ENVIRONMENTAL BASELINE STUDY
FOR GEOTHERMAL DEVELOPMENT
IN PUNA, HAWAII

R. M. Kamins, M. J. Chun, A. J. Berger, W. B. Bonk, B. A. & S. M. Siegel, T. Speitel, L. S. Lau, R. W. Buddemaier, P. Kroopnick, T. Hufen.

Hawaii Geothermal Project
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1. INTRODUCTION

The Hawaii Geothermal Project, a coordinated research effort of the University of Hawaii funded by the County and State of Hawaii, as well as ERDA, was initiated in mid-1973 in order to identify and help develop geothermal energy on the Big Island of Hawaii. To develop a geothermal resource, a number of stages preliminary to production are required: exploration and selection of a site for drilling; exploratory drilling; testing to determine critical characteristics of the well or wells; and -- optionally -- operating a model plant to test output potential.

By the spring of 1974 Phase I of the Project had been completed, when a site for an exploratory well was located and permission for drilling was obtained from the private corporation owning the site. After the competitive bidding process was completed, a drilling contract was awarded in November, 1975 and actual drilling began in December of last year. The drilling was completed late in April, 1976, when a depth of approximately 6,400 feet had been penetrated -- approximately 6,000 feet below sea level. A slotted liner for the bottom portion of the well was installed in June, 1976. The well flashed spontaneously on 3 July and was blown to rid it of drilling debris on 22 July 1976, after which testing of its physical properties was begun.

From the beginning of the Hawaii Geothermal Project it has been recognized that the successive steps of geothermal development starting with drilling must be carefully scrutinized to ascertain in a timely way if there would be any adverse effects on the environment and local ecosystems, and, should they occur, that it was necessary to identify and recommend measures to minimize such impacts. For this reason, in the summer of 1975, once the drill site had been selected and long before the drilling began, baseline data were collected on critical aspects of environmental conditions as they existed before any significant disturbance by the Project. These included ground water supply, air, soil and the flora, as well as the archaeology of the area surrounding the drill site. In February, 1976 the area was studied to see if it provided a habitat for birds which are endemic, or otherwise of special interest.

Generally, the area examined for environmental impact lies within a circle having a radius of approximately a half mile from the center of the four-acre drill site. However, the testing of ground water included sampling wells and a spring more than a mile from the site.

Additional tests of the water and air were conducted at the site in June, 1976, after the drilling was completed but before the well was blown to free it of debris accumulated during drilling. The results of that testing, along with results obtained before the drilling began, are summarized in this assessment statement. The results of the pre-drilling studies were such as to enable the University of Hawaii, under the regulations of the Hawaii Environmental Quality Commission, to issue a negative declaration concerning the exploratory hole -- i.e. that the drilling of the well seemed to pose no significant threat to the environment in the vicinity of the well site in Puna, Hawaii.

It is hoped and intended that the environmental data established by this study will serve as baselines from which to measure changes which may be associated with geothermal development, not only in the area immediately neighboring the present drill site, but, with appropriate adjustments, for development which may occur elsewhere in the Puna District. How transferable the baselines may be to other areas, say other districts of the Island of Hawaii or to other islands within this archipelago, is a question which must be examined in context as further geothermal exploration is undertaken.

2. RESEARCHERS AND THEIR AREAS OF STUDY

The following members of the faculty of the University of Hawaii participated in this environmental baseline study:

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.*

Dr. Andrew J. Berger, Professor of Zoology, investigated potential effects on birdlife in the area.

Mr. William Bonk, Professor of Anthropology at the Hilo Campus of the University of Hawaii, investigated potential effects on archaeological sites.

* The following students voluntarily worked with the Professors Siegel on geotoxicology testing: Willie Cade, Melvin Calvan, Anne LaRosa, Kapuanani Lee and Hope Stevens.

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 collaborated in the investigation of potential effects on groundwater supplies in the area.

Dr. Michael J. Chun, Associate Professor of Public Health, coordinated the pre-drilling testing program.

Dr. Robert M. Kamins, Co-Principal Investigator in the Hawaii Geothermal Project, administered the overall baseline study.

3. DESCRIPTION OF THE ENVIRONMENT OF THE WELL SITE

A. General: the Area

The site of the exploratory well of the Hawaii Geothermal Project is a four-acre area in the Puna District of Hawaii, lying just mauka (away from the sea) of the Pohoiki Road. It is approximately three miles east of Pahoa (1970 population 924) and about an equal distance from the ocean, in the eastern-most projection of the Island of Hawaii. Figure 1 shows the well site in relationship to other points on the map of Puna, including places of archaeological interest.

