AN ASSESSMENT OF GEOTHERMAL DEVELOPMENT IN PUNA, HAWAII

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PREFACE

This Assessment of geothermal development on the Island of Hawaii is the third and concluding report of the legal-socioeconomics program within the Hawaii Geothermal Project, a project of the University of Hawaii. The other publications of this trilogy are Legal and Public Policy Setting for Geothermal Resource Development in Hawaii, issued in February 1976, and an Environmental Baseline Study for Geothermal Development in Puna, Hawaii, issued in September 1976.

The central event of the Hawaii Geothermal Project has been the drilling of an experimental well early in 1976. That well, still being tested, has a temperature and pressure capable of generating approximately five megawatts of electricity, a demonstration of the existence of a geothermal reservoir in the Puna District of the Island of Hawaii sufficient to arouse commercial as well as scientific interest. At this moment, prospective developers of the potential resource are, along with others, awaiting promulgation of rules by the Hawaii State Department of Land and Natural Resources which the Department has drafted for regulating the drilling and operation of geothermal wells.

Plans, whether of government agencies or private enterprisers, for the exploitation of Hawaii's geothermal resources have not yet been offered. The specifics necessary for a standard environmental impact statement -- notably, the size and location of the resource and the mode of using it in production -- are not yet available. Consequently, this

Assessment is not presented as an Environmental Impact Statement. However, it does supply much of the information and analysis needed for an E.I.S., including an appraisal of the physical environment and the socioeconomic setting in the District of Puna, where the first geothermal development is likely to take place.

The Assessment is directed especially to policy-makers in Hawaii, and to those people, concerned with how this development may take place, who may want to help establish a geothermal policy for the state. For these persons and such other readers as this report may have, it attempts to identify the elements of a Hawaii geothermal policy and alternate modes for implementing the policy once it is established.

AN ASSESSMENT OF GEOTHERMAL DEVELOPMENT IN PUNA, HAWAII

1. PRELIMINARY

A. The Nature of the Projected Development

Scientific exploration has established the existence of geothermal resources on the Island of Hawaii. First, in 1973, a 4,000 foot deep exploratory well drilled in the Hawaii Volcanoes National Park by Dr. George Keller, of the Colorado Schools of Mines, under a grant from the National Science Foundation, demonstrated that at depth a heat gradient existed which, projected to areas well below sea-level, would generate steam -- if sufficient water penetrated the rock at that depth.

Then, in the first half of 1976, the Hawaii Geothermal Project drilled a 6,400 foot research well in Puna, down some 6,000 feet below sea level. It tested out with temperatures in excess of 600 degrees Farenheit, possessing a recharging water source which flashed into steam with a wellhead pressure between 60 and 70 p.s.i. This pressure, if sustained, is sufficient to power an electric generating unit of approximately five megawatts -- in itself a resource of some commercial value, but more important as evidence that a larger development of geothermal resources may be economically feasible on the Big Island.

Geophysical and geological evidence suggests that other areas of the Island of Hawaii besides Puna and the Hawaii Volcanoes National Park

(where economic exploitation of resources is not permitted) have geothermal potential. In fact, on the basis of that evidence the Hawaii Geothermal Project had planned to drill at two additional sites, on the southwest rifts of Kilauea and of Mauna Loa, but abandoned this more ambitious program of exploration for lack of funds.

Private enterprise has already shown interest in geothermal development on Hawaii. In 1961-62 a company formed by Magma Power, a major geothermal company of California, drilled shallow wells in the Puna District which were not productive. The Magma affiliate still holds leases on some of the Puna lands which it explored in the last decade. More recently, Water Resources International and Geothermal Exploration and Development Company have acquired land or drilling rights in the District.

Most attention on geothermal development in Hawaii, as elsewhere in the nation, has been centered on the generation of electricity, directing steam derived from wells to the turbines of a generating plant. Many producing wells are needed for a commercial electric plant; for example four wells averaging eight megawatts would be required for a relatively small generating station having a capacity of 32 megawatts. Regardless of capacity, a station is likely to have a cooling tower to increase its efficiency of operation and must have a system of collecting pipes to bring the hot water or steam coming from the producing wells to the generators. Further, a parallel set of pipes would be installed to direct the water back into the earth after it has passed through the generating

station, if the desirable procedure of reinjection of geothermal fluid is used to maintain the aquifer below the field, and for that purpose reinjection wells would have to be drilled.

Spaced at intervals of one well per 20 acres, a field of four production wells would occupy approximately 80 acres, the equivalent of a medium-sized housing subdivision.

Alternative uses of geothermal resources are to be found in other geothermal areas of the world, and may become of consequence in Hawaii. These include applications to agriculture (as in Iceland and the USSR); space heating -- and, less advanced in technology, space cooling (as in New Zealand and Iceland); direct use of geothermal water in industrial processing (also New Zealand and Iceland); and spas (the mainland United States, Japan, Czechoslovakia and several other countries). Indeed, a recent survey showed that, globally, the non-electrical uses of geothermal resources were much larger in terms of thermal units employed than the electrical applications.[1/]

The physical facilities and environmental impact associated with each of these alternative applications of geothermal waters, and those associated with yet other uses (as in aquaculture and in the recovery of minerals dissolved in the hot fluid), would vary greatly from a geothermal electric generating plant. Because of the variety of developmental patterns which

1/ R. A. Peterson and N. El-Ramly, The Worldwide Electric and Non-Electric Industry (Mimeo, University of Hawaii Geothermal Project, 1975), p. 16.

these alternative applications would require, and because of the greater uncertainty of their application compared with electrical generation, it is not feasible to trace the environmental impacts of non-electric geothermal uses with much specificity. Consequently, this report deals primarily with geothermal electric development and only secondarily with other modes of geothermal development. By no means does this focus imply that non-electrical applications are unimportant or undesirable. On the contrary, the writer is of the opinion that a multi-purpose development may be necessary to spread over several products the high costs of drilling and constructing one or more geothermal fields on the Island of Hawaii.

B. Potential significance of geothermal development in Hawaii.

The paradoxical position of the State of Hawaii with respect to energy has been much commented on since the national petroleum crisis in the winter of 1974. Naturally, Hawaii is lavishly supplied with energy from the sun, tradewinds and action of the sea, but completely lacks the fossil fuels used as standard energy sources by contemporary technology. A few tiny hydroelectric facilities on Kauai and Hawaii produce some power on those islands, and on the Island of Hawaii burning the bagasse (left in the sugar mill after the juices have been extracted from the cane stalks) generates considerably more -- but the combined contribution of these two indigenous energy sources to the state's consumption of BTU's is only a

fraction of one per cent of the total.[2/] More than 99 per cent is derived from petroleum products, the bulk of which is refined on Oahu from crude oil imported from abroad and then sold at prices above those which generally prevail on the continental U.S.

Partly as a consequence of the high cost of petroleum, electricity rates in Hawaii are among the most expensive in the United States. The average here is brought up by the rates in the neighbor islands. For example, as of September 21, 1976, residences using 500 kilowatt-hours in a month would have paid these bills: on Oahu, $23.37, Maui, $32.82, Hawaii, $35.89, Lanai, $34.32, Kauai, $36.74, Molokai, $35.03.[3/]

Since 1974 there has been a heightened concern about Hawaii's virtually complete dependence on petroleum shipments, not only the costliness but also the uncertainty of maintaining the vital flow of oil under the hazards of political instability in the Middle East and in Southeast Asia. A variety of energy sources indigenous to Hawaii (as well as nuclear power plants which apparently are not yet scaled down to a size economical for Hawaii) are being investigated. These include solar collectors; wind

2/ In 1974, the amount coming from hydroelectric was 0.03 per cent while 0.31 per cent of the total energy consumption came from the burning of solid wastes, i.e. bagasse. See flow chart in Alternate Energy Sources for Hawaii (Honolulu, University of Hawaii and Department of Planning and Economic Development), February 1975, p. 25.

3/ Rates supplied by Hawaii State Public Utilities Commission. For comparison with mainland cities, see Federal Power Commission, Typical Electric Bills (Washington, D.C., annual).

energy conversion; solid waste and biomass conversion; utilizing the energy of waves, tides and ocean currents; and geothermal energy.

Several of these potential new sources of power -- notably solar, biomass conversion, wind ocean thermal and geothermal energy -- offer promise of supplying significant quantities of energy, taking "significant" to mean 10 per cent or more of the total electrical energy demand of the state.[4/] At this writing, geothermal power seems to offer greater possibilities of near-term development to economic significance than any other indigenous energy source, even though solar heat is the first to be used, already being utilized in a few homes in Hawaii to heat domestic water supplies.

The exploratory well, drilled in the District of Puna by the Hawaii Geothermal Project between December 1975 and April 1976, and which occasioned the writing of this assessment, gives preliminary indication that one or more geothermal reservoirs may exist in Hawaii, having a temperature and pressure adequate for commercial exploitation, either in the production of electric power or by direct applications of the hot water/steam coming from wells tapping the resource. Potential direct applications will be considered later in this report, but even the single

4/ Comparison of these potential energy sources is made in a 1975 report of the [Hawaii] State Advisory Task Force on Energy Policy in Alternate Energy Sources for Hawaii (Honolulu, Natural Energy Institute of the University of Hawaii and the Department of Planning and Economic Development).

utilization of generating electricity warrants an examination of the possible impact of geothermal resource development on the islands and society of Hawaii. That examination is made here for the District of Puna, site of the exploratory drilling and first successful geothermal well in Hawaii, with the explicit suggestion that the factors presently considered for Puna also be taken into account for other areas where this new energy source may be sought in the future.

2. THE DISTRICT OF PUNA PRIOR TO GEOTHERMAL DEVELOPMENT

A. The physical environment generally.[1/]

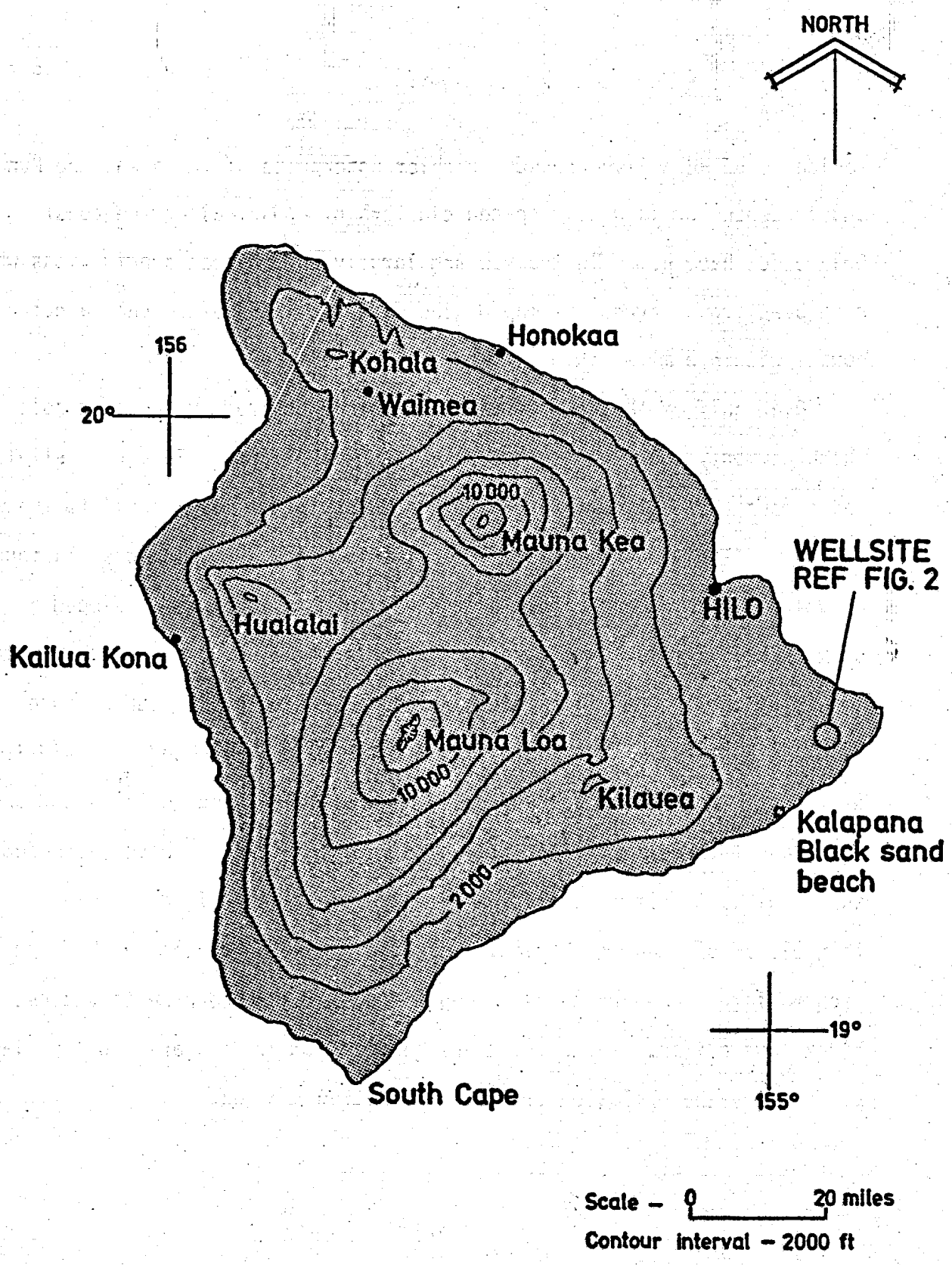
The Puna District, site of the exploratory geothermal well, is the easternmost projection of the Island of Hawaii, comprising approximately one eighth of the 4,038 square miles of the Big Island. Much of the District is formed by undissected volcanic uplands -- that of Kilauea to the north and that of Kalapana to the south -- but between, running from the Kilauea Caldera Complex eastward to the sea around Cape Kumukahi, is the Puna cone and crater area, marked by pu'us and craters of recent eruptions, notably that of 1955.

With an estimated mid-1976 population of 8,200, Puna is the second most populous of the nine districts of the Big Island -- some distance behind South Hilo District, where approximately 40,000 people live. The basis of comparison is made clearer by noting that only two "towns" in Puna, Kea'au and Pahoa, contain as many as -- and not much more than -- a thousand people. (Under the highly centralized structure of government which distinguishes the State of Hawaii politically, neither of these localities, or any urban center anywhere in the state, is organized as a local government. Only the counties are so organized.) Most of the

1/ Much of this section derives from an earlier report of the Hawaii Geothermal Project, Environmental Baseline Study for Geothermal Development in Puna, Hawaii, (University of Hawaii, September 1976).

