (Kamins, 1979a, 1979b). Hawaiians may still have a special interest in the State's revenues from geothermal development. If geothermal revenues are part of the "ceded lands" trust, then the State must dedicate 20 percent of those revenues for Native Hawaiians (Kamins, 1980; Ward, 1988).

"Ceded lands" are public lands that were transferred from the Republic of Hawaii to the U.S. Government at Annexation in 1898. These lands were defined, in the Newlands Resolution of 1898, as a trust held for the people of Hawaii, unlike other Federal government lands. When these lands were returned to the State of Hawaii in 1959, the State took on the responsibility to act as trustee for its people.

The 1959 Act identified five purposes for which revenues from the land are to be dedicated. One of those purposes is "the betterment of the condition of native Hawaiians." In practice, this means that 20 percent of the revenue would go into a trust administered by the Office of Hawaiian Affairs (Ward, 1988). ("Native Hawaiian" is defined by Act of Congress as limited to persons of 50 percent or more Hawaiian ancestry.)

The "ceded lands" clause clearly deals with the State's title to most State-owned land. Whether some or all mineral rights are part of the "ceded lands" trust is a complex legal issue.

Half the Puna Hawaiian respondents thought that Native Hawaiians should receive income from geothermal development (Puna Hui 'Ohana, 1982). Kamins (1979a, 1980) however cites precedents and reasons for holding that the State owes nothing to Hawaiians or Native Hawaiians from leases for geothermal development.

For some Hawaiians, if a share of the income from geothermal leases is not reserved for Native Hawaiians, the result would be a taking of resources without compensation to rightful claimants.

The State administration is working with an Office of Hawaiian Affairs task force to resolve problems associated with public lands trusts. The question at issue here is a broad legal one with a special application to geothermal development, rather than a problem raised specifically by such development.