The Puna District lies athwart the East Rift, which cuts down from the slope of Kilauea Volcano, reaches the sea near Kapoho Point and continues along the ocean floor eastward of the Point. Consequently, tectonic activity in the area is frequent. The 1955 eruption of Kilauea broke through the earth's crust approximately 1,500 feet from the well site, forming Pu'ulena

Crater. Nevertheless -- as is true of other parts of the Island of Hawaii -- subdivision of land for home sites has continued here, and on the opposite side of the road from the well site, centered on Pu'ulena Crater, there is a subdivision of approximately 600 lots. Streets have been bulldozed in the subdivision, but no construction has yet begun. There are only a few scattered houses, approximately a dozen, within a radius of a mile from the geothermal well.

The land of Puna is an area of marked environmental contrast: there is fertile soil and lush vegetation over the older, 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 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, these, too, are usually black, produced by the explosion of hot lava meeting the sea.

There is only limited human activity within a radius of two miles of the geothermal well. About three miles to the west is the boundary of the Puna Sugar Company plantation and an equal distance to the east, nearer the coast, is a major area of papaya cultivation. Closer still, less than a half mile to the east towards Pahoa, is Lava Tree State Park, a preserve marked by the Hawaii Visitor's Bureau, which brings in a small volume of tourist traffic. In most hours of most days, however, the quiet of the

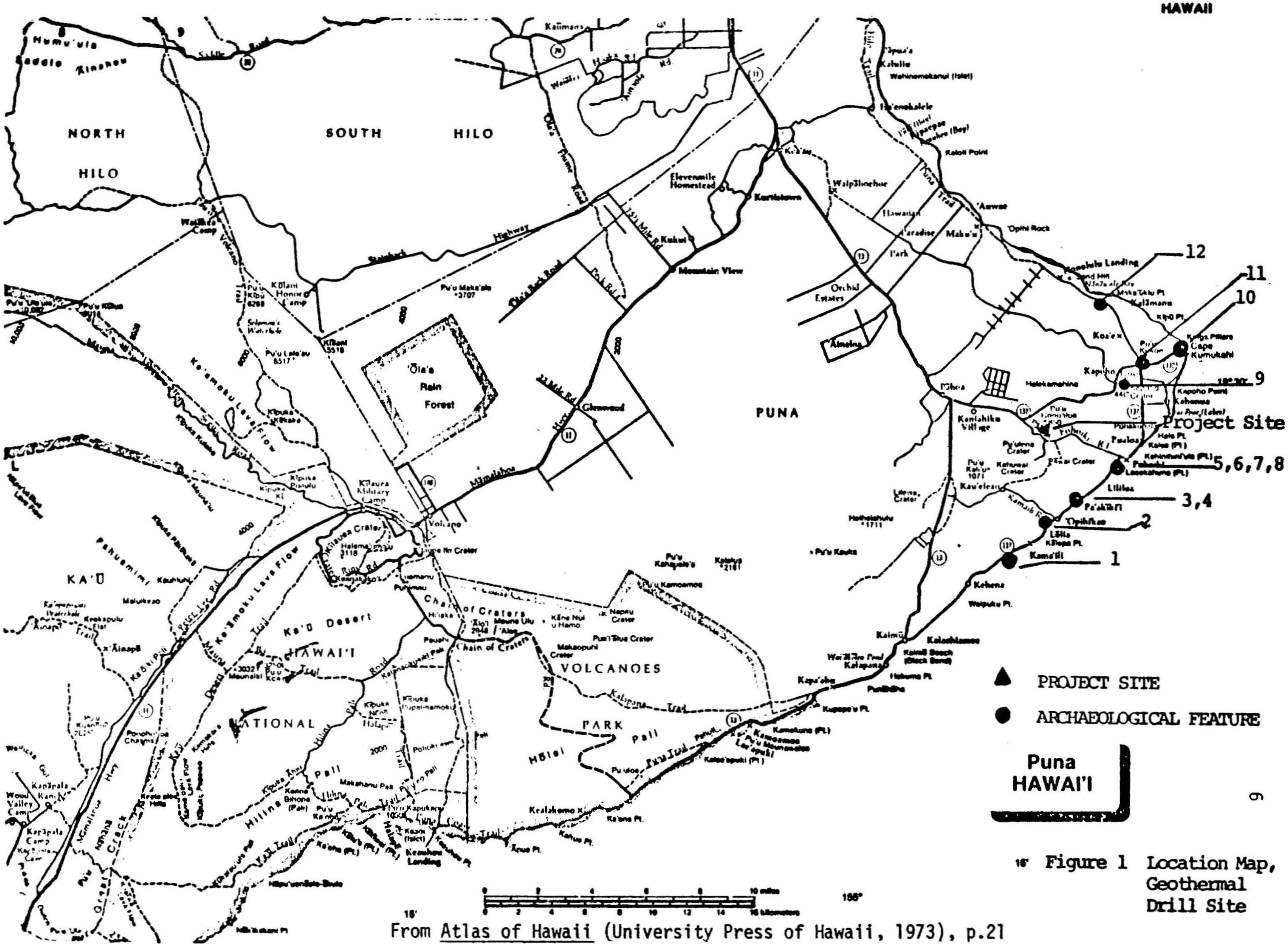

Figure 1 Location Map, Geothermal Drill Site

From Atlas of Hawaii (University Press of Hawaii, 1973), p.21

roads in this portion of the Puna District is not much disturbed by passenger cars, or by an occasional truck or bus, most of them traversing the distance to beaches on the Puna coast. (The well drilling itself generated a fair amount of traffic, not only from the dozen members of the drill crew and scientist observers, but also from some tour buses, whose operators were glad to find a drilling rig to add to the attractions of tourism in this outstandingly quiet corner of the Island of Hawaii.)