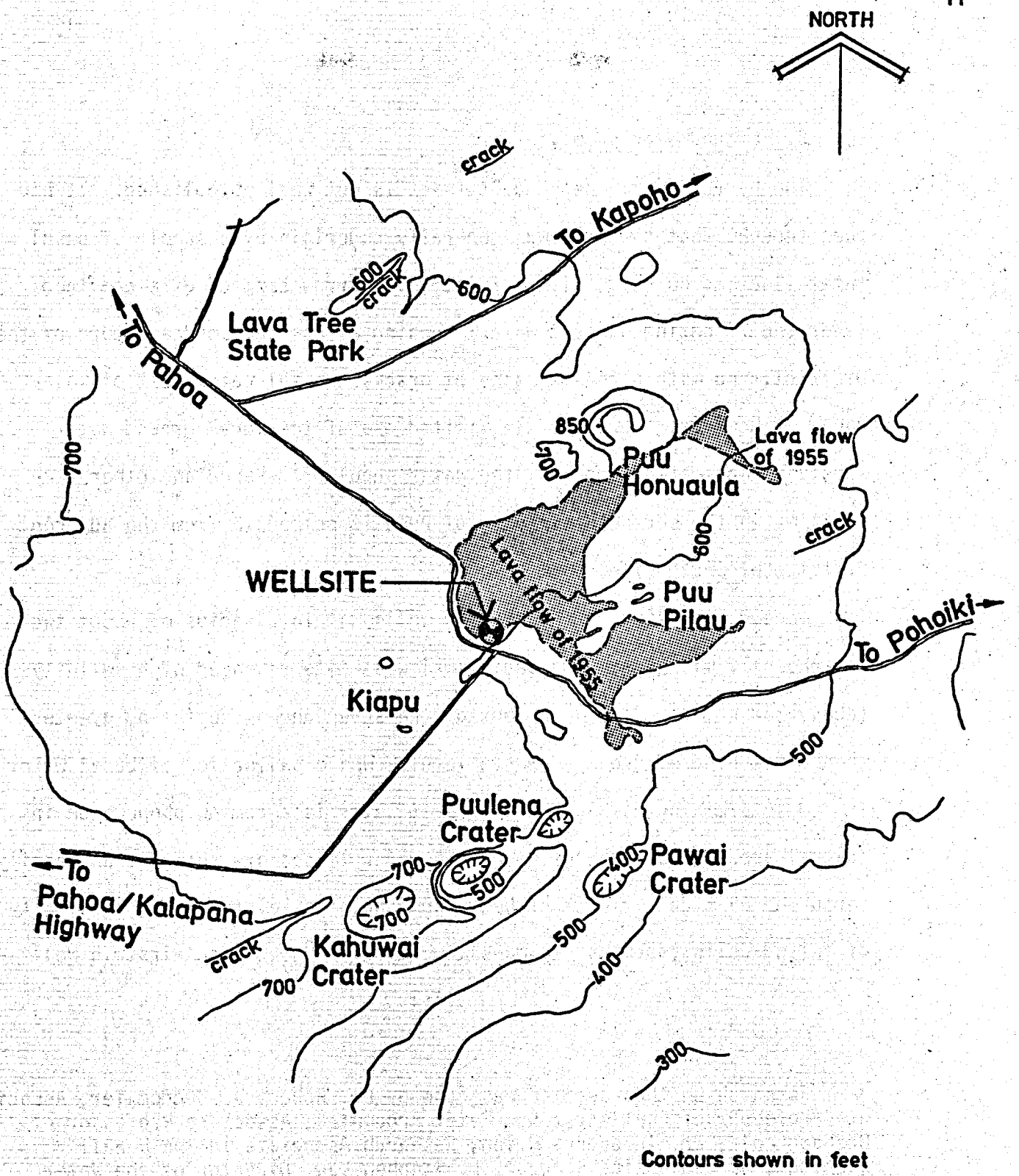
residents of Puna live around the chief enterprise of the area, the Puna Sugar Company or in widely spaced clusters of houses along the coast. Only a few have homes in the new and largely undeveloped subdivisions which have been drawn across the map of the District. There are only a dozen houses within a mile radius of the drill site itself.

Over half of the Puna District is thinly covered by the histosols which commonly occur on geologically young lava lands. In a band stretching across the west central part of the District -- mostly well to the west of the drill site -- is an area of entisols, weakly developed soils found on volcanic ash, among other locations. On this land has developed an area of marked environmental contrast: there is fertile soil and lush vegetation over the lower-lying fields, while the geologically younger upper slopes are dotted with ohias, which are the most common and most widely distributed species of native trees in Hawaii. Between fertile land and the slopes, there is dry desert, where recent lava flows have blackened the land, giving it a desolate and empty appearance. In a few places, thin plumes of steam mark vents where the underground heat of the area escapes into the atmosphere. Along the coast, the ocean beats against black lava cliffs. Where there are beaches, they, too, are usually black, produced by the explosion of hot lava meeting the sea.



Source: Hawaii Geothermal Project Well Completion Report, HGP-A, Kingston, Reynolds, Thom & Allardice, Ltd. (Auckland, N.Z., 1976)

Figure 1 Map of Hawaii



Source: Same as Figure 1.

Figure 2 - Site Location, Experimental Well HGP-A

B. Groundwater supply*

The hydrology of the Puna District is not well established. It had been thought that the area was generally underlain by a supply of basal water floating on salt, with a relatively narrow band of dike-confined water (not floating on salt water) running across the southern part of the District, and with a coastal zone of brackish basal water west of Kalapana.[2/] However, there is only limited use of the local ground water supply for domestic purposes; the water supply for Pahoa and other communities in the southeastern part of Puna is pumped in from the adjacent District of South Hilo.

Indeed, sampling of seven water wells within a radius of about two and one-half miles from the geothermal well site revealed high salinity (above 270 mg. per liter) in four of the seven and at depths no greater than a few hundred feet below sea level. While salination of basal water due to intermixing with underlying salt water is a common phenomenon in coastal areas, where unconfined fresh water lenses are thinnest and easily perturbed by tidal effects or heavy pumping, the relatively high salinity of inland wells (such as Malama-ki, Geothermal No. 3, and Airstrip Well --

* Research on this section was done by Dr. Robert W. Buddemaier, Associate Professor of Chemistry, Dr. Peter Kroopnick, Associate Professor of Oceanography, Dr. Theodorus Hufen, Research Associate in the Hawaii Institute of Geophysics, and Dr. L. Stephen Lau, Director of the Water Resources Research Center.

2/ H. T. Stearns, Geology of the Hawaiian Islands (Honolulu, Department of Land and Natural Resources, 1967. Reprint of Bulletin 8 of 1946).

see Figure 3) suggests that a classic Ghyben-Herzberg lens, in which fresh water floats on salt water, does not exist in the portion of Puna around the exploratory drill site.

Groundwater in the area, (and a rainwater sample as well for control purposes) was tested not only for the chemical characteristics displayed in Table 1, but also for its microbiological qualities (Table 2). Moderately high values for coliform bacteria were recorded at Isaac Hale Park Spring where the geothermally heated pool is used for casual bathing, and a much higher count was made of the sample from Allison Well. Since some of the microorganisms contributing to the high value may have been introduced during sampling, this well is being sampled again. Otherwise, no results of a cautionary nature were reported in the baseline study. As testing of the exploratory geothermal well proceeds, the existing water wells will be monitored for changes in chemistry or microbiology which may accompany the test flowing.

C. Geothermally-related chemical toxicants in air, water, soil*

Particular attention must be given to ascertaining if the chemicals commonly found in geothermal water or steam would pose a threat to the environment. Consequently, from May 1975 to July 1976, the Hawaii Geothermal Project (HGP) Puna drill site environs were monitored for mercury

* Dr. Barbara A. Siegel and Dr. Sanford M. Siegel, respectively Associate Professor of Microbiology and Professor of Botany, jointly investigated potential effects on air quality, the soil and plant life in the area, with the assistance of Dr. Thomas Speitel, Research Associate in the Department of Botany, and the following students voluntarily worked with the Professors Siegel on geotoxicology testing: Willie Cade, Melvin Calvan, Anna LaRosa, Kapuanani Lee and Hope Stevens.

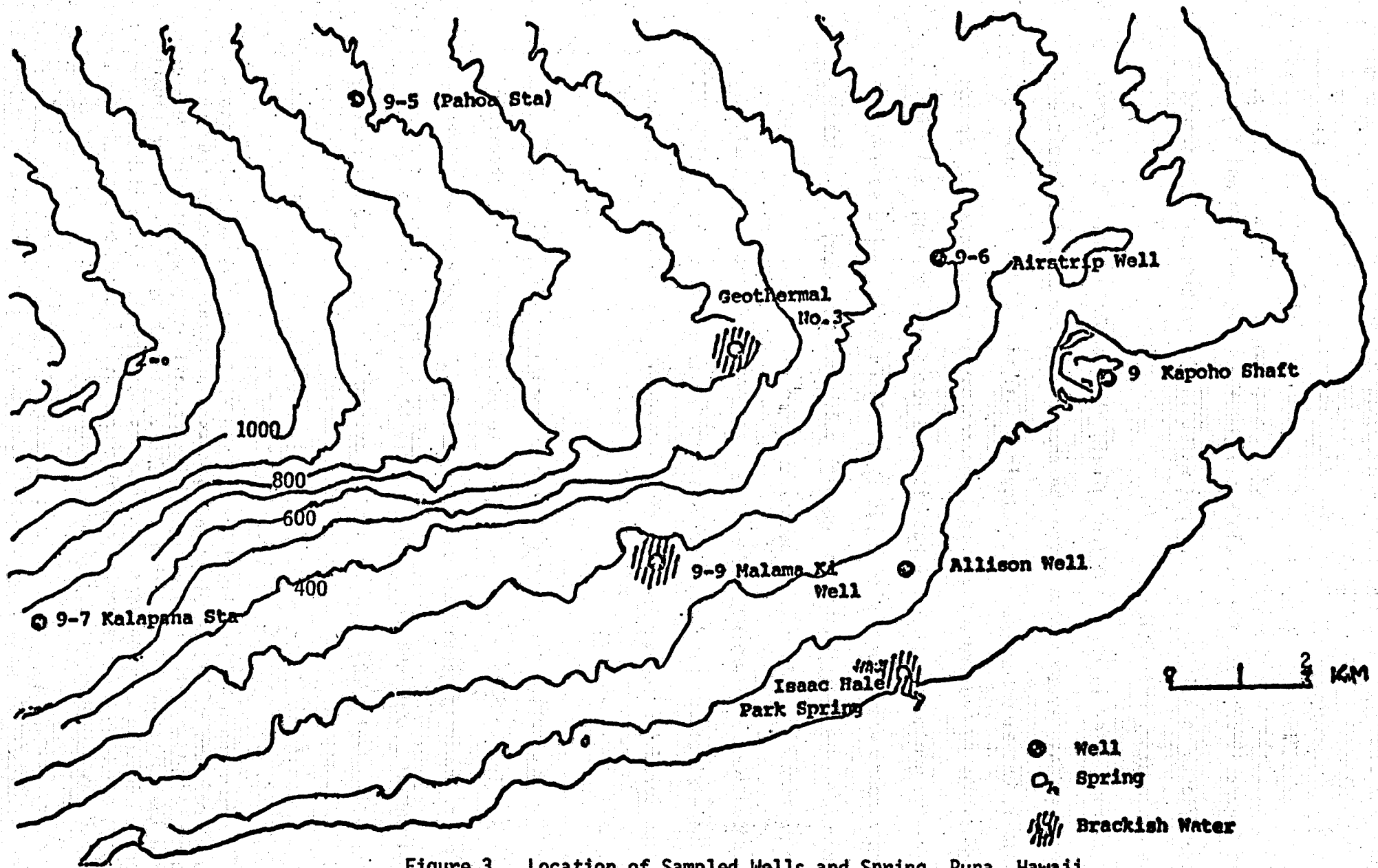


Figure 3. Location of Sampled Wells and Spring, Puna, Hawaii

TABLE 1. CHEMICAL DATA ON GROUNDWATER AND RAINWATER

PUNA, HAWAII, PRIOR TO DRILLING

EXPLORATORY GEOTHERMAL WELL

OLD NO.	STATE NO.	NAME	DATE	T*	pH	Na**	K	Ca	Mg	Cl	HCO_3	SO_4	SiO_2	N***	P
9-5	2986-01	PAHOA STATION	1-6-75		7.30	36.0	2.72	1.58	2.7	13.5	48	21.1	50.0	0.252	0.078
9-7	2487-01	KALAPANA STATION	1-6-75	28.5	7.68	89.6	5.20	5.30	6.6	132.2	38	37.2	44.5	0.070	0.056
9	3080-02	KAPOHO SHAFT	1-6-75	25.5	7.80	85.8	6.60	42.4	37	16.9	372	20	53.6	0.378	0.233
9-6	3081-01	AIRSTRIP WELL	1-6-75	33.0	7.42	238	13.6	23.0	28	303.5	48	204	71.3	0.014	0.040
	2881	ALLISON WELL	1-7-75	37.5	7.35	216	10.8	13.4	15.	281	132	69.2	24.1	>14	<0.002
		ISAAC HALE PARK SPRING	1-7-75	36.0	7.75	2020	86.0	32.4	200	3534	56	507	81.5	1.218	0.016
9-9	2783-01	MALAMA KI WELL	1-7-75	52.3	7.02	2105	109	66.8	210	3811	144	471	100.7	0.280	0.006
		GEOTHERMAL #3	1-7-75	93.0	6.85	2050	190	76.8	52	3274	30	314	96.6	0.003	0.006
		RAIN AT KALAPANA STATION	1-6-75			4.5	0.25	0.25	0.75	7.2		~2.5	0	0.024	<0.002

*TEMPERATURE GIVEN AS °C

**CHEMICAL DATA IN mg/l

***NO_2 NO_3 as N

TABLE 2. MICROBIOLOGICAL QUALITY OF GROUNDWATER

PUNA, HAWAII, PRIOR TO DRILLING

EXPLORATORY GEOTHERMAL WELL

WELL/SHAFT NO.	STATE NO.	NAME	DATE OF SAMPLE	COLIFORM MPN No. per 100 ml	FECAL COLIFORM MPN No. per 100 ml	REMARK
9-5	2986	PAHOA	1-6-75	<3	<3	Unchlorinated sample
9-7	2487-01	KALAPANA	1-6-75	<3	<3	Unchlorinated sample
9	3080-02	KAPOHO SHAFT	1-6-75	460	<3	
9-6	3081	AIRSTRIP	1-6-75	<3	<3	
9-9	2783	MALAMA KI	1-7-75	<3	<3	
—	----	ISAAC HALE BEACH PARK HOT SPRING WATER	1-7-75	1500	7	
—	2881	ALLISON	1-7-75	≥24,000	93	Well bottom mud in sample

and several toxic gases, particularly the sulfur compounds known to be emitted in geothermal areas. With respect to the fixed gases -- SO_2 and H_2S -- there has been no evidence of change from pre-drilling through the recent flashing experiment (Table 3). These values have been consistently at or below detection thresholds and well under hazardous levels in spite of the proximity (25 miles) of natural vents in the Volcanoes National Park supplying these sulfurous gases continuously. In these fumarole areas, measurement during 1971-76 yielded peak values as high as 25 ppm for SO_2 and 5 ppm for H_2S. These toxic emissions apparently do not reach the HGP drill site area, or do so only infrequently and for brief periods. Their lack of persistence may be an important environmental consideration. Aside from convective and wind dispersal processes, these gases may be oxidized both photochemically and biochemically to sulfate, and the capacity both of soil microorganisms and vegetation for metabolizing these sulfur gases may contribute to ecological "detoxification".

The same consideration cannot be applied to mercury. It is a potential toxicant in any form, although more so in elemental and alkyl forms.

Various figures have been cited for maximum allowable air mercury. Schroeder[3/] has suggested an 8-hour occupational limit of $10\mu g/m^3$ but recommends no more than $0.1\mu\ g/m^3$ for continuous exposure of the popula-

3/ Schroeder, H., Air Quality Monograph No. 70-16, American Petroleum Institute, Washington, 1971.