B. Vegetation

The well site is on an exposed lava flow, dating from 1955. The undisturbed part of the flow consists of barren aa, covered by a dense growth of lichens, with scattered ferns and ohia lehua (Metrosidoros collina) saplings -- a typical succession of plants on lava flows in Hawaii. Further off, as around Lava Tree State Park, are areas of forest, consisting predominantly of ohia, the size of the trees being related to the age of the underlying lava flow. Hence, most trees are of small to medium height, but there are infrequent kipukas (islands of growth on land not subject to recent lava flows) in which some trees reach approximately 100 feet in height. The groundcover around the ohia trees largely consists of false staghorn ferns (Dicranopteris linearis), grasses and several species of wild orchids. Around the larger trees are some treeferns (Cibotium) and ieie vines (Freycinetia arborea). All these endemic species are common to areas in Hawaii covered by lava flows of no great age.

In locations disturbed by roads, footpaths, jeep trails and bulldozers, however, the vegetation consists largely of introduced trees, shrubs, vines and grasses. Such exotic vegetation is 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 (Mangifera indica), papaya (Carica sp.), guava (Psidium guajava), bamboo (Bambusa sp.), kukui tree (Aleurites moluccana), sugarcane (Saccharum officinarum), banana (Musa sp.), Indian pluchea (Pluchea indica), Jamaica vervain (Stachytarpheta jamaicensis), and sensitive plant (Mimosa pudica). A stand of Norfolk pines (Araucara excelsa) rises between the Park and the well site, and there are groves of albizia (Albizia falcataria) along the road and at the Park.

C. Floral Species Density; Mercury Analysis

Within the study area, sampling for estimation of floral species density was performed, using a sampling pattern of two quadrats with two transects. A complete species list, along with frequency and cover of individual species for each transect and quadrat, are given in Table 1.

In addition to identification of species, limited investigations in geotoxicology were performed. In these baseline investigations, mercury was given high priority. Principal indicators selected were the staghorn fern (Dicranopteris sp.), ohia (Metrisideros collina, var. polymorpha), and nut grass (Cyperus rotundus). Where these indicator species were not present, alternative indicators were used and included guava (Psidium sp.), Boston fern (Nephrolepsis exaltata var. Bostoniensis) and lycopodium (Lycopodium cernvum).

Relatively speaking, the staghorn fern showed a remarkedly uniform mercury content over the entire area sampled. Most values were between 150 and 210 ppb, although ohia in a stand to the rear (roughly north) of the drill site gave an unusually high value, circa 500 ppb. Again, most representative samples of this species yielded mercury contents of 150-200 ppb.

In each case the data for any species at any site were based upon tissue collection representing at least 5, and more commonly 8-12 individual plants. For the entire sample population, representing over 120 assorted individual plants, the mean mercury content was 159 with a standard error of only 19 ppb, which amounts to only 12% of the mean. This speaks for the remarkedly low degree of variability in mixed population.

For purposes of comparison, ohia and Boston fern collected near Volcano House in a steam zone yielded 180-250 ppb of mercury and lycopodium collected at the Sulfur Banks in Hawaii Volcanoes National Park contained 187 ppb.

The transect used to study nut grass involved an extended linear survey of soil and plant mercury over a distance of 150 meters. This line extended from Highway 132 in a relatively barren area which develops into a milkweed-nut grass community running most of the length of the drill site. The line however, was extended beyond a discontinuity created where lava boulders had been moved, apparently by bulldozing. Upon these boulders, and to some extent between them, ohia, Boston fern, and sterocanlon has become established. The boulders grade into a higher ground to the south. The mercury content of the nut grass shows three high values at roadside, and on either side of the boulder line. No obvious explanation can be offered at present for this behavior although it should be pointed out that the soil mercury associated with those same plants shows maxima that coincide almost perfectly with the plant maxima.

D. Groundwater

In general, groundwater occurring in the basaltic rocks underlying the Puna District is unconfined basal water, i.e. fresh water coexisting with salt water in a lens-like configuration. However, as will be shown below, sampling from sources in the vicinity of the geothermal well suggests that a classic Ghyben-Herzberg lens, in which the fresh water floats on the salt water, does not exist in this portion of Puna.

Only a few water wells have been drilled to supply the area near the geothermal well. Freshwater supplies to Pahoa and the houses adjacent to that nearest community are piped from sources closer to Hilo, and there is a terminal outlet to that distribution system approximately a quarter mile down the Kapoho Road from the well site in the direction of Pahoa. However, it was an environmental concern of the Hawaii Geothermal Project that the drilling of the well not pose any threat to whatever groundwater supply exists. Lining the hole as drilling proceeded insured that potential pollutants would not be introduced into any fresh water lens or perched water supply penetrated by the geothermal well.

To establish baseline conditions before drilling began, during January 1975 samples of groundwater were collected at eight selected stations within a radius of approximately two and one-half miles from the geothermal well

TABLE 1. FLORAL SPECIES AND EXTENT OF COVER

	Quadrat 1	Quadrat 2	Transect 1	Transect 2
Total area (m^2)	4.0	14.5	1.1	2.7
Fraction of total area with plant cover	.31	.39	.36	.28

Species list	n/frequency/fraction of total cover			
	Quadrat 1	Quadrat 2	Transect 1	Transect 2
ASCLEPIADACEAE				
Asclepias curassavica L.	27/.44/.34	19/.23/.10	6/.08/.41	17/.21/.31
BURNAMMIACEAE				
Emilia javanica (Burm. l.) C.B. Robins			1/.01/<.01	
COMPOSITAE				
Ageratum haustaneanum Mill				
Erichtites valerianefolia (Wolf) D.C.	4/.06/.03		7/.09/.01	6/.07/.02
Erigeron bonariensis L.	2/.03/.02	1/.01/.01		1/.02/.01
Pluchea odorata (L.) Cass		1/.01/.01		
Vernonia cinerea (l.) Less	1/.02/<.01		4/.05/<.01	5/.06/<.01
CYPERACEAE				
Cyperus rotundus L.	1/.02/<.01	6/.07/.03	19/.24/.09	13/.16/.02
Rhychospora lavarum Gaud.	1/.02/<.01	3/.04/.02	5/.06/.01	6/.08/.02
Carex sp.	3/.05/<.02		2/.03/<.01	5/.06/.07
FELICINEAE				
Spheriomeris chiensis (L.) Maxon		2/.02/.02		
GRAMINEAE				
Andropogon virinicus L.	19/.31/.46	10/.12/.10	17/.21/.28	23/.29/.48
Brachiaria mutica (Forsk.) Stapp				
Melinis minutiflora Beauty				
Saccolepis indica (L.) Chase			11/.14/.04	

IRADACEAE				
Tritonia crocosmiflora		11/.07/.04		
LAURACEAE				
Metrosideros collina subsp. polymorpha (Gaud) Rock		3/.04/.02		
LEGUMINOSAE				
Cassia eschenaultiana				
Desmodium triflorum (L.) D.C.			1/.01/<.01	2/.02/.39
LYDOPODIACEAE				
Lydopodium Sp.				
LYTHRACEAE				
Cuphea carthagenesis (Jacq) MacBride				
MELASTOMACEAE				
Melastoma malabathnicum L.	1/.02/.11	4/.05/.03		
ORCHIDACEAE				
Arundima bambusaefolia (Roxb.) Lindl.				
Spatholglottis plicata Bl.				
PARKERIACEAE				
Nephrolepis exaltata (L.) Schott				
POLYDODIACEAE				
Pteridium sp.		11/.13/.52		
ROSACEAE				
Rubus penetrans Bailey	2/.03/.01	7/.08/.04		2/.03/.01
SCROPHULARIACEAE				
Castilleja arvensis Schlect & Chom		5/.06/.04		
VERBENACEAE				
Lantana camara L.				
Stachytarpheta cayennensis (L.C. Rich) Vahl				
Stachytarpheta urticaefolia (Salish) Sims		3/.04/.02	3/.04/.03	

site: seven of these are water wells and the eighth a geothermal spring which feeds a pool at Isaac Hale Park, on the coast southeast of the site. (See Figure 2) As another check, rainwater at Kalapana, a black sand beach about 10 miles southwest of the site, was also sampled. Analysis of the chemical quality of the groundwater taken (see Table 2) supplemented by data previously reported by other investigators indicates that these groundwater samples were either basal water or basal water mixed with salt water.

Basal groundwater in basaltic aquifers in the Hawaiian Islands normally has low concentrations of dissolved chemicals and is typically of a sodium-bicarbonate type. In this regard, the samples from Well 9-5, Well 9-7 and Shaft 9 are representative of basal waters with respect to their chemical composition. The bicarbonate content of Shaft 9 (Kapoho) is anomalously high for reasons yet unknown.