TABLE 3

STATUS OF CHEMICAL TOXICANTS AT THE

HAWAII GEOTHERMAL PROJECT DRILL SITE: A CHRONOLOGY

DATE	EVENT	RESULTS OF ANALYSIS					
		FIXED GASES[1]		MERCURY			
		SO_2	H_2S	Air[2]	Water[3]	Soil[4]	Plant[5]
May 1975	Pre-drilling	<0.5	<0.5	1.1	2.5	43-59	130/263[5]
May 1976	Post drilling	<0.5	<0.2	1.2	5.0	141/356	160/571
June 1976	Preliminary well test	<0.5	<0.2	1	3.0	--	--
July 1976	Flashing	<0.5	<0.2	9.9*	4.6	--	--

1 In ppm

2 In $\mu g/m^3$

3 In $\mu g/l$

4 In $\mu g/kg$

5 Nutgrass within 50m, Ohia-fern at ca. 100m distance.

* Subsequent field tests, made October 31-November 3 and November 29-December 1, 1976, yielded air values above 9.9, even when the well was shut down. Such high mercury values seem to reflect recently elevated activity along the East Rift with the formation of new emission centers, such as Heiheiahulu.

tion at large. Using a suggested provisional Federal exposure value of 1μg/m^3 as a reference figure, it is immediately obvious that HGP drill site levels were at threshold up to the flashing experiment. It should be clear from our measurements that up to the 22 July 1976 flashing, the air mercury levels were area values not related to drill site operations. The same conclusion applies to soil, plant and water mercury content. Hawaiian thermal areas are essentially like those elsewhere in the world with respect to mercury in air, water, soil and plants (Table 4 and Table 5). The norms or baselines tend to be appreciably higher than in non-thermal areas.

The upsurge of air mercury levels during flashing may only have been a "burst" releasing accumulated mercury at depth. Whether or not this short-term high release rate is representative of the long-term output to be anticipated during future well-flowing trials can only be determined by continuing on-site measurements. If well-flowing does in fact increase air mercury levels, then immediate air measurements must be followed up by an assessment of changes in water, soils and vegetation. We have identified useful indicator species, such as nutgrass, false staghorn fern and ohia, that can provide information about bioconcentration in plants as a source of increases in the local mercury burden and hazard potential.

At this writing (January 1977) there is no evidence of a sustained buildup of mercury at or around the drill site that can be attributed to geothermal energy development operations.

TABLE 4

MERCURY LEVELS OUTSIDE THE HGP-PUNA DRILL SITE AREA:

COMPARATIVE AIR AND WATER DATA, 1971-1976

SAMPLE	HG CONTENT
Air	$\mu g/m^3$
Thermal	
Hawaii	0.7-40.7
Iceland	1.3-37.0
U.S.S.R. Kamchatka-Kuriles	0.3-18
Non-thermal	
Hawaii	0.04-0.3
Iceland	0.62-1.0
New York	$\leq$0.014
Cincinnati	0.03-0.21
Eastern Pacific (open sea-west of California)	$\leq$0.0007
Water	µg/l
Poipu Beach (Kauai)	2.1
Kuhio Beach (Oahu)	2.3
Nuuanu Stream	0.6
Oahu aquifer	<0.2
Rain, Hawaii, January 1972 . Island of Hawaii, general	0.20-0.25
HVNP fumarole condensate, 1972	20-40
Western Atlantic, general	0.01-0.30
Hawaii aquifer (Puna)	$\leq$0.5

TABLE 5

MERCURY LEVELS OUTSIDE THE HGP-PUNA DRILLSITE:

COMPARATIVE SOIL AND PLANT DATA, 1971-1976

SAMPLE		HG CONTENT µg/kg
SOILS		
	Hawaii	20-305
	Oahu	2-40
	Iceland	3-400
PLANTS		
	General (about 400 samples)	<1->900
	Misc. ferns, HVNP	19-1400
	Ohia, HVNP	22-1200

D. Flora and Fauna

(i) Plants*

While there are trees on the Puna landscape -- the ohia just noted, roadside or backyard mangoes, citrus, monkeypods and other ornamentals -- the District is by no means forest-covered. There are four state forest reserves in the District (Nanawele, Malama-ki, Keauhohana and Puna), but only the latter is extensive and none rate among the choice timber areas of the Big Island. Norfolk pines have been planted east of Pahoa in an attempt to supply the local Christmas tree market, but they have not flourished.

It was beyond the resources of the Hawaii Geothermal Project to assess the lesser flora of the Puna District in any detail. However, an area within a mile of the drill site was examined, and it seems sufficiently representative of those inland sections of the District which are not either in cultivation or well populated -- and these relatively empty places comprise the bulk of the District -- to warrant inclusion in this description of Puna at large.

The well site is on an exposed lava flow of 1955. The undisturbed part of the flow consists of barren aa, covered by a dense growth of lichens, with scattered ferns and ohia lehua. Further off, around Lava Tree State Park approximately three-quarters mile to the west, there are areas of forest, consisting primarily of ohia, the size of the trees

* Research on this section was done by Barbara A. Siegel and Sanford M. Siegel, assisted by Thomas Speitel and the following students: Willie Cade, Melvin Calvan, Anne LaRosa, Kapuanani Lee and Hope Stevens.

being related to the age of the underlying lava flow. Hence, most trees are small to medium height, but there are infrequent kipukas (islands of growth on land not subject to recent volcanism), in which some trees reach up to 100 feet. The groundcover around the ohia trees consists largely of false staghorn ferns, grasses and several species of wild orchids. Around the larger trees are some treeferns and ieie vines (Freycinetia arborea). All these endemic species are common to areas of Hawaii covered by lava flows of no great age.

In locations disturbed by roads, footpaths, trails and bulldozer tracks, however, there is a heavy admixture of introduced trees, shrubs, vines and grasses. Such exotic flora are found, for example, in the vicinity of Lava Tree State Park and in many areas downslope from the well site. This exotic plant population includes mango trees, papayas, guava, bamboo, kukui trees (Aleurites moluccana), sugar cane, bananas, Indian pluchea, Jamaica vervain, and sensitive plant (Mimosa pudica). A stand of Norfolk pines, already noted, rises between the well site and the Park, and there are groves of albizia along the road and at the Park.

It is impossible to make an absolute determination as to the absence of endangered and threatened species of plants within any area of appreciable size around the drillsite. However, in the process of making baseline studies of possible geotoxicants sometimes associated with geothermal activity quadrat and transect analyses were carried out in

May 1975 and re-examined in January 1976 at the drillsite.[4/] The genera of plants found at the site, identified in consultation with Dr. Darrel Herbst, then of the Department of Botany, are listed in Table 6.

Comparing Table 6 with the most relevant list of known endangered genera and their familial associations -- a tally of families, genera and species prepared by Charles Lamoureaux, Professor and Chairman, Department of Botany for adjacent Hawaii Volcanoes National Park -- and with the comprehensive list of endangered, threatened and extinct species presented by the Secretary of the Smithsonian Institution to the Congress of the United States as House Document N. 94-51, 15 December 1974, we conclude that endangered and threatened species of plants, if present at all at the HGP drill site, are extremely infrequent. Thus, the probability that drill site operations will create this type of biohazard is deemed to be minimal.

With respect to the more general question of hazards to vegetation, it should be noted (1) that toxic emissions resulting from future drill site operations are not likely to differ from those normal to natural vents and magmatic outgassing in Hawaii, and (2) that natural populations established by post-eruption colonization in areas of recent or current vulcanism are likely to be more resistant to toxic geothermal emissions than would be the case in non-volcanic mainland locations.

4/ The mode of analysis is described in an earlier report of the Hawaii Geothermal Project, Environmental Baseline Study for Geothermal Development in Puna, Hawaii (Honolulu, September 1976).

TABLE 6

GENERA OF PLANTS IDENTIFIED IN AND AROUND HGP-PUNA

Drillsite May 1975-Jan. 1976

Ageratum
Andropogon
Arundina
Asclepias
Brachiaria
Carex
Cassia
Castilleja
Cuphea
Cyperus
Desmodium
Dicranopteris
Emilia
Erichtites
Erigeron
Lantana
Lycopodium
Melastoma
Melinis
Metrisideros
Nephrolepis
Pluchea
Pteridium
Rhychospora
Rubus
Saccolepis
Spathoglottis
Sphenomaris
Stachytarpheta
Tritenia
Vernonia

(ii) Animals, particularly birds

The region of Puna around the geothermal well site, limited as it is in natural food sources for mammals, is not rich in fauna. The sugarcane fields to the west and the papaya farms to the east of the site support the rats (Polynesian and Norway) which are found on all eight main islands of Hawaii. The mongoose is also well established locally. On the slopes of the mountains of the Big Island deer and feral goats are at once quarry for hunters and problems for those who would preserve the ecosystem, but they do not come to this section of Puna.

The only valued animals which might be disturbed or conceivably threatened by geothermal development in the District are birds. There are on the Island of Hawaii several species of indigenous or endangered species, and it was necessary to study the area around the well site to ensure that none of these species were adversely affected by the geothermal exploration. Consequently, the environmental assessment was limited to birdlife which might feed or breed in the area of Puna near the well site.*

Field observations in February 1976 were concentrated on looking for the two species of endemic land birds which might be expected at the low elevation (approximately 400 feet above sea level) of the drill site. These are the Hawaiian Hawk (Buteo solitarius), which is classified as

* The assessment was made by Andrew J. Berger, Chairman of the Zoology Department, University of Hawaii at Manoa.

"rare and endangered" by the U. S. Department of the Interior and the State Department of Land and Natural Resources, and the Hawaiian Short-eared Owl, or Pueo (Asio flammeus sandwichensis). No evidence of either was found -- perhaps because most of the native vegetation in the area has been replaced by exotic plants -- but of course it is possible that at times both species may occur in the general area. The hawk, in particular, is a wide-ranging species. This, however, is speculative, since no evidence was found.

Nor is the area heavily populated with introduced birds. During the survey, only seven species were observed:

1. Spotted Dove (Streptopelia c. chinensis)
2. Melodius Laughing-thrush (Garrulax canorus)
3. Japanese White-eye (Zosterops j. japonica)
4. Common Myna (Acridotheres t. tristis)
5. House Finch (Carpodacus mexicanus frontalis)
6. Spotted Munia (Ricebird) (Lonchura punctulata)
7. Cardinal (Cardinalis cardinalis)

It is the considered opinion of the ornithologist who studied the area that the activities at the geothermal well drilling site have had no adverse effect on any bird species inhabiting the area. Even an adverse effect on some of the introduced birds would not necessarily be detrimental, since some of these species, as the House Finch and Spotted Munia, have been highly pestiferous in destroying crops on Hawaii, but no impact on any species was discerned.

In summary, with no evidence or past records of rare and endangered species inhabiting the area, and no indication of adverse effects on introduced species, we conclude that any impact of geothermal drilling on the limited birdlife of the area adjacent to the site has not been significant. A judgment concerning the impact of geothermal development which might occur in other portions of Puna would of course require a localized study.

E. Archaeological Sites*

Puna has played a relatively insignificant role in the political history of Hawaii. During all of its known history, the District has produced no great family or chief whose support was crucial for control over land contested by warring factions. Why it was that Puna never developed a political power base -- for lack of population or inadequate food sources to support a sufficiently strong army -- is not clear, but it is evident that in Polynesian times control over Puna was wielded by the bordering districts of Hilo and Ka'u.

Consequently, there are relatively few archaeological sites in Puna, say in comparison with the Kona coast or the northwest corner of the Island of Hawaii, and there is no major site of archaeological research in the District. What few sites there are are mostly along the coast, some distance from likely areas of geothermal development, which are along the rift zones inland.

* Research on this section was done by William Bonk, Professor of Anthropology at the Hilo Campus of the University of Hawaii.

The sole archaeological site complex in Puna is Kahuwaii Village at Makaukiu, above Cape Kumukahi, which is the easternmost projection of the Island. Around the cape to the south, near Isaac Hale Park, is Mahinaakaka heiau, in relatively good condition, except for the sea erosion of its eastern wall. Another ten miles down the coast are two additional heiaus and adjacent sites with petroglyphs, at Apua and Wahaula-Puuloa.

More petroglyphs are found near Kapoho, about three miles inland from Cape Kumukahi, and almost four miles from the exploratory geothermal well. These figures are unusual in that they are cut into the face of larger upright basaltic slabs, instead of the usual flat pahoehoe, and exhibit an "ear plug" seen at only a few other sites in Hawaii.

In the same general area, approximately two miles north of Kapoho, are the ruins of Kukii Heiau, repeatedly robbed of its stone -- for the building of the foundation walls of Iolani Palace in Honolulu in 1879, again for Queen Kapiolani's residence, and more recently for other construction.

With the exception of the petroglyphs at the Kapoho dome, none of the archaeological sites of Puna seem to be in the path of likely geothermal development in the District. If the Kapoho area is planned or authorized for development, protection of these petroglyphs should be assured before the development begins.[5/]

5/ A brief description of sites in Puna is appended to the Environmental Baseline Study for Geothermal Development in Puna, Hawaii (Hawaii Geothermal Project, University of Hawaii, September 1976).

F. Aesthetic Considerations

Three qualities of developed geothermal fields must be considered for their impact on the aesthetic conditions of a geothermal area: they are rather noisy, they may emit sulfurous fumes, and they are likely to be covered with large structures. The noise caused by the escape of steam under pressure can be considerable, enough to make conversation difficult within a hundred yards downwind of a producing well, enough to be a nuisance to persons living within about a half-mile of the well -- unless the sound is adequately muffled. With appropriate muffling devices, the sound level can be held down to tolerable levels, the tolerability being understood as a function of the number of persons affected as well as a function of decibels. For example, there is only one house within a half-mile of the present exploratory well site. If, by way of hypothesis, production from that well could be muffled to reduce the noise to reasonable levels specified under the environmental protection laws only by installing devices which would also greatly reduce the effective output of that well, it may be socially rational to compensate that one household by buying its home, and so allow the well to function efficiently. (This is hypothetical. Silencers constructed at the experimental well, costing $40,000 have reduced the noise level 100 feet from the well from approximately 200 to 100 decibels without great loss of pressure.)

In any case, the noise levels of wells in any future geothermal field in Hawaii must be considered before development takes place, both for individual wells and, cumulatively, for a field. Given the expanse of little-

used land in Puna, and developing technologies for muffling the noise, there should be a good possibility for solving the noise problem in an environmentally acceptible manner.

The consideration of proximity to population also applies to the sulfur smells which may be released with geothermal waters. The experimental well is notably un-smelly, and if that happy condition generally occurs as other wells are drilled, the problem may be minor -- no worse, for example, than the slight "rotten egg" odor encountered near fumeroles in the Volcanoes National Park. However, the possibility of bad smells as well as loud noises must be addressed in proposals for developing specific areas.

Questions of aesthetic appearance arise because productive geothermal fields must have a network of steam-collecting pipes to supply the power plant, must have the power plant itself, and may well require a set of cooling towers at the plant to enhance the efficiency of operation. (Under a vapor-turbine cycle mode of production, large cooling towers may not be required, and less noise-abatement equipment may be needed, but this technology may not be feasible for Hawaii's geothermal resource, or at least not in the near future.)

The pipes and generating station need not be conspicuous in the rather wild landscape of Puna. They can be kept low and painted to blend with the dark grey of lava lands and the green of the ground cover. Greater difficulty will be encountered with tall cooling towers, if they are required. One possible solution would be to construct sta-

tion and towers within pu'us (volcanic cones) in the field. This would serve not only to limit the visibility of the installations but also to provide a natural, if incomplete, wall of lava against future lava flows. Each area would have its own problems and opportunities with respect to the appearance of the geothermal field, which would have to be considered in the planning and environmental impact statement for that field.

G. Summary

Consideration of the area of the Puna District immediately adjacent to (within a radius of two miles from) the site of the exploratory geothermal well indicates that there is little likelihood of environmental threat to the area from geothermal production at that site. Neither human habitations nor economic crops would be endangered; there are no archaeological remains nearby; no rare or endangered species of either fauna or flora were discovered. Nor were any dangerous levels of toxidity found in tests of air, water or soil after the well was completed and tested. The one possible exception was the level of mercury in the air, which is relatively high in thermal areas -- such as the Volcanoes National Park, upwind of the drill site. This level must be monitored throughout geothermal development to make certain that cautionary thresholds are not exceeded.