Samples from Well 9-6, Allison Well, Isaac Hale Spring, Well 9-9, and Geothermal Drill Hole No. 3 showed chloride contents higher in varying degrees than average basal water. Salination of basal water due to intermixing with underlying salt water is a common phenomena, especially in coastal areas where unconfined lenses are thinnest and easily perturbed by tidal effects or heavy pumping. Therefore, the slightly above-normal chloride concentrations of samples from Well 9-6 and Allison Well are not too surprising, considering that they are located about 5 and 1.5 km from the coast, respectively. By the same token, water from Isaac Hale Spring, which is located only a few meters inland from the beach, can be expected to be heavily brackish, which indeed it is.

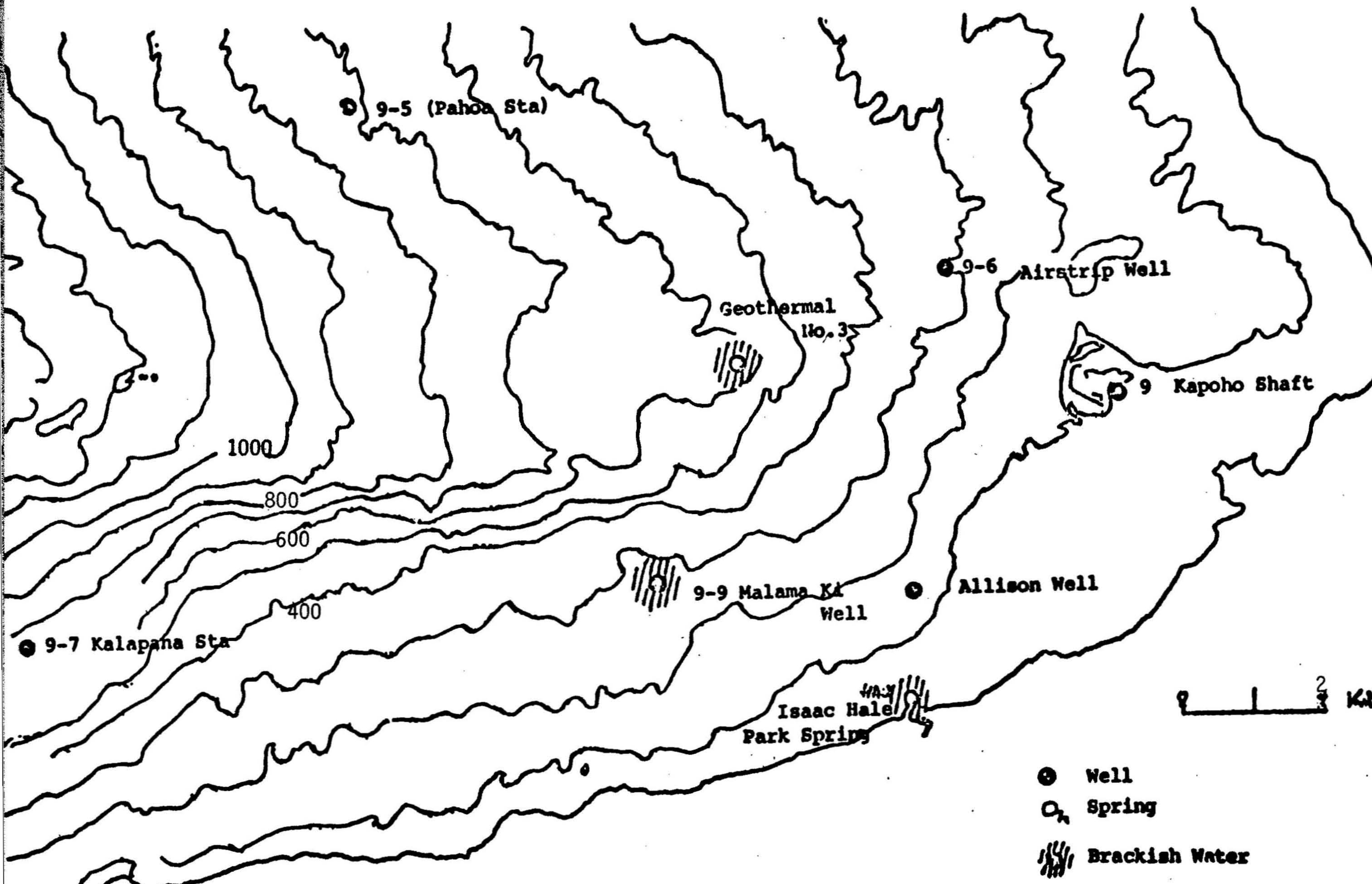

Figure 2. Location of Sampled Wells and Spring, Puna, Hawaii

Considering the upslope locations of Well 9-9 and Geothermal Drill Hole No. 3 with respect to the other wells and their greater distance from the coast, they should penetrate a layer of fresh water whose chemical composition should be comparable or superior to that of Well 9-6 and Allison Well, respectively. However, samples from both wells were also quite brackish, with chloride contents comparable to that of water from Isaac Hale Spring. Since the temperatures of samples from Well 9-9 and Geothermal Drill Hole No. 3 are quite high, it is reasonable to conclude that basal water and salt water have been mixed (locally?) due to upward movement of heated salt water.

The heating of groundwater in the Puna area not only induces fresh water-salt water mixing but evidently increases chemical interaction between groundwater and basaltic rock as well. Chemical composition of warm water samples (above 30 degrees C) were compared with concentrations of hypothetical mixtures between basal water and salt water, using chloride ion concentrations as a mixing ratio index. The brackish water samples were found to contain excess potassium and deficit magnesium concentrations that change dramatically as a function of temperature, indicating temperature-dependent ion exchange reactions. Alternation of aquifer material is further indicated by the large amount of silica in all but one of the warm waters.

At the same time -- in January 1975 -- analysis was made of the microbiological quality of groundwater, using the same samples. Data in Table 3 reporting coliform and fecal coliform readings of the sample waters show

TABLE 2. 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 3. 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

them to be generally free of pollution by micro-organisms. The high values for the Allison Well samples are attributed to local pollution, and probably introduced during sampling.

Water flowing from the well was tested at the wellhead on 24 June 1976, before it was flashed but after six hours of flow to clear it of drilling mud and debris. Table 4 shows the values of significant chemicals in the fluid as shown in laboratory analyses conducted through July 1976.

Table 4. CHEMICAL DATA ON WATER SAMPLES FROM HAWAII GEOTHERMAL PROJECT WELL IN PUNA (in mg/ℓ)

Na	400		
K	50	SO_4	160
Ca	5	SiO_2	151
Mg	1	N	(not yet measured)
Cl	600	P	(not yet measured)

The analysis of this water, and also of fluid obtained after the flashing of the well on 22 July, is continuing. Results to date show that the water is non-toxic, relatively low in salinity, with trace metals of no higher concentration then in the pre-existing wells of the Puna District shown in Figure 2. Among those wells, only Kapoho Shaft is down-slope; it is being monitored to ascertain if there are any changes in water quality occurring after the drilling.

E. Geotoxicology: Air and Well Water

Before drilling began, samples of air were taken and analyzed in May 1975 to establish baseline conditions with respect to mercury, considered to be the toxic element most likely to be associated with geothermal activity. At the same time, for comparative purposes the air quality at Banyon Drive, along the ocean front at Hilo, and at the Sulfur Banks in the Hawaii Volcanoes National Park, was also sampled for the same elements. The levels of mercury then obtained are shown in Table 5.

TABLE 5. AIR AND FALLOUT VALUES FOR MERCURY, ISLAND OF HAWAII, 22 MAY 1975.

Location	Measurement
Drill Site Air	$1.11 \pm 0.58\ \mu g \cdot m^{-3}$
Hilo Air	$0.44 \pm 0.27\ \mu g \cdot m^{-3}$
Sulfur Banks, Hawaii Volcanoes National Park Air	$2.6 \pm 0.51\ \mu g \cdot m^{-3}$
Sulfur Banks, Hawaii National Park Fallout	Hg^0, $250 \pm 80\ \mu g \cdot m^{-2}$ Hg^{2+}, $540 \pm 60\ \mu g \cdot m^{-2}$

During the period 24-27 June 1976, aerometric measurements were carried out at the drill site in conjunction with a proposed trial flashing of the exploratory well. Although the well did not flash during this period, hot water and steam plumes were produced.

The results of these measurements give no indication that human activities at the drill site have affected local air values for the fixed gases H_2S, SO_2, CO, CO_2 and NO_2, (Table 6). What was observed is that natural venting in the Hawaii Volcanoes National Park continues to inject high, and in some cases toxic, levels of these substances into the atmosphere. (Compare also Table 7).

As of April 1976, the Air Pollution Health Effects Report of the American Lung Association cites a maximum 24-hr. concentration for SO_2 at 0.14 ppm set by the Federal Environmental Protection Agency. It is possible that although we found < 0.5 ppm (detection limit), the EPA standard may well be exceeded -- indeed that the federal standard is and has been exceeded in many localities of the Big Island. If so, one has only to examine the levels of SO_2 at the Sulfur Banks in the Park and other open natural vent sites to account for the source of this gas at Puna. (The same report calls attention to sulfates and the S-oxide-particulate complexes. Neither sulfuric acid aerosols nor sulfate particulates have been included in our determinations, but it is obvious that this omission should be rectified in the future.)

In contrast with the well waters surfacing during the June survey, which smelled only faintly of H_2S (if at all), and did not precipitate PbS from saturated lead chloride solutions, the water produced during spontaneous flashing on 3 July 1976 did so. The sulfide concentration has not yet been determined.