To generalize from observations made for the drill site area to all of the Puna District, it seems readily possible to find other tracts within the District where environmental circumstances are also favorable for geothermal activities, i.e. where there are few houses, little land in

crops which may be affected, no archaeological sites, no evidence of rare or endangered species of either plants or animals, no potable ground water supply to be concerned about. The latter factor should be stressed. Geological evidence yielded by the experimental well suggests there may be no Ghyben-Herzberg fresh water lens near the well site. If that is generally true for potential geothermal areas along the rift zone which transverses Puna, it would remove from the list of environmental concerns one of the most consequential questions: would geothermal development threaten a fresh water supply? In fact, the results at the well raise the possibility of producing fresh water as a by-product of geothermal production.

Of course, the ground water system at any proposed drill site should be carefully considered before extensive drilling is undertaken to guard against possible damage, since local situations may vary considerably. It may be a long while before dependable generalizations can be made about ground water conditions along the rift zone of Puna.

3. SOCIOECONOMIC CONDITIONS

A. Population

Population size of the Puna District in this second half of the twentieth century has roughly paralleled demographic changes of the entire County of Hawaii -- declining during the 1950's, remaining essentially stable in the '60's, then rising in the 70's so that the estimated 1976 level is somewhat above the population totals reported in the mid-century Census. Projections for future changes are positive, both for the County and for the District.

TABLE 7

POPULATION TRENDS: HAWAII COUNTY, SOUTH HILO AND PUNA

1920-1990

Year [1/]	Hawaii County	South Hilo	Puna District
1920	64,895	23,828	7,282
1930	73,325	29,572	8,284
1940	73,276	32,588	7,733
1950	68,350	34,448	6,747
1960	61,332	31,553	5,030
1970	63,468	33,915	5,154
1975	73,000	38,000	7,900
	Estimates [2/]		
1980	84-99,000	35-47,000	5,500-10,000
1990	115-137,000	37-55,000	8,400-13,000

1/ As of January 1 for 1920, April for (Censuses of) 1930-1970, July 1 for 1975; unspecified for projected estimates.

2/ Range is that established by three series of projections: one made by Department of Planning and Economic Development, State of Hawaii in 1975, another by Belt, Colline and Associates, Honolulu, in 1973, and a third by Daly and Associates, Honolulu, in mid-1976. The minima shown for 1980 and 1990 are obviously too low, barring some catastrophe.

The reduction in population for Puna -- as for Hawaii County as a whole -- between 1940 and 1960, is at least partly attributable to the mechanization of sugar plantations, for long the chief employer on the Island and in the Puna District. South Hilo District, which demographically approximates the City of Hilo, showed a growth over most of this period, to include over half of the total Island population by 1970, a factor of significance to Puna, as will be noted more fully below, since the District increasingly came to serve as a "bedroom" area for persons working in the city.

The lower end of the range of estimates of future population shown in Table 7 appear to be too low, at least for Hilo and Puna. They might prove to be true if the current depression of the sugar industry were to cause more layoffs, and if tourism and other industries which have been replacing sugar in the Island's economy were to level off or drop, but at this writing that basis of forecasting seems unduly pessimistic. And even if there were to be a levelling off or decline in economic activity in the eastern end of the Island, the demographic response may lag, i.e. people who prefer to live in the area will persist in seeking jobs there until personal savings, unemployment compensation, welfare payments and other sources of consumption maintenance having become inadequate, they would move away.

A more likely, and for planning purposes more prudent, assumption is that the growth of population experienced in the Puna District during the first half of this decade will continue into the next several years, though perhaps at a decreased rate. A rise from the approximately 8,000 population

now in the District to some 12,000 by 1990, as projected by Daly and Associates in a current study for the County of Hawaii, seems to be a reasonable expectation. If the still empty subdivisions of Puna should begin to fill up with residents -- and that may be a function of national and even international conditions, quite as much as what is happening in the local economy -- this projected level would almost certainly be attained, and could well be exceeded. Economic contraction on the Big Island combined with a continued slow rate of construction on the extensive subdivisions south of Hilo could keep the population actually living in Puna below the projected totals. On balance, projections of 10,000 for 1980 and 12,000 for 1990 are acceptible for appraising the circumstances and needs of the District over the next two decades.

During the last six years, a disapportionately large part of the population growth in Puna has occurred in the age bracket where people are most likely to be in the labor market, from ages 22 through 44. This economically significant demographic development is shown in Table 8, which is derived from data collected by Daly and Associates for a Puna Development Plan.

The changing pattern of age distribution has obvious significance for infrastructure needs of the District, to be discussed below as they relate to geothermal development. The under-22 portion of the population particularly relates to projected demand for schools and play spaces, those between 22 and 64 for roads and police protection, those over 64 for public health services, recreation and mass transit facilities.

TABLE 8

POPULATION OF PUNA DISTRICT BY AGE GROUP

1970 and 1976

AGE GROUP	1970 (Actual) No.	Percentage of Total	1976 (Estimated) No.	Percentage of Total
Under 22 years	1,961	38.0	3,060	37.2
22-44 years	1,206	23.4	2,227	27.0
45-64 years	1,314	25.5	1,902	23.1
65 and over	673	13.1	1,042	12.7
TOTAL	5,154	100.0	8,231	100.0

Sources: For 1970, U.S. Bureau of the Census, 1970 Census of Population and Housing: Census Tracts; Data Book, 1975, Department of Research and Development, County of Hawaii, p. 10; Department of Planning and Economic Development, State of Hawaii, Community Profiles, County of Hawaii, 1975. For 1976, unpublished data in Office of Economic Opportunity, County of Hawaii, extracted by Daly and Associates.

B. Housing

Judging from the limited data available, the quantity of housing available in Puna is relatively adequate. The basis of this observation is an interdistrict comparison made by the Department of Research and Development of the County of Hawaii, shown in Table 9, which indicates that the ratio of population-to-housing units in Puna was second lowest among the nine districts of the Big Island and well below the county average.

TABLE 9

HOUSING UNITS AND POPULATION-TO-HOUSING UNIT RATIOS

COUNTY OF HAWAII, BY DISTRICT

1969, 1971 and 1973

District	Housing Units as of: July 1969	December 1971	July 1973	Ratio of Population to Housing Units: July 1973
PUNA	1,777	2,049	2,561	2.42
South Hilo	9,654	10,925	12,218	3.15
North Hilo	590	539	543	2.83
Hamakua	1,510	1,575	1,597	2.85
North Kohala	952	970	982	3.10
South Kohala	849	947	1,138	2.48
North Kona	1,764	2,727	3,144	2.07
South Kona	1,041	1,134	1,164	3.09
Ka'u	1,046	1,100	1,171	2.97
County Totals	19,183	21,966	24,518	2.86

Source: Data Book 1975, County of Hawaii Department of Research and Development (Hilo, Hawaii, 1975), Table 74, p. 69.

Since mid-1973, some 300 additional units, net of those razed or otherwise removed from the supply, have been constructed in Puna, bringing the mid-1976 inventory of housing units in the district to approximately 2,900.[1/] This rate of increase in housing is greater than the growth rate in the District's population, so the ratio shown in Table 9 is even more favorable now.

And, if recency of construction is a reliable indicator of quality, the level average quality should also be rising in Puna. Over one-third of the units are less than six years old; about half are less than 16 years old. Only about 5 per cent are judged to be in poor condition structurally and over 97 per cent have complete plumbing and kitchen facilities.[2/] By way of comparison, the 1970 U.S. Census of Housing concluded that 5.6 per cent of all housing units in this state then lacked some or all plumbing equipment.[3/]

The supply of housing, then, seems reasonably adequate for the near term -- enough to support any modest increase in population which might accompany a limited economic expansion of the District, as a small geo-

1/ Based on unpublished data in files of Hawaii County Department of Planning.

2/ According to yet unpublished study of the Puna Development Plan prepared by Daly and Associates for the County of Hawaii. Extensive housing data is presented in this study.

3/ U.S. Census of Housing: 1970, Final Report HC (1) A13, reported in State of Hawaii Data Book: 1975 (Department of Planning and Economic Development), Table 271.

thermal development. Since an even larger supply of housing lies in Hilo and along the roads connecting the county capital with Puna, all within a commuting range of less than one hour, it is difficult to see any likely constriction on geothermal development which housing supply would impose.

However, the social support structure needed to serve an increasing population may present different demands, even if the supply of housing itself continues to be adequate. Housing areas must be served by connecting roads and perhaps public transportation; by water supply and sewage disposal systems; police, fire and public health facilities; schools and libraries; and other infrastructure which is most efficiently -- or at least customarily -- supplied by government. These are examined next.

C. Infrastructure

Public investment in the Puna District, as measured against the amenities taken for granted in more urban areas, cannot be said to be large. Within the District, rather immediately available to the Puna population of some 8,000 persons, are the following public facilities:

1. Water supply. Only around the more built-up areas in Kea'au and Pahoa, and in the beach area around Kaimu does the Hawaii County system provide a public supply. The distribution line serving the Pahoa community presently ends about a quarter mile from the geothermal drill site, and would have to be extended to serve the extensive housing subdivisions nearby, when houses are constructed.

2. Sewage disposal. There is no public sewage disposal or treatment facility in Puna. Residences and other habitations must provide their own septic tanks, or other methods of disposal.

3. Roads and highways. There are approximately 168 miles of county roads in Puna, most of the mileage being along Highway 11, which connects Kea'au at the northern end of the District with the Hawaii Volcanoes National Park, along Highway 13, which comes down from Kea'au to Pahoa in the center of the District and then continues to the black sand beaches on the southern coast of Puna, and along Highway 132, which goes from Pahoa, past the site of the geothermal project, through the papaya-growing area near Kapoho and then to Cape Kumukahi, the easternmost point of the Big Island. The coastal road, Number 137, damaged by an earthquake in 1975, connects with the scenic Chain of Craters road winding up to the Volcanoes National Park, but travel along that touristically important route is interdicted by recent lava flows which cover about 10 miles of the highway.

The quality of the Puna roads varies considerably. Highways 11 and 13 are generally broad and well-paved, while Highway 132 is neither in places -- for example in the area immediately bordering the geothermal drill site, where the highway is broken by an unpaved stretch of road.

4. Public transportation. Along with other readily accessible areas of the Big Island, Puna is served by a public bus system, based in Hilo, which provides twice-daily service -- once in the morning and once in the

afternoon. There are no local taxis, shuttles or U-drive companies; these are concentrated in Hilo and its airport.

5. Police and fire stations. Within Puna District, there are two fire stations (at Kea'au and Pahoa) and a single police station (at Kea'au). Emergencies have to be serviced from Hilo.

6. Public Health facilities. There are no hospitals or clinics in Puna District. The nearest hospitals are in Hilo, less than an hour's drive from most communities in the District.

7. Schools and libraries. There are four public, no private, schools in Puna: an elementary school at Keakealani, elementary-and-intermediate schools at Kea'au and Mountain View, and a kindergarten-through-high school at Pahoa, which is relatively central in the District. The single public library in Puna is also at Pahoa.

8. Recreational areas and facilities. The one category of public facilities with which Puna is well endowed is natural recreational areas. The Hawaiian Volcanoes National Park is readily available for anyone who has a car, or a friend with a car. So are the beach parks: Harry K. Brown, Isaac Hale, McKenzie, Kaimu Beach, the area around Queen's Bath. Tour buses may be noisesome at the black sand beaches of Kaimu and Kalapana, but seldom stop at the other beach parks. Less than a mile from the geothermal drill site is Lava Tree State Park, also not much disturbed by tourism.

In the population centers, there are five ball parks or general public parks, playgrounds at the Kea'au and Pahoa schools, and two gymnasiums open to the public. The one moviehouse in Puna is at Pahoa. An

hour's drive to Hilo brings the motor-borne to all the recreational areas and fleshpots of the county capital.

Conclusion. It would appear that any large increase in population for the Puna District would require expansion of the public water supply and provision of a sewage disposal system, if the increase were concentrated in urban-like neighborhoods, rather than spread out in detached farm areas. The big uncertainty in the development of the District is whether the presently demarcated but empty subdivisions will be constructed on, or remain vacant. Geothermal development would relate to this question, but, for reasons to be stated below, would seem to be of a second order of importance in determining the amount of population growth and, hence, the need for a public water and sewage system.

The pattern of growth, in an area as large as Puna, will obviously be of importance in determining the need for additional infrastructure investments. Should that growth center near Pahoa and Kea'au, the population may perhaps be served at a level of service acceptible to them by the existing schools, fire and police stations, the parks and playgrounds. And it is in this central area of Puna, along the rift zone, where geothermal development is most likely to occur. However, should areas zoned for subdivisions, but unimproved for want of a sufficient demand for these residential lots, be rezoned and developed for geothermally-related purposes, and should population growth move to areas more remote from Pahoa and Kea'au, there may be created a need for more social infrastructure investment, possibly including schools, playgrounds,

libraries, fire and police stations, and access roads for the new housing areas. In any case, it would seem that a larger population in Puna would require some local health facilities for at least emergency care before patients are transported to Hilo.

To quantify, however approximately, the cost of providing additional facilities for a Puna population increased by local economic development, greater specificity is necessary concerning the location, timing, and use of geothermal development within the District. That specificity would be necessary for any proposal to tap and exploit the indicated geothermal resources of the District and could then provide a factual basis for estimating infrastructure investment attendant on the success of the project.

D. Economic circumstances; jobs.

i. Sugar Historically, sugar has been the principal source of income in the Puna District. There are approximately 15,000 acres planted to sugarcane in Puna, producing between 50 and 60 tons of sugar annually, or about one eighth of total sugar production on the Island of Hawaii. Acreage has not greatly changed in recent years, but mechanization of the plantation, here as throughout the state, greatly reduced employment in the local sugar industry -- from almost 2,000 in 1940 to some 500 in 1960. Since that time, sugar employment in Puna has remained more or less stable, currently standing at about 500, including jobs in the Puna Sugar Company mill as well as in field operations.

Profitibility of sugar operations has varied enormously in the past two years, with a temporary boom in sugar prices on the U.S. and world

markets in 1973-75 being followed by a precipitous drop in 1975-76. At this moment there is great uncertainty concerning the long-run prospects for sugar production throughout Hawaii unless the U.S. price is again pushed upward by high tariffs, import quotas or other protective legislation.

ii. Papaya During the past decade other categories of agricultural output have become economically significant on Hawaii and particularly in Puna. The largest element of diversified agriculture locally is the growing of papayas for markets on the mainland and abroad, as well as in the state. Almost 90 per cent of total papaya production in the state comes from Puna. According to data of the Hawaii State Department of Agriculture, between 1970 and 1976, the area planted to papayas in Puna increased from some 1,000 acres to approximately 1,800 acres, the value of papayas from this area which were sold rose from $2.1 million in 1970 to $4.9 million in 1975. When that value is compared with the annual gross value of the Puna sugar crop (as unprocessed cane) -- which ranged from about $5 million in 1970 to some $24 million in the unprecedented boom year of 1974 but now again approximates the 1970 level -- it will be seen that papayas will challenge the primacy of sugar production in Puna unless sugar prices are reflated by action of the federal government.

Patterns of employment in papaya are quite different from those in sugar. Due to mechanization and unionization, sugar employment is quite stable, with little seasonality and little turnover in jobs. The new

papaya "industry", on the contrary, employs almost as many seasonal (late spring, early summer) workers as it does full-time, year-round workers. In this past year there were approximately 500 persons employed in papaya growing, harvesting and processing in the Puna District, about the same total as for sugar, but representing only about half as many man-hours.