TABLE 6. COMPARISON OF PAST AND CURRENT FIXED GAS AEROMETRIC DATA AT THE SULFUR BANKS AND HGP DRILL SITE (PUNA)

Gas	Concentrations (ppm)					
	1971-75		1-2 May 1976		24-26 June 1976	
	Sulfur Bks.	Puna	Sulfur Bks.	Puna	Sulfur Bks.	Puna
H_2S	up to 5	< 0.5	3-4	< 0.2	6.4 ± 0.8	< 0.2
SO_2	up to 25	< 0.5	14-16	< 0.5	18.0 ± 2.2	< 0.5
CO	up to 3	< 0.5	1.3-2.0	< 0.5	5.1 ± 1.3	< 0.5
CO_2	—	—	> 1000	330	1750 ± 650	360
NO_2	< 0.2	—	< 0.2	< 0.2	< 0.1	< 0.1

TABLE 7. AEROMETRIC DATA FOR 24-26 JUNE 1976 AT HGP-PUNA AND OTHER SITES, ISLAND OF HAWAII

Gas	Concentrations (ppm)				
	Sulfur Banks Solfotara	Sulfur Banks Steam Vent	Halemaumau Kau	HGP-Puna	Kilauea Caldera
H_2S	6.4 ± 0.8	1	< 0.25	< 0.2	< 0.25
SO_2	18.0 ± 2.2	4.5	7.2	< 0.5	0.5
CO	5.1 ± 1.3	ca 2	< 0.5	< 0.5	< 0.5
CO_2	1750 ± 650	440	400	360	385
NO_2	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1

Mercury aerometry, although limited except at the Sulfur Banks, shows the Puna drill site to have little more than Hilo air (Table 8). More important, this figure shows no upward trend during the year in which the drilling program was carried out.

Further, the water emerging from the well on 24 June had no detectable mercury, although the Puna reservoir yielded ca 3 $\mu g \cdot \ell^{-1}$ (vs. 5 in the previous analysis). On the other hand, water produced at depth during the spontaneous flashing of 3 July (analyzed on 6 July from a sample provided by P. Kroopnik) contains ca 5.9 $\mu g \cdot \ell^{-1}$, presumably the highest value for water ever recorded in Hawaii. This may create some problems with condensate water in the future, but it cannot be regarded as a significant source of atmospheric mercury because the metal is necessarily present as non-volatile HgS (presumably as a co-precipitate with Cu, Zn, etc.). Although, as pointed out, the sulfide content of this water has not yet been determined, it is clearly far in excess of the concentration required to precipitate the 3×10^{-8} moles$\cdot \ell^{-1}$ of Hg found (solubility product for HgS < 10^{-50}).

Mercury fall-out data (Table 9) suggest a moderate decrease in air levels from May to late June 1976 at Puna and elsewhere, but more significantly, they show a great reduction in elemental mercury, Hg^o accompanying a moderate rise in oxidized mercury, Hg. These changes do not reflect upon local HGP activities but appear to be associated with geothermal activity in the larger area.

TABLE 8. PAST AND CURRENT MERCURY EMISSION DATA AT HGP-PUNA AND OTHER SITES, ISLAND OF HAWAII

Date	Sulfur Banks	Halemaumau Kau	Mauna Ulu	HGP-Puna	Hilo
		Concentrations ($\mu g \cdot m^{-3}$)			
Apr. 1971	22.6	_	_	_	_
May 1971	20.5	_	_	_	0.31
Aug. 1971	40.7	40.5	_	_	_
Jan. 1972	2.2	0.7	_	_	_
Apr. 1972	33.5	_	35.3	_	_
Dec. 1973	0.9	_	_	_	_
May 1975	2.6	_	5.3	1.1	0.44
May 1976	5.3-10.0	_	_	1.2	_
June 1976	47.5	5.0	_	< 1	_

TABLE 9. FALL-OUT OF ELEMENTAL AND OXIDIZED MERCURY, ISLAND OF HAWAII

Date of Sample	Hg Deposited ($\mu g \cdot m^{-2}$) Trapping Surface			
	Au (Hg°)	Cu (Hg oxidized)	Total	% Hg°
Jan. 1972	80	377	457	17.5
May 1975	250	540	790	31.6
Dec. 1975	438	42	480	89.4
May 1976	1075	250	1325	80.1
June 1976				
Solfotara	135	600	735	18.4
Steam Vent	75	750	825	9.9
Halemaumau	130	500	630	20.6
HGP-Puna	138	600	738	18.7

We conclude that at this writing there is no analytical evidence that the drilling of the geothermal well at Puna has induced hazardous changes in environmental chemistry. There is, however, good reason for continued surveillance.

F. Avifauna

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 sugar cane 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 the geothermal drilling 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.

In February, 1976 -- after the drilling had started but while it was in an early stage -- a search was made for birds and possible nesting grounds within a one-mile radius from the site. Two days of field observations 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 "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. Melodious 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 the impact of geothermal drilling on the limited birdlife of the area adjacent to the site has not been significant.