Despite some difficulty in retaining workers, many of whom are not unionized, and problems of getting dependable airline scheduling from Hilo to the West Coast and mid-continental markets, papaya production in Puna has been profitable and acreage planted to papaya is expected to continue increasing.

How closely employment will follow an upward trend in planting is questionable. Production methods, not only in cultivation and harvesting but also in processing for out-of-state markets, are emphatically subject to change. An interesting case in point is the effect of selling under a Federal Marketing Order, promulgated at the request of Hawaii papaya farmers to ensure quality control in the interest of higher prices on Mainland markets. Under this Order, only "Hawaii No. 1" quality may be sold on commercial markets, in Hawaii as well as on the Mainland. Consequently, labor-costly grading and sorting must be done; consequently, a large amount of papayas which are sweet and good, but fail to meet Hawaii No. 1 standards of appearance, are left to rot or are fed to the pigs. One adjustment to reduce this waste would be to establish a lower standard for intrastate sales. Another would be to find alternative uses

for the culls, as in the preparation of papain (a meat tenderizer), or for processing into jams, jellies, juices, either straight or mixed with other fruits. This possibility will be examined below.

iii. Other agriculture. The production of macadamia nuts, marketing guavas and raising antherium and orchids are also of economic significance in the Puna District. Great expectations for profits from macadamia nuts have been only modestly realized, at least in Puna where the sales value of this high-priced delicacy fell from $1.7 million in 1970 to $0.8 million in 1973, according to the Hawaii State Department of Agriculture. There followed a recovery in the following years to regain the million dollar level, but market resistance to higher prices, increased foreign competition and continued problems in the now-mechanized harvesting process raise questions concerning further expansion of production and jobs in this specialty area. Peak season employment in Puna by C. Brewer and Co., based in Kea'au, is somewhat under 300, with even a greater seasonality of work than for papaya.

Guava production, highly touted for the Big Island in the 1950's, has gained a modest base in Puna, where approximately 75 acres are cultivated for this tropical fruit, most of it to be processed into juice or preserves for bottling, canning or freezing. With improved efficiency in production and market promotion, an expansion of this base of operations may well be realized,[4/] but the impact on employment in Puna would

4/ For one aspect of potential development, see Scott, F. S. and Shorake, R., Economic Analysis of the Market for Guava Nectar, Hawaii Agricultural Experiment Station, University of Hawaii (Research Report 230, 1974).

be quite limited. A small number of self-employed persons work the orchards year-round and on a part-time basis; harvesting is done mostly by students and other casual workers. Establishment of a processing plant, should the level of production in Puna justify one commercially, would establish a few year-round and several seasonal jobs.

Oranges and other citrus fruit have been planted in Puna for commercial marketing but the enterprise has not been successful, largely because the fruit doesn't match the cosmetic standards established by the fruit industry of California and Florida, but also because of the heavy seasonality of production and the non-availability of facilities for making and freezing juice. Many of the orchards are now out of cultivation.

More successful has been the cultivation in Puna of tropical plants for the commercial market, particularly antheriums and orchids. The proximity of the Hilo airport, which not only creates an immediate market in the local tourist trade but also ensures ready connection with markets in Honolulu and on the Mainland -- indeed, to Japan and many other parts of the world -- has greatly stimulated the demand for these horticultural specialities.

Puna now supplies well over half of the total commercial production of antheriums for the entire state, and approximately 90 per cent of Big Island production. Despite large increases in output -- an approximate trebling of sales between 1964 and 1974 -- the "industry" has remained essentially one of family enterprise with part-time employment of workers outside the family. In 1975, it was estimated that about 330 people were

employed in cultivating, picking, packing and wholesaling antheriums in Puna, with a projected growth of 20 to 30 jobs per year as the marketing of this flower retains its healthy growth.[5/]

Orchid cultivation for the market in Puna is in a much earlier stage of development than is growing antheriums. Several small orchid farms are in production in the District, but nurseries for more intensive and better controlled cultivation have been established only recently. These, like the antherium enterprises, are mostly family businesses, employing in all fewer than 50 people. Good growing conditions and a large potential market is expected to stimulate more production in Puna, but starting from such a small base the additions to employment and income to be derived from this activity must be expected to be small.

Table 10 presents a recent census of employment for Puna by industrial occupation. It is informative, but requires explanation to make it square with employment data presented above. Agricultural jobs, estimated for sugar, papaya, macadamia nuts, etc., would come to far more than the 718 shown in the table for "Agriculture". The table, using Census categories, puts jobs in sugar mills and food processing plants under its own rubrics, and so many of them in this instance may be under "Manufacturing", which helps explain the relatively large percentage under that classification.

5/ Estimates are by Daly and Associates, in preparing their Puna Community Development Plan (1976).

TABLE 10

EMPLOYMENT OF PUNA RESIDENTS, BY INDUSTRY

INDUSTRY	NUMBER	PERCENTAGE DISTRIBUTION
Agriculture	718*	24.9%
Fishing, Hunting	12	0.4
Construction	502	17.4
Manufacturing	309	10.7
Transportation, Communications, Utilities	228	7.9
Retail/Wholesale Trade	548	19.0
Finance, Insurance, Real Estate	101	3.5
Service (including government)	467	16.2
Total	2,885	100.0%

* May exclude some employment in sugar, papaya and macadamia nut processing.

Source: Office of Economic Opportunity Census Update, County of Hawaii (1976), unpublished, as reported by Daly and Associates in Puna Community Development Plan.

The table does clearly show that Puna includes many people who have urban-related employment, as in the stores, offices and schools of Pahoa and Kea'au, those who commute to jobs in the hotels and shopping centers of Hilo, or who work in the filling stations along the highway. The unexpectedly large percentages under "Construction" and "Transportation, Communication, Utilities" may reflect the employment of people who live in Puna but commute to jobs in Hilo and adjacent areas.

There is no category in Table 10 for tourism. If there were, the number of positions reported would be very small, for Puna is an area which tourists traverse but spend little money in. There are no hotels, car rental agencies or touristic restaurants in the District. Tour buses and individual motorists do come down from Hilo in some numbers to see the black sand beaches and the painted church near Kalapana-Kaimu on the coast of Puna, and sometimes they stop to see the steam rising from vents in the geothermal area (and currently to see the experimental geothermal well), but after looking around they head back to Hilo without having added to the gross product of Puna. How geothermal development may create an economic basis for tourism in Puna is a question we will return to in a later section of this report.

Unemployment

The desirability of creating a larger economic base in the District is indicated by the unemployment rate in Puna. As Table 11 indicates, that rate has been high -- above 12 per cent of the civilian labor force in the last quarter of 1974 -- both in absolute terms and also relative to other parts of the Big Island. The labor force, it appears, has been growing faster than work opportunities. How occupational skills within the local labor force would match with the demand for more jobs which might be created by geothermal development would have to be ascertained, but in gross one may observe that such development may be able to find a local supply for many positions which do not require unusual technical skills.

E. Summary

The Puna District is, by conventional American standards, relatively undeveloped. Within an hour's driving time from the capital and chief city of the county, and its international airport, Puna itself has only limited urban areas and urban facilities. Across much of its lava lands, housing subdivisions are laid out, but these yet contain few houses or construction crews. The chief sources of employment are agriculturally based, though many of its 8,000 population drive to jobs in Hilo.

There is a potential for development in the diverse agricultural activities of the District: papayas, guavas, macadamia nuts and tropical ornamental plants, as well as the historic mainstay of Puna's economy, sugarcane. The housing supply seems above average, both in quality and quantity, and should be able to accommodate the projected population increase at least for several years. Public services, however, will be

TABLE 11

UNEMPLOYMENT IN HAWAII COUNTY

by selected Census Tract combinations

Fourth Quarter 1974

	Hilo District (201-209)	Puna District (210-211)	West Hawaii (213-216)	Kohala (217-218)	Total Island (201-221)
Civilian labor force	17,770	2,720	4,540	2,890	32,420
Unemployed	1,360	330	490	240	2,610
Rate of unemployment	7.7%	12.2%	10.7%	8.1%	8.0%

Source: Department of Labor and Industrial Relations, reported in County of Hawaii, Data Book 1975 (Hilo, Department of Research and Development 1975), Table 37, p. 31.

strained by a continued increase in population, including the systems for delivering fresh water and removing wastes. There may well be a need for other infrastructure expenditures, as for schools, police and fire stations, a local health service facility, etc.

A significant geothermal development in Puna would affect, and be affected by, all these considerations. It might compete for land with some of the agricultural uses, though the areas most promising for drilling may be too active thermally for commercial agriculture. It would create jobs, both directly and indirectly, tending to relieve local unemployment, which has been high, and also attract people from other areas. Depending on the mode of geothermal development, it could diversify as well as enlarge the base for economic activity in Puna, as by stimulating tourism, now only a negligible source of income to the population of the District, and the establishment of new enterprises, a possibility to be examined in the next section.

4. ALTERNATIVE MODES OF GEOTHERMAL DEVELOPMENT

A. Single-use application: generating electricity

Hawaii, as a new area for geothermal development, can choose among different modes of development. The circumstances under which exploration of the potential resource has taken place -- the continuing "energy crisis" following the abrupt raising of oil prices in 1973-74 -- has concentrated attention on substituting indigenous geothermal energy for imported oil. Using geothermal steam to run electric generators instead of having to burn oil for power generation has been and continues to be the focus of intention, both nationally and in Hawaii.

There is ample precedent for a single-use development mode in the rather brief history of geothermal applications to industry and commerce. The wells of Lardarello, Italy, originally drilled in 1812 to extract borax from geothermal waters, have been used exclusively for electricity generation since 1909. The one large developed field in the United States, The Geysers in northern California, is exploited solely for producing megawatts of power; so is the other large field in North America, Cerro Prieto, in Baja California, Mexico.

In other parts of the world, however, geothermal resources have been used for a variety of purposes, and occasionally for more than one at a given field. Iceland has used the hot water for space heating since the 1930's. Recently, it has diversified the application to include geothermal greenhouses for cultivating fruits, vegetables and ornamental plants, the refining of diatomite (a mineral used in filters), and for

generating electricity. Freeze-drying fish has been done on an experimental scale, using geothermal heat in the refrigeration process.

Japan's hot springs, used for recreation and physical therapy from time immemorial, in recent decades have been put to other purposes: greenhouse cultivation, space-heating, raising alligators and other tropical animals, the recovery of salt and sulfur, as well as generating electricity. Multipurpose plants, producing power and minerals or fresh water as by-products, have been operated experimentally.

New Zealand has also made multiple use of its geothermal facilities. At Kawerau, on the North Island, the steam is used to produce newsprint, cure lumber and to generate electricity; at Rotorua, the wells heat homes and public buildings and also power a geothermal air-conditioning system in a hotel. In the Lake Taupo area, geothermal heat is used for many purposes, from steaming of raw garbage to be swill for feeding hogs, to sterilizing equipment and drying seeds and lumber.[1/]

The incentive to establish a multiple use of a geothermal resource rather than limiting its output to electrical power is obviously a function of the cost of developing a field, relative to the price of electricity at the site. If it is commercially feasible to depend entirely on sales of steam for power generation, simplicity of design,

1/ Useful compilations of geothermal applications are made by James B. Koenig in "Worldwide Status of Geothermal Resources Development", Chapter 2 in Geothermal Energy by Paul Kruger and Carel Otte (Stanford University Press, Stanford, California, 1973), and by Richard E. Peterson and Nabil El-Ramly in The Worldwide Electric and Nonelectric Geothermal Industry (University of Hawaii Geothermal Project, Honolulu, 1975).

financing and operation of the geothermal field may be decisive in setting a one-product mode of development, as at The Geysers. However, if development costs are so high as to make highly uncertain the profitibility of a single-purpose operation, multi-product modes may be considered.

Such may well be the case in Hawaii. Costs of drilling are considerably above those usually experienced on the mainland, not only because of a generally higher price level here but also because the volcanic substrata of Hawaii are more difficult to drill through than the rocks typically encountered in other geothermal areas. Even if the costs of drilling the two deep geothermal wells on the Island of Hawaii (one in 1972 and this well in 1976) were appropriately discounted to reflect that the wells were experimental and hence included many testing operations not to be expected in drilling for commercial purposes, the discounted prices would still remain above -- probably well above -- costs on the mainland U.S.

Drilling costs have been increasing so rapidly in the past several years that it is almost futile to reckon them, but it may be useful to consider the order of magnitude of outlay in developing a geothermal field of any significant size. Pioneer work in such estimation has been done by Bob Greider of Chevron Corporation. In a paper presented to the Second United Nations Symposium on the Development and Use of Geothermal Resources (San Francisco, 1975)[2/] he estimated that an efficient field

2/ "Status of Economics and Financing Geothermal Power Production", p. 2305.

development operation would locate, drill, test and connect production wells at an average of around $450,000 -- which is much less than half of just drilling the Hawaii experimental well. Translated to Hawaii conditions, a cost of $600,000 per well seems conservative. Assuming an average output per well of 4 MW,[3/] and the need to have one well to reinject the fluid into the earth for every four producing wells, it would require 10 wells to run a generating plant of 32 MW capacity -- about enough to supply the city of Hilo.

The cost of the drilling operation, at $600,000 per well, would approximate $6 million. Assuming the cost of the steam-collecting system and generating station at $400 per KW (Greider's estimate for the mainland is $392 and disregarding the relatively modest economies of scale affecting that estimate)[4/] our hypothetical 32 MW plant would cost about $13 million to construct. Totalling that outlay, drilling costs, and allowing $6 million for transmission lines, interest, organizational and other expenses during the five-year period estimated to construct the field and station, a total cost of $25 million can be approximated.

3/ This approximates the estimated capacity of the exploratory well at Puna.

4/ Estimates made by Dow Chemical Company in 1974, cited by Greider, show declining average costs for generating plants up to 80 MW. Calculations by C. H. Bloomster in 1975 project declining capital costs per unit of output for plant capacity up to 250 MW, while average operating costs decline up to a size of approximately 100 MW and then become essentially constant. An Economic Model for Geothermal Cost Analysis (Battelle, Pacific Northwest Laboratories, 1975). pp. 15-16. Tod Larson, in a paper on "Capital Costs of Geothermal Development" issued March 18, 1976 by the Dry Lands Research Institute of the University of California, Riverside, suggests that Greider's estimate of generating plant costs may be high, but use of a lower figure he points to would not much affect our order-of-magnitude estimate.

Investments of this magnitude in a new power source may be commercially justified in the future, if the price of oil continues to rise and if sugar production (the bagasse from which now constitutes a significant fuel supply for generating electricity on the Big Island) should decline. Low-interest loans, made or guaranteed by the national Energy Research and Development Administration, would make such investments the more likely.

However, the size of investment as well as the risk of drilling dry holes may slow down the rate of geothermal development on the Island of Hawaii. Without special inducement, the local electric company might well be inclined to construct geothermally-powered generating capacity only as required to meet local demands, or to replace existing plants as they become over-age. Unless there occurs a technological breakthrough, as the invention of a hydrogen economy capable of exporting energy from the Island of Hawaii to Honolulu and other commercial/industrial centers, the development of geothermal resources on the Big Island is likely to be slow -- if application is limited to the generation of electricity. It could be a useful development, reducing somewhat the State's utter dependence on imported oil, creating a few permanent jobs, perhaps holding down electric rates, but nevertheless very limited in its socioeconomic impact.

B. Multiple uses of geothermal resources

A more rapid and significant development of Hawaii's geothermal resources would seem to require an application broader than, though encompassing, the production of electric power. If these resources can

be put to multiple uses, each application can bear part of the development expenses, bringing down the cost curve for all users, thereby stimulating larger output at lower price by each. At play is the familiar economic model of joint products, exemplified in their different ways by the stockyards (where steers are converted to leather, chemicals, bone meal and many other by-products, as well as sides of beef) and airports (where shops and restaurants help pay for the cost of the terminal building, whose central function is accommodating the arrival and departure of passengers and freight).

What joint products can be produced from geothermal resources on the Island of Hawaii, and particularly in the Puna District where the resource is now known to exist? The examples of other geothermal areas, cited at the beginning of this section, indicate the wide range of applications to which geothermal resources have been put. Mostly the applications are local in nature (the long, insulated pipeline bringing hot water into Reykjavik, Iceland is an exception) and energy-intensive, that is, they use a great quantity of geothermal fluid relative to product value. Some multiple-use production is centered around space-heating in cold climates (Iceland, New Zealand, Kamchatka) which is not much of a problem in Hawaii. What are the opportunities in this state, in Puna?

1. Processing tropical fruits.

By chance, the first Hawaii geothermal well site sits in the middle of the major area of papaya cultivation in the state. As noted in the preceding section, the still-young papaya industry is enjoying a

large measure of success and plantings continue to expand to supply a rising national demand for the fruit. However, the papaya growers are faced by two problems, to which a geothermal facility may give partial answers. One problem, already alluded to, is the huge quantity of culls selected out as substandard for marketing. In 1976, some 45 million pounds of the fruit grown in Puna, more than half of the total amount produced, were destroyed or fed to animals, virtually a complete loss economically.[5/] Much of the fruit kept off the market was perfectly edible, but not up to the size, shape or color required to be "Hawaii Standard A".

The second problem is one of transportation. Even with processing, papaya ripens and then softens in about a week or ten days after picking. Air shipments must be used to reach mainland U.S. and Japanese markets in good time for retail sales, and occasionally airline strikes or other tie-ups cut the transportation linkage between Hilo -- the export point for papayas -- and the outside world. That happened in 1975, and the local papaya industry took losses which were severe, since only a portion of the export crop could be sold in the state and the rest, all up to standard, had to be left to rot; there was no alternative use for the fresh fruit.

5/ In addition, a large quantity (approximately 20 million pounds) of unripened fruit is destroyed in bulldozing an orchard when it is prepared for new plantings of the short-lived trees.

That alternative could be a local processing industry which converts fresh fruit which cannot reach the market into nectar, frozen or dried chunks, jams and other preserves, or by-products (such as papain, used as meat tenderizer) which can be stored for long periods of time. The beginnings of a processing industry now exist in Hilo, in the form of one plant which makes jams and jellies and another which extracts the juice of papayas, guavas and other fruit.

There may be an opportunity for an expansion of this modest base into a local industry of some significance, using geothermal waters to process -- by cooking or freezing -- the fruit production already in the Puna District. As noted in the preceding section, this includes not only papaya and guavas, but also local oranges, which are not sufficiently attractive to be displayed in supermarkets because of their blotchy color, but which have an excellent flavor. Adding lilikoi, (passion fruit) which grows readily almost anywhere in Hawaii, and the delicate poha berry, which grows best in the nearby Volcano area, would provide a range of fruit flavors and textures to supply fruit-preserving facilities at the geothermal region of Puna. It might also prove to be advantageous to shift the papaya treatment plants which prepare the fresh fruit for market by immersion in 120^0 C. water (and/or chemical treatment) from Hilo to Puna, close to both the orchards and the geothermal water.

By creating an inexpensive source of heat for treating fresh fruit for export, for cooking it, freezing it, reducing it to juice or nectar,

for sterilizing the containers in which the processed fruit goes to market, while simultaneously providing electricity for this energy-intensive industry, a geothermal plant may make possible the growth of a significant fruit processing center in Puna. This development, in turn, could stimulate production of the tropical fruits, besides papaya, in which the District has a comparative advantage, thus reviving a dormant branch of Hawaiian horticulture.

ii. Wood processing; paper manufacture.

The growth of timber on the Island of Hawaii has attracted much interest over the past several decades and some investment in recent years. The Big Island, as befits its extensive area, has far and away the largest stands of potentially useable trees, both native and introduced species, in the state. Periodically, studies have been made of this potential -- for hardwoods to be used in construction and handicrafts, for softer woods to be made into press-board, cardboard or paper -- but only a limited commercial operation is actually underway. A Japanese firm is cutting eucalyptus in the area northwest of Hilo for export as woodchips, the processing to be done elsewhere.

With larger but similar resources, timber and geothermal water, New Zealand has done much more to promote its economic base. Lumber is cured geothermally, wood is processed, paper is manufactured -- all using the hot water of the Kawerau field after it has driven the generators of an electric station. Since the wood and paper industry is energy-intensive, the savings from the use of geothermal resources instead of oil or other imported fuel is significant.

iii. Geothermal Industrial Park.

A logical extension of the multiple use of a geothermal field, not yet attempted in any country, is to lay out in series several industrial or commercial applications of the resource. The series would begin with driving the turbines of an electrical generating station, which requires the greatest heat and pressure. The water, still at boiling, could then pass through insulated pipes to an industrial application, such as the drying of lumber or production of paper, and then perhaps to a fruit processing plant, a refrigerator and freezing plant -- and to such other uses as may be served by the now sub-boiling, but still hot, water. A side or end product could be potable water distilled from the geothermal fluid before it was reinjected into the geothermal reservoir.

An elaboration of an industrial park energized by a geothermal source would continue the series of uses to include such non-industrial applications as fish farming and raising prawns, where the warm water could support an intensive cultivation in brackish pools, or canning, chilling and freeze-drying locally grown foodstuffs (as Kona coffee or Parker Ranch beef). Should pessimistic views of the future of sugar cultivation in Hawaii prove to be correct, a large acreage of good-to-excellent agricultural land may become available on the Island of Hawaii for alternative uses. The existence of a geothermally powered food processing complex could provide the industrial base for a diversified agriculture to replace sugar.

The concept of a geothermal production complex, including a power station to generate electricity, some of which would be used within the complex and the remainder sold for use in the transmission grid serving the area outside, is intuitively attractive and may prove the most efficient model for geothermal development in Hawaii. However, one caution must be made. The more fluid and more calories taken from the geothermal flow as it is piped through a series of applications on the earth's surface, the less is available for reinjection into the geothermal reservoir. It is not yet known how dependent on reinjection reservoirs on Hawaii will be and, until such knowledge is gained, it cannot be taken for granted that the gains from multiple use of the resource will necessarily exceed the losses in reservoir life due to reduced reinjection.

iv. Heavy industry.

For economic potential, one of the more glamorous potential applications of a large-scale geothermal development in Hawaii is to use the energy to refine the metals encrusted in the manganese nodules said to be deposited below the ocean waters of this state and on the floor of the Pacific lying to the east of the Big Island. One assessment of this potential envisages a demand of approximately 500 employees for a single refinery, exclusive of support services.

A metallurgical industry utilizing manganese nodules would require substantial port facilities for the specially-designed ore ships, as well as a major geothermal generating plant, since a large refinery may take

up to 200 megawatts, almost double the entire capacity now serving the Island of Hawaii. These requirements, plus the environmental consequences of installing a large refining plant in an agricultural/residential area, may rule out bringing such heavy industry to Puna -- even if it should be commercially attractive, which can now be only conjectured. An island area already laid waste, such as Kahoolawe, might be a more appropriate site for refining manganese, nickel, cobalt and copper from these nodules, when they are mined from the adjacent sea.

v. Tourist attractions.

More compatible with present patterns of land use and living in Puna than a growth of heavy industry based on geothermal power, and less threatening to the environment, would be touristic applications of the new resource.

As mentioned before, the Puna District gets very little of tourist expenditures on Hawaii, since there are practically no commercial facilities for tourists in this corner of the Big Island -- no hotels, touristic restaurants, golf courses, U-drive agencies or other enterprises catering to visitors. If visitors want to see more of Puna than a quick swing-through by a tour bus out of Hilo affords, they have to make their own arrangements.

The example of Japan, from which many visitors to the Island of Hawaii come, shows that geothermal waters offer a potential touristic attraction for the Puna region. If the waters contain minerals thought

to be beneficial for various ailments (and this seems to be a wide range, judging from the many geothermal clinics in Europe, mainland United States,[6/] and Japan) the essential ingredient for establishing a spa would be present. Around a spa, inventive management could, as it has for many centuries and in many parts of the world, construct in Puna facilities to attract and accommodate visitors seeking health treatment with creature comforts.

Most spas have hotels for their guests near the thermal waters. That arrangement may not be practical for Puna, since the risk of lava flows may discourage construction of costly buildings. However, it may be feasible to provide cabanas for the day-time use of visitors to the geothermal spa, along with restaurants and other service facilities, while at night the visitors returned to their hotels in Hilo.

Skillful landscaping and design, including adequate muffling of discharge from the wells, might make it possible to combine operation of a spa with the generating of electricity and even a geothermal industrial park. Filters and chemical treatment of the thermal waters should be able to handle bacteriological and aesthetic problems of using the geothermal resource for many purposes, in series, subject to the constraint that the application needing highest temperatures and steam pressures (presumably electricity generation) would receive the flow first, out of the well, while applications using lower temperatures are made downstream.

6/ Recreational and therapeutic uses of geothermal waters in several hot springs areas in the western U.S. and in British Columbia are described by Professor Richard E. Peterson in "Nonelectric Geothermal", Geothermal Energy, Volume 4, Number 11, (November 1976), p. 8.

A geothermal station in Puna, even if limited to a demonstration plant, would itself be of some touristic significance. The drill site for the experimental well has already attracted tour buses and casual visitors, though no provision has been made for their reception. A geothermal production plant or a geothermal science facility could provide a modest base for local tourism enterprise, in getting visitors to and from the site, guiding and feeding them. By the experience of other islands -- Japan, New Zealand and Iceland -- tourists are interested in seeing, hearing and even smelling a geothermal field in operation. The touristic potential remains to be tapped in Hawaii.

It is, of course, possible for an unsightly development of geothermal resources, or one which diminishes or pollutes watercourses, to spoil the environment for tourism. On a limited scale, this has occurred in The Geysers and in New Zealand.[7/] Given the fact that there are no lakes or streams in Puna, the opportunities for such damage are limited, but any significant degradation to the environment, as from noise or odors, must be guarded against for the protection of local residents and visitor, alike.

C. Summary

Attention to the possible uses of geothermal resources in Hawaii has been centered on the generation of electricity. Substituting this new energy source for the burning of imported oil offers many advantages,

7/ See Stuart Wilson, "Possible Conflict Between the Interests of Tourism and Geothermal Power Development", Proceedings of the Second U.N. Symposium on the Development and Use of Geothermal Resources (San Francisco, 1975), p. 2457.

economically and environmentally. However, given the high cost of drilling wells in this state, it may not be commercially feasible to have this one use of geothermal energy pay for its development.

Therefore, this section has considered alternate, multiple use of geothermal resources, all drawn from the experience of other geothermal areas. At hand in Puna, near the rift zone where drilling is most likely to take place, is a supply of tropical fruits, much of which now goes to waste, which could be processed in a variety of ways by geothermal heat. Further off on the same island are other products -- wood, coffee, beef, fish -- which could also use the thermal waters, and help share the costs of bringing them to the surface. Other industrial applications, including the extraction of minerals from the geothermal resource, or from manganese nodules to be dredged from the nearby seabottom, may be made in tandem in a geothermal industrial park, but these uses may be more expensive in terms of their environmental impact.

Another joint use of geothermal water is in spas -- the chief application of this resource in Japan and Europe. Lacking as it does a base for profiting from its limited traffic in tourism, Puna might be a good location for a thermal spa. The very existence of a geothermal plant, to whatever use put, will attract some visitors and, given reasonable opportunity, they will spend money at this still novel kind of operation.

Cost/benefit calculations have been made for none of these potential applications of geothermal resources on the Island of Hawaii. Some of the suggested applications may turn out to be impractical; others, not

here considered, may be more useful. The purpose of listing specific applications, however hypothetical, is to attract attention to the basic idea of multiple use for the geothermal resources of Hawaii. Limited to any single use, even the generation of electric power on which attention has hitherto been focused almost exclusively, the development of the new resource may be too expensive for private industry to invest in or for government to subsidize. By spreading the costs of drilling among more than one use, however, geothermal development may prove to be not only feasible, but profitable.

5. SOCIAL BENEFITS AND COSTS OF GEOTHERMAL DEVELOPMENT

Any new power source can become the genie released from the bottle. Who could have written an adequate environmental impact statement about the first oil well in Pennsylvania, or about the first controlled use of nuclear energy behind the grandstand at Chicago's Stagg Field? And yet it is rational policy to demand that assessments be made of potential new departures, such as geothermal energy, so that human foresight can be directed, within its short range, to the maximimization of benefits from the projected development and to the avoidance of harm. Without attempting an environmental impact statement about the projected geothermal development on the Island of Hawaii, for there is not yet sufficient specificity about the project to make that statement, it is possible to array the benefits and costs likely to be experienced over the first decades of developing geothermal resources, as at Puna.

A. Potential Benefits[1/]

i. An Indigenous Energy Source.

Hawaii is the state of the Union most vulnerable to the recurrence of an oil crisis, such as that which temporarily sobered the nation in 1974-75, and to continued increases in the price of petroleum. Every other state either has its own energy supplies (Alaska) or is

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1/ The advantages to Hawaii of developing geothermal energy are examined at greater length by the author in "Geothermal Development Policy for an Isolated State: The Case of Hawaii" in Proceedings of the Second U.N. Symposium on the Development and Use of Geothermal Resources (San Francisco, 1975), p. 2383.

connected to a regional power grid which can be fed at many points with oil or alternative fuels. Non-contiguous Hawaii presently has neither its own fuel supplies nor connections to depend on, should the importation of oil into this state be halted or become too expensive.

More than any other state, therefore, Hawaii has reason to seek energy sources within its own boundaries, and currently, in different stages of advance, searches are underway for means of tapping a variety of indigenous power sources. These include solar energy, wind energy, ocean thermal energy, energy from biomass conversion, and geothermal energy. While solar energy is already used on a small scale for heating domestic water supplies, the utilization of geothermal energy offers the technology most advanced for supplying other energy needs (outside the sugar industry, where the burning of bagasse is an efficient means of generating power for the plantation mills and the communities around them).

An indigenous power source, such as geothermal, would substitute for oil, which continues to rise in price. The potential gain is not only in holding down costs, but also in reducing economic uncertainty. After the 1974 oil embargo by the OPEC nations, all large users of oil-fed energy must take into account the possibility that without notice their power may be cut off, reduced or drastically increased in cost. The possibility pervades the economic climate, reducing incentives to invest in energy-intensive enterprises, stimulating the construction of

oil-storage facilities and the substitution of less-energy-using methods for energy-intensive technology. These reactions may be patriotic and, given the uncertainty of supply, perfectly rational, but they do come at a cost. An indigenous energy source, if commercially feasible, could also reduce dependence on imported oil, and at a lower economic price.

ii. Economic Growth; More Jobs; More State Revenues.

In itself, geothermal power development need not be a sustaining source of either economic growth or job creation. Initially, as wells were being drilled and production facilities at the field were being built for a new geothermal facility, the construction industry would be stimulated. However, following the construction phase, if the only application of the geothermal resource were to be the generation of electricity, the economic significance of the development would be extremely limited. Since power stations are highly automated, only a few workers would be employed at the generating plant. They could benefit, and so could the owners and customers of Hawaiian Electric Light Company, but in all likelihood, the gains would be too small to be visible in the economy of the state.

More significant economic and employment effects would depend on the applications made of geothermal power. In the event that large amounts of electricity were generated, and at a cost considerably below that from burning fuel oil, it is possible that new enterprises in number would be attracted to the Big Island, and that existing enterprises might be expanded sufficiently to create many new jobs. Alternatively -- or

simultaneously -- firms which use geothermal water directly (such as fruit processing, wood and paper production and other applications suggested in the last section) might be clustered at the geothermal field, providing employment visibly connected with the new energy source.

Direct and indirect stimulation of employment would be particularly beneficial to Puna. As noted previously, unemployment rates in the District during the past few years have averaged about 10 per cent, among the highest in the state. Unless the prices and profitability of the local sugar industry are reflated, the shrinkage of the plantations may be suddenly accelerated and in Puna -- and generally on the Island of Hawaii -- that would threaten a major source of jobs and income. A diversification of agriculture and agriculturally-based industry, stimulated by geothermal development, may well be timely in the next decade.

Conceivably, the economic activity generated from geothermal development on the Island of Hawaii might benefit the public sector, as well as the private. In addition to royalties which the state would receive from its geothermal deposits, state and county tax revenues would be increased by a geothermal industry, as land values in and around geothermal fields rose, taxable buildings and other improvements were put into place, gross income stemming from the fields and from productive facilities powered by geothermal energy would be subject to the state's general excise and electricity sales to the public utility tax; profits and salaries from the geothermal "industry" would be taxed under Hawaii's

corporate and personal net income taxes. By the operation of the multiplier, income streams created by the geothermal industry would feed into the overall economy of the state, generating additional tax revenues with the re-spending of each geothermal dollar.

However, as a prospect for the 20th Century, net government income from geothermal development in Hawaii is highly unlikely. It is more probable that, at least for several years, the development of geothermal resources will require investment by the state government and its counties at a level which will exceed the tax revenues from this new source. Already, the State and County of Hawaii have granted $700,000 for the experimental well. Even if no additional financial support is given for drilling wells, it is likely that any significant economic development stimulated by geothermal exploitation will also stimulate outlays by the state or county governments. These may either be in direct support of geothermal utilization (such as access roads to the geothermal fields, harbor improvements to accommodate ships bringing manganese nodules to a geothermal refinery), or the infrastructure investment (water supply, waste removal systems) mentioned in Section 3 as being necessary to support development in the Puna District.

After geothermal development is well underway, the industry established and the infrastructure in place, the development should turn into a net revenue producer for the governments which have fostered it. That, however, is a long-term prospect.

iii. Decongestion of Population.

The creation of jobs in an expansion of the Big Island's economy powered by a new energy source could help implement the announced policy of the state administration to reduce the concentration of population in and around Honolulu. Despite the enunciation of this policy at the beginning of this decade, Oahu continues to hold more than four-fifths of the population of the state, with no viable program for reducing the congestion of the capital city.

It is unlikely that development of a geothermal resource in itself, unless the field were unexpectedly huge, would provide such massive employment as to cause the transfer of many people to the Big Island. And it may well be that the Big Island would not welcome a large in-migration. However, it is possible that a geothermal development would fuel a general economic growth -- in agriculture, industry and tourism -- which the authorities of Hawaii County would either welcome or be unable to control. How much of this hypothesized growth would be reckoned a plus for the Island of Hawaii is a question, but, should it occur, it would be an increase in the gross state product and, perhaps, would marginally reduce crowding on Oahu.

iv. Environmental Effects: Geothermal versus Other Energy Sources.

It is not likely that geothermal development would improve the physical environment. In Section 2, we concluded that drilling per se was not likely to have much impact, and that the environmental effects of building generating plants and other facilities to use the geothermal resource could be limited by muffling, landscaping, spacing, etc. Nevertheless, there may well be people in the community who would prefer to

leave Puna, and other potential development sites, unchanged, or not changed in this way.

Put to a referendum on the issue of geothermal development versus no change in the environment (and setting aside economic/job effects), the votes in opposition might well be a majority. However, that is probably not the choice which will confront the people of Hawaii. Given the strong probability that oil resources will become extremely scarce by the end of this century, it is most likely that some energy source will displace oil, or that only grades of oil with high sulfur content will be available at an affordable price.

If the alternatives available for Hawaii's future energy needs should be limited to what is now technically and economically feasible, the choice would be between more (and higher-sulfur) oil, coal, nuclear power, and geothermal energy. With these alternatives on the ballot, a rational choice on environmental grounds could well go to geothermal energy, which is much less polluting than coal or other hydrocarbons, and less dangerous than nuclear power. In this sense, as one of the least polluting power sources, geothermal resource development would be a positive factor for preserving the environmental quality of Hawaii.[2/]

2/ In the judgment of persons serving on the investigatory groups which prepared the report on Alternative Energy Sources for Hawaii for the State Advisory Task Force on Energy Policy (University of Hawaii and Department of Planning and Economic Development, 1975), geothermal energy was preferable with respect to environmental impact over land-based use of coal, specifically in their relative impact on water and air and in the discharge of solid wastes. An ocean-based coal power station or the burning of liquified coal rated slightly better than geothermal energy in the opinion of the three persons serving on the task force on the environment, while in the opinion of some 50 people who served on the alternative energy source task forces, geothermal power was preferable to coal, however utilized. (Op. cit., pp. K-3 and 4)

B. Potential costs and their minimization

The opportunity costs of using geothermal resources will probably be relatively low. The lands around the rift zones of Kilauea which seemingly overlay the hot water are frequently picturesque but seldom of much economic value. Only a small portion of these lands are in cultivation, and use of the terrain for housing is limited by many factors, not least of which is the tectonic activity of the area: it was subjected to a destructive earthquake as recently as November 1975. Lands utilized in a geothermal field within Puna are not likely to be taken from any highly productive alternative use.

If geothermal wells penetrated an extensive Ghyben-Herzberg lens, then there would be danger of paying a high cost in the pollution of the local groundwater supply. However, as stated above in Section 2, the experience from well-drilling in the Puna area does not seem to indicate the existence of a fresh water lens. For such fresh water reservoirs as may be encountered, appropriate well-casing programs and well maintenance should be able to guard against polluting groundwater otherwise usable for household needs or irrigation.

Other environmental pollution, which might add to the social costs of geothermal development, can be held to a minimum by appropriate safeguards. Already mentioned are mufflers to reduce the noise of steam issuing from the wells, landscaping to limit visual intrusion, constant monitoring to ensure that noxious gases or particulates do not exceed safe maxima. Effluents can be reinjected into the reservoir after passage

through a closed system, which would minimize the environmental impact of using the geothermal resource.[3/]

More likely to be an obstacle to geothermal development is obtaining the investment capital necessary for creating a production field and application of the resource to productive usages. The order of magnitude of such investment has already been indicated: it will cost tens of millions just to create a medium-sized electric power facility. How to raise such funds for an investment as inherently risky as drilling wells into hidden subterranean reservoirs will present the first economic barrier to geothermal exploitation. If grants or low-interest loans can be obtained from the national government (the Energy Research and Development Administration has a loan program just getting well under way), the drain upon Hawaii-based capital -- and hence the opportunity costs of the investment to the Hawaii economy -- can be kept down. Attracting investment capital from the mainland U.S. or abroad could have a similar effect in terms of opportunity costs, but would raise questions of out-of-state control over the geothermal development and possibly increase the out-of-state flow of funds generated by a successful development.

A kind of economic cost which is unique to resources tapped by wells, that is oil, gas, water and geothermal resources, is waste through competitive exploitation. Since the reservoirs holding these subterranean resources frequently underlie lands held by more than one party, there is

3/ A framework for environmental oversight is provided in the regulations on geothermal drilling which were in the process of being adopted by the Hawaii Department of Land and Natural Resources at the time of this writing.

a temptation for competing enterprises to drill as many wells -- either straight down, or slanted under adjacent properties -- as will maximize their share of the output. However, such drilling programs may not maximize total output from the field. On the contrary, by puncturing the reservoir excessively, it may cause a loss of pressure which leaves below the surface, unrecoverable except with costly techniques, some of the resource which a more efficient drilling program could have tapped, and with fewer wells.

By its policies and regulation, the State of Hawaii can restrain inefficient modes of exploiting a geothermal field. The proposed rules of the Hawaii State Department of Land and Natural Resources relating to geothermal wells allow for unit, or cooperative, development of a geothermal pool by several drillers, but do not require this approach to resource conservation. It may be that the limited facilities and expertise for deep drilling in Hawaii will make for a monopoly in development of the resource, but if not, the losses from uneconomical beggar-thy-neighbor exploitation could be significant.

C. Summary

Geothermal energy offers potential benefits to Hawaii, which, given this state's virtually complete dependence on oil, are of importance to its economy. Reducing this utter dependence by substituting indigenous geothermal water for imported petroleum to fuel the generation of electricity would not only reduce cash outflows (and perhaps hold down the price of electricity) but would lower the present uncertainty of continued reliance on oil from overseas suppliers.

However, a geothermal development limited to a small or medium size (say 50 MW) electric generating plant, would not have a great impact on the Hawaii economy. That might be achieved from a generating facility sufficiently large to bring down the cost of electricity and stimulate many industrial applications on the Big Island (or, when technological breakthroughs permit, the export of energy to industrial markets off the Island). Multiple use of even a limited geothermal resource might create a significant number of jobs, not to be expected from an automated generating plant itself. (Possible multiple uses in the Puna District were sketched in Section 4.)

An increase in job opportunities on Hawaii would help the state to implement its announced policy of avoiding further congestion of population in and around Honolulu. Geothermal development and associated economic growth in Puna would require the construction of water supply and waste disposal systems, plus other infrastructure, to serve a larger population. Such public costs would offset, perhaps exceed, additional tax revenues generated by an economic expansion based on geothermal production. Only after many years is it to be expected that the royalties received on state mineral leases, plus the taxes on geothermally-stimulated business, would exceed the cost to the government of preparing the way for and perhaps participating in the development of the new resource. What that participation might be is considered in the next section.

6. GEOTHERMAL DEVELOPMENT POLICY AND ITS DIRECTION

The rate, size and quality of geothermal development, in Puna and whatever other portions of these islands the resource may be located, will be affected by the policies of the government relating to geothermal resources. The federal government, primarily under the Energy Research Development Administration, has been encouraging geothermal development with grants to projects seeking to establish the existence of the resource, to improve engineering and technology for utilizing the resource, and to remove institutional barriers to resource development. A loan program, thus far not much used, is available to help enterprisers begin geothermal production.

As a matter of policy, ERDA and other federal agencies have to this date held back from taking an initiative in the development of geothermal resources in any given area, preferring such action to come from private enterprise, regulated as need be by the several states. That federal policy of course applies to Hawaii, which, alone of the western states, lacks any federal lands which could be leased for exploitation under the geothermal leasing program administered by the Department of the Interior. However, the state government of Hawaii does itself assert legal right to minerals underlying much of the land surface in the Islands and, as will be considered shortly, that ownership may shape the course of geothermal development here.

A. Alternative Policies for Development[1/]

A variety of factors, including feelings of urgency to create an indigenous energy source, the condition of the state economy, attitudes concerning the proper role of government in economic operation and in regulating private enterprise, opinions as to the riskiness of this new departure in energy utilization (as aginst the riskiness of continuing to rely on oil or switching to nuclear reactors), these as well as history and happenstance will shape the policy of Hawaii towards geothermal development. That policy has been to support exploration; now that a resource has been discovered, a policy with respect to the manner of exploiting it remains to be articulated.

Any number of approaches, ranging from complete laissez-faire to government operation, may be devised. The cardinal points of these various policy directions may be indicated by delineating four basic models: (i) minimal government intervention; (ii) private operation with government support; (iii) same, to obtain designated state objectives; (iv) joint venture between government and private enterprise; and (v) government monopoly. In each case, for "government" read "state government", since in Hawaii fiscal and other powers are so strongly centralized in the state that the counties, sole agencies of local government, are not in a position to set geothermal policy. They may certainly, however, participate in geothermal development action, once policy is set.

1/ These alternatives are considered by Eugene M. Grabbe and Robert M. Kamins in State Policy Considerations for Geothermal Development in Hawaii (Hawaii Department of Planning and Economic Development, 1975).

i. Minimal government intervention.

This model would be appropriate for a state policy of neutrality towards the development of this or any other indigenous energy source. It would limit state action to what is already required by law -- but even this is considerable. Under Act 246 of 1974 (to be considered below), the Department of Land and Natural Resources administers mineral deposits to the state, "minerals" now being defined to include geothermal resources. Under the law, the Department can regulate geothermal drilling and production, set lease rents for the use of state lands and royalties on production from reserved mineral resources. Along with the State Environmental Quality Commission, it can oversee the compliance of developers with environmental protection regulations, from the filing of the first environmental impact statement to a report on the abandonment of the last well.

Land use is regulated by both state and county governments. Before acreage classified as "conservation" or "agricultural" land (the most likely present classifications for areas considered as drilling sites) are legally available for commercial production, they would have to be reclassified as "commercial" or "industrial". This action falls under the authority of the State Land Use Commission, but once accomplished the land so reclassified into an "urban" use comes under the jurisdiction of the county government and its planning agency.

Once zoning, environmental, safety, and bonding requirements for drilling had been complied with, the development of a field could begin.

If undertaken by an enterprise which would sell the steam to an electric company, the geothermal steam company would be subject to regulation by the Public Utilities Division of the Department of Regulatory Agencies. In any case, the PUD would be concerned with the effects of geothermal power on the costs, profits and rates of an electric company using the power.

Aside from these routine applications of Hawaii law and administrative regulation, under this minimal interference model the government would leave the private exploiters of geothermal resources free to make their own bargains -- and to pay the existing taxes, notably realty, gross sales and net income taxes, on their property and operations.

ii. Private operation, with government support to maximize production.

Alternatively, state policy may be to hold down government involvement in geothermal development, but subject to the condition that the development proceed quickly and with full utilization of the resources which may be discovered. To accomplish these joint policy objectives, the state would encourage all reasonable and mutually compatible efforts by private enterprise to develop the geothermal resources. It could:

1. Expedite drilling by minimizing the time necessary to grant access to public lands for exploration and drilling (and helping to get access to private lands, if necessary using its powers to compel entry); minimizing formal compliance with environmental protection require-

ments; giving all assurances possible under the law that successful explorers would obtain drilling rights and that all successful drillers would have production rights over long periods of time.

2. Make direct subsidies to support geothermal development: pay for some of the costs of drilling; minimize or completely waive royalty payments on state-owned geothermal resources; give special tax benefits to drillers and producers.

3. Make indirect subsidies: provide access roads, water supply and other infrastructure needs of a geothermal area; regulate electricity rates so that benefits of geothermal power are shared between developers and utility company, and not passed back to consumers in lower prices per kilowatt-hour. (Essentially, this is the outcome at The Geysers, where the Pacific Gas and Electric Company pays to the geothermal steam supplier a rate tied to the price of fuel oil.)

4. Make loans. The state government could lend its funds or its credit (by guaranteeing bank loans) to geothermal developers. However, the Federal government is far better situated to serve as lender, and is authorized to do so under the Geothermal Energy Research, Development, and Demonstration Act of 1974.

iii. Private operation, with government support and direction to attain State objectives.

The means just listed under (ii) could be used to help accomplish ends desired by the State government, in addition to the maximization of production from geothermal resources. This can be done by

making the granting of permission to drill, the granting of subsidies or loans, the qualification for tax exemptions, etc. conditional on geothermal development being carried out in a manner which would further those ends. For example, if the purpose of the State is to disperse population, it would support projects to develop geothermal resources on the Neighbor Islands, as at Puna, but not necessarily on Oahu. If its purpose is to reduce electric bills, it would support development likely to produce electricity and ensure that rate regulation passed on to consumers part of the economies from geothermal generation. If it wants to encourage agricultural and other non-industrial uses of geothermal energy, these can be preferred in state actions of support. If the government wants to maximize geothermal output over time, it would try to ensure that the resource had been adequately identified before permitting production drilling, would require reinjection of fluids, might require unit exploitation of any single reservoir, would require and monitor production programs capable of attaining high rates of resource extraction, etc.

iv. Joint venture between government and private industry.

Since drilling and geothermal resource development are highly risky and expensive, private investment alone may not develop the resource to a point necessary to achieve public purposes which may be set by the State, e.g. reduction of dependence on oil, creation of jobs, economic diversification. This possibility, in fact, is what provides

possible justification for the direct or indirect subsidization of development.

A mode of operations for implementing state geothermal policy, one which could directly affect the rate and pattern of geothermal development, is for the state and/or county government to enter into a joint venture with one or more private firms. The public agency would furnish some of the capital, technical knowledge and other necessary resources, sharing in the management perhaps, and sharing in the profits (or losses) of the geothermal enterprise. The joint venture, or consortium, arrangement might encompass the entire operation, from exploration to production and marketing, or it might provide for a division of labor between the public and private partners. One possibility is for the state to do the drilling and production of steam, selling the steam to the Hawaii Electric Light Company, or other private user. Alternatively, a private firm could drill and produce (steam, electricity, distilled water or other by-products) and sell its production to the state or county government for direct use and for distribution. Hawaii County, for example, might want to buy geothermally produced electricity for distribution to agricultural users on the Big Island as a means of directing economic development. Other combinations of public and private enterprise, hooked together in series or in parallel, can be constructed.

v. Government monopoly.

At the end of this spectrum of possible roles for Hawaii government in geothermal development is for the state or a county itself to

undertake the development and itself market the electricity or other output produced. Again, a variety of institutional arrangements can be envisioned. One is provided by the well-known example of the Tennessee Valley Authority, where a special, quasi-independent unit of government serves as producer and wholesale distributor, but not, generally, as retailer, leaving that function to other enterprises. Closer to home is the example of the Honolulu Board of Water Supply, which operates rather independently within the county government, and with a record of high technical competence, to produce and distribute the potable water supply, over which it has a legal monopoly. Municipal power companies are of course commonplace in other parts of the U.S.

Given the magnitude of investment required for geothermal development, (a single year's outlay for a large field might take a third or more of the entire operating budget of the County of Hawaii, recently running at approximately $30 million annually), sole operation by local government may not be financially possible. Loans or grants from the federal government might carry part of the initial burden of investment, but at least until this point (January 1977) the policy of the Energy Research and Development Administration has been against financial assistance to government agencies for production in the geothermal field. This could change under a new national administration, but there is yet no legislative program for supporting initiatives of state or local governments in geothermal resource development.

B. Who Owns the Resource in Hawaii?

For the moment, the implementation of any policy towards geothermal development in Hawaii would face a legal barrier which inhibits investment by either private or public agencies. That barrier is uncertainty as to who owns geothermal resources: with respect to a reservoir under private lands, is it the party with title to the overlying land, or is it the state government?

Because geothermal resources are only beginning to be exploited in most American jurisdictions for purposes other than hot baths, property law has not yet clearly established their ownership. The fact that geothermal resources do not readily fit into familiar categories -- are they water, mineral, both, neither? -- complicates the task of creating a legal regime for this heat-of-the-earth. The Hawaii State Legislature enacted a statute (Act 246 of 1974) to establish a legal regime for geothermal resources by defining them to be mineral. The intended effect was to make them the property of the state, thus allowing development to go forward, based on a certain knowledge of ownership. The 1974 law was predicated on the assumption that all (or virtually all) land placed under private ownership following the Great Mahele of the mid-19th century was granted subject to the reservation of mineral rights to the sovereign -- now the State of Hawaii.

And indeed this had been the case for a period of time, from 1846 to annexation in 1898. For that half-century, in checking the land registration records for parcels in the Puna District adjacent to the experimental

well and around another potential drilling site, we found no land grant or patent which failed to reserve to the King -- and then to the Provisional Government and the Republic of Hawaii -- rights to all minerals under the lands placed in private ownership. However, after 1900 and until the enactment of mineral reservation statutes in 1962 and 1963, lands were frequently, perhaps typically, conveyed by the Territory and then the State of Hawaii without reservation of mineral rights to the government.

Problems of interpretation arose when, after 1900 and before 1962, large tracts of land previously conveyed to private owners under a Land Commission Award (recognizing previous occupancy or other entitlement) followed by a Royal Patent (showing the commutation or payment had been made) which did contain a mineral reservation were later divided into pieces (apanas) for which new land patents were issued by the Hawaii government without mineral reservations. This was true of several large tracts in Puna: they were originally patented subject to a reservation and then fractioned into apanas under new patents which were not so conditioned.

[A memorandum from Deputy Attorney General Eric Marn to the Chairman of the Board of Land and Natural Resources, dated August 25, 1976, points out that the mineral reservation clause was provided by an 1856 statute of the Kingdom which was omitted in the compilation of the Civil Code of 1859. In the case of In Re Title of Robinson, the Hawaii Supreme Court held that the omission constituted a repeal of the mineral rights re-

quirement, and that therefore the reservation did not apply unless explicitly provided for in the land patent or grant. This memorandum, however, did not address the problem of conflicting patents, where that on the whole tract includes the reservation clause and those on the apanas do not.]

Two theories may be applied, with contrary results. One is the idea that the more recent action governs, that by failing to reiterate with respect to the apana the mineral reservation originally attached to the entire award, the reservation was waived or eliminated. The alternative notion is that the reservation contained in the original Royal Patent issued on a Land Commission Award remains in force with respect to all acreage covered by it. Under this theory, based on the idea that land office officials in succeeding political regimes were never authorized to rescind reservations already in force, mineral reservations in an original patent would remain operative over the entire area encompassed by that patent, even if patents subsequently granted on apanas lacked the reservation.[2/]

The question of applicability of mineral reservations is of some consequence in determining who, under Hawaii's existing laws, own geo-

2/ Examples of Royal Patents on Land Commission Awards and Royal Patent Grants (on government land sold to private persons) which contain the mineral reservation are shown by Judge Jon J. Chinen in his monograph Original Land Titles in Hawaii (Honolulu, 1961), a book essential to an understanding of the unique land system of this state.

thermal resources which may be found beneath private lands in the state. Search was made of Land Commission Awards, Royal Patents and post-Mahele land grants covering two areas of Puna to see how the pattern of reservation/non-reservation applies in locales with potential for geothermal development. One area is that included within a circle of two-mile radius drawn around the experimental well, called HGP-A of the Hawaii Geothermal Project; the other is within a similar circle around the site which had been considered by geologists as the best alternative to HGP-A.

Within these two circles, it was ascertained that for some 40 per cent of the area (about 5,800 acres) the government had title to whatever geothermal resources may subsist under the land, either because the state or county itself owns the land (1,900 acres) or because private lands there are under grants or awards which contain the mineral reservation (3,900 acres). Another 16 per cent of the acreage in these two circles (approximately 2,300 acres) is held under grants against which the reservation had never been made, and so presumably the private owners of these lands also own the minerals below. That leaves 44 per cent (over 6,000 acres) where the reservation is in doubt because they are apanas within original grants subject to the mineral reservation but which were subsequently divided off by grants which made no mention of the reservation. There is no reason to think that this ambiguity of mineral ownership is peculiar to Puna, since lands throughout the state were distributed under the same laws and procedures.

Should Hawaii's geothermal resources prove to be valuable, it is unlikely that this ambiguity and uncertainty of resource ownership will

long continue. The Legislature may be moved to repeal Act 246, replacing it with a statute more clearly declaring geothermal resources wherever situated to belong to the state, or, alternatively, declaring them to be resources which are non-mineral and belonging to the owners of overlying land.

Whether or not Act 246 is amended, repealed or superseded by legislative act, there is likely to be a judicial review of Hawaii's geothermal statutes. It may be initiated by enterprisers interested in geothermal development who would prefer dealing with private owners of the resource, rather than the state. Alternatively, a statute limiting or abolishing state claims to ownership may be challenged by public interest groups. Or, a declaratory judgment may be asked of the court by the state government to settle the legal ambiguity. Only after a court review will the uncertainties of property rights in geothermal resources be completely removed as a barrier to the development of the potential new energy source.

C. Control Points

Once the State of Hawaii has adopted a policy or set of policies to guide the development of geothermal resources, it does not lack means of controlling events to effectuate its policy goals. Some of these have already been referred to, but it remains to put them together. The order of presentation is chronological with respect to the course of development. By asterisks (*) are identified elements of control included in the regulations of the Department of Land and Natural Resources governing geothermal exploration, drilling and well operation, which are now in draft form.

i. Attracting and conditioning private investment.

a. Royalties on state-owned resources.* By setting royalties high or low, the Department of Land and Natural Resources can influence the level of investment.

b. Taxes on geothermal property and operations. A similar influence can be exerted by tax policy. Particularly important are rates and exemptions under the real property, general excise, net income and public service company (utility) taxes.

c. Government subsidies. Provision of access roads, water, sewage disposal and other infrastructure investment by the Hawaii government can encourage private development. These can be more readily conditioned upon the State's satisfaction with private development plans than can the variation of royalties or of taxes, which tend to be offered to all comers.

ii. Providing and controlling access to the resource.

a. Leasing state lands/and state-owned geothermal resources under private lands.* By Chapter 182 ("Reservation and Disposition of Government Mineral Rights") Hawaii Revised Statutes, the Department of Land and Natural Resources may issue leases on state lands, and on lands for which it has reserved mineral rights, to "mine" for geothermal "deposits". It may lie within the power of the Department to make the issuance of leases conditional upon development plans which are compatible with policies established by the Legislature.

b. Zoning: State powers. Under Chapter 205 ("Land Use Commission"), of the Hawaii Revised Statutes, controls over land use are shared by the state and the counties. Conservation districts are under the control of the Department of Land and Natural Resources; agricultural districts generally are under state control. The latter category is defined (Section 205-1) to permit the operation of "processing facilities", and so may encompass this application of geothermal energy, as for the processing of tropical fruits. However, it would appear that the creation of a geothermal field and generating plant would be considered an "urban" activity under the categories of Chapter 205. If this is the case, the land would have to be zoned as an urban district. The zoning authority is the State Land Use Commission and, if the state had a set of policies with respect to geothermal development, this could be a control point for their implementation.

c. Zoning: County powers. Land zoned as an urban district, presumably the category in which geothermally developed areas would fall, come under control of county governments, specifically their planning and land use agencies, their councils and mayors. Permission to construct facilities on "urban" lands has to be obtained from the county, which gives it an opportunity to require compliance with public policy for geothermal development, where such policy exists.

iii. Controlling physical aspects of production.

a. Environmental controls. Generally, the use of state or

county lands, or of lands classified as "conservation", or the use of Hawaii government funds, for geothermal development would require the filing of an environmental impact statement under Chapter 343 ("Environmental Quality Commission"), Hawaii Revised Statutes. The Department of Land and Natural Resources* proposes to require operators of geothermal wells to protect the environment and rehabilitate disturbed lands. The draft regulations (Rule 14) state that operations must be conducted "in accordance with the spirit and objectives of all applicable environmental legislation", providing a control point for enforcing policy on the physical aspects of geothermal development.

b. Conservation of the resource.* The proposed regulations make geothermal production leases subject to the requirement that lessees use "all reasonable precautions" to prevent waste of geothermal resources. (Rule 7.5) Payments for losses through avoidable waste may be required. Unitized development, another way of maximizing output from a field, is provided for in the rules (#3.15), but is not mandatory. Were it state policy to maximize recovery of the resource, it might be legally possible for the Department to require a plan of development which coordinated the output of all wells tapping a given reservoir.

iv. Financing development.

Entrepreneurial direction affords the strongest control over the direction a new geothermal industry might take. As in most other parts of the United States, government in Hawaii has not generally attempted the role of producer, except for the provision of fresh water supply, local bus transportation, and similar public services. In areas where private enterprise operates, the state government has used preferential tax treatment and occasionally subsidy (notably to help finance national advertising of Hawaii's touristic attractions) to stimulate and direct economic growth. Given this history, it would require an exceptionally strong governmental initiative for the state to directly invest in geothermal development -- beyond contributing to the costs of initial exploration, as it already has.

However, the heavy cost of drilling a geothermal field may lead private enterprise to seek a public partner to share the burden of providing risk capital. Should the state government enter into a joint venture, it would have the opportunity of establishing for the enterprise a plan of development which would further the goals of the state with respect to geothermal resources.

Under the present organization of the Hawaii government, it is its Department of Planning and Economic Development which would appropriately take the lead in implementing geothermal policy, not only because of the developmental mission of the Department, but because its director has the collateral duty of serving as the Energy Resources Director of the State. However, so numerous are the linkages between geothermal devel-

opment and the entire economy of Hawaii, that it may require a viewpoint broader than any single agency can provide to draft a general policy for the state.

This has been the experience of California, which after more than a decade of intensive development of its geothermal resources, still has no cohesive policy for geothermal energy. Last year the California Legislature established a task force to draft a policy, with members from nine state agencies, four legislators and three representatives of the public. As in Hawaii, California lacks even an accepted legal definition of geothermal resources. (In a 1976 lower court decision, Geothermal Kinetics v. Union Oil Co. they were held to be "mineral", but the decision is being appealed.)[3/] Hawaii may be able to benefit from the experience of California in trying to integrate the multiple, sometimes conflicting considerations which would enter into a viable policy for geothermal development.

D. Summary

The State of Hawaii, through its Department of Land and Natural Resources, is now in the process of adopting regulations for the exploitation of geothermal resources. However, the state does not have a policy for geothermal development, except that it generally favors it.

3/ No. 75314, in Superior Court of the State of California for the County of Sonoma, May 28, 1976. In its decision, the court noted that it differed from the opinion of a federal district court (United States v. Union Oil Co., 369 F. Supp. 1289) that geothermal steam is not a mineral. The latter case is on appeal in the Ninth District.

That indeed may be a sufficient policy, unless the state has objectives which may be better attained by some modes of geothermal development than by others. Among such possible objectives are a rapid attainment of an indigenous energy source; creation of jobs within a more diversified economy; checking population congestion on Oahu; minimization of adverse effects of energy sources on the environment.

Should the state adopt a policy to shape geothermal so as to attain these or other objectives, it has several control points at its command. These include regulation of land use, power shared with the counties; regulation of geothermal exploration, drilling and production; environmental controls; public utility regulation; tax policy; grants and public expenditures on infrastructure in support of geothermal development; as well as putative ownership of the geothermal resources themselves.

Despite the adoption of Act 246 by the 1974 Legislature (which, by declaring geothermal resources to be "mineral", sought to include them among the resources reserved to the Hawaii government under land patents issued subsequent to the Great Mahele), there is uncertainty as to ownership of the resource for many parcels. The uncertainty arises because it sometimes happened that while the reservation was included in the patents for large tracts of land made in the mid-19th century, it was omitted from grants subsequently issued on subdivisions of the tracts. Until settled by legislation or judicial decision, the question of ownership remains ambiguous, placing an obstacle of uncertainty in the path of geothermal development.

Constructing a policy, or set of policies, for geothermal development in Hawaii would necessarily require substantial inputs from the Department of Planning and Economic Development, whose director is the state's energy resources coordinator, and from the Department of Land and Natural Resources. However, it may take a special effort of the state government, also involving the counties, in an ad hoc group to develop policy to guide development of the new resource.

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