G. Archaeological and Cultural Sites

Historically, Puna has played a relatively insignificant role in the centuries of seesaw relationships that had marked the political power and control activities on the Island of Hawaii. During all of its known history, Puna produced no great family or chief whose support was crucial in deciding control over lands contested by the many warring factions. Why it was that this district never developed strong leadership or a political power base is not known. Perhaps the size of the population was inadequate, or perhaps local ecological conditions were disadvantageous and would not allow for the necessary logistical support of a sufficiently strong army. Or perhaps time alone was a negative factor in the required socio-economic development of the culture prevalent in the region. Whatever the reasons, the fact remains that the political control of Puna was wielded by the bordering districts of Hilo and Ka'u.

An area within a mile radius of the exploratory well site was studied for its archaeological significance. The area consists of recent as well as prehistoric lava flows. The 1955 eruption of Kilauea Volcano broke through the earth's crust approximately one-quarter mile from the drilling site and as a result of this relatively recent volcanic activity any archaeologically significant material in the study area, or for that matter within the region covered by this flow, has been obliterated, if indeed any was ever present prior to this environmental change.

Examination of this lava-layered region, as well as the geologically older ground within the study area, failed to uncover any evidence of archaeological sites, artifacts, or other data that would indicate prehistoric occupation or activity in this tract of land. If this area of Puna was anciently altered in any way by man, it presents no evidence to this effect. Possibly agricultural plots may have been developed at some time in the prehistoric past, but these too, if ever present, show no signs of existence at the present time.

The contemporary flora, consisting generally of scrub _ohia_ trees, brush, some ferns and a fair amount of grass and weed overlay, is not ideal for the differentiation and location of archaeological remains. However, it is sufficiently traversable so as to allow confidence in those negative conclusions.

Although no archaeological features or evidence were found within the study area, there are a number of sites further off in the northeastern portion of the District. The location of these sites is shown in Figure 1.

Approximately one-half mile west of the project site, near the intersection of Highway 132 and Pahoiki Road, is located the Lava Tree State Park, a feature not of archaeological significance but of geological interest. This 17-acre park, known locally as Kanakaloloa, consists of about 75 standing lava tree casts formed during historic flows through this originally forested area. These tree casts were formed when the lava encapsulated standing trees, which then burned out, leaving an almost perfect mold of each tree. To safeguard this park, the sole area of exceptional interest close to the drill site, it will be necessary to monitor future operations at the geothermal well, but nothing in the observations made to the point of test-flowing the well indicates that the Park, or anything else of value to man, has been adversely affected by the drilling.

4. SUMMARY OF FINDINGS AS TO ENVIRONMENTAL CONDITIONS IN VICINITY OF WELL SITE

The area of the Puna District within a mile radius of the exploratory well is relatively impervious to adverse environmental change caused by geothermal development. It is an area almost empty of population and with but limited economic activity. Its chief surface features are recent lava flows, across which have been scratched roads for residential subdivisions which have been marketed but not constructed. Beneath the land, no fresh water lens has been discovered: the few wells bored within the mile-radius circle have yielded hot and brackish water at sea level.

The rather meager flora in this sector is common to lands in Hawaii recently covered by lava flows; no rare or endangered species of plants were encountered. The fauna of the area is even more limited: rats, mongooses, a few domestic animals and the introduced birds widely distributed in Hawaii. Search was made for indigenous, rare or endangered species of birds which might possibly inhabit this portion of Puna, lying between mountains and ocean, but none were observed.

Nor are there known archaeological sites in this tectonically active corner of the Big Island, never a center of Hawaiian culture but rather a lonely place through which people hastened on their way to the shores of Puna.

Chemical tests of air and ground water yielded results which were readily predictable for an area so close to the vulcanism of Kilauea. Levels of SO_2 in the air were relatively high, as they are at the Sulfur Banks in the Hawaiian Volcanoes National Park and other natural open-vent sites. Some of the values for H_2S, CO, CO_2, and NO_2 detected at the well site were also relatively large, but not so high as to suggest any adverse affects on flora or fauna. The one element which alerted the geotoxicologists to the need for continued surveillance was mercury -- not by its absolute level, but because of the rise noted in measurements made as the drilling proceeded and the well was allowed to flow.

In sum, the baseline studies show no threat which the exploratory well poses to the environment of the area immediately (within one mile radius) adjacent to the drill site. Rather, the studies have identified certain elements which should be monitored as testing of the well continues and before a final judgment can be made of the environmental impact, notably mercury and other heavy metals.

5. POSTSCRIPT ON THE INITIAL TESTING OF THE WELL

On the afternoon of 22 July 1976 the exploratory well was flashed to test its relevant physical properties. The flow began at approximately 2:00 P.M. and continued until 6:00 P.M., yielding steam and water of an unexpected degree of freshness (*i.e.* low in sulfuric elements and not brackish). Tests of the water are continuing and will be reported later.

Between 2:10 and 3:10 aerometric data were collected for fixed-gas contaminants and mercury, during which time winds were moderate and variable in direction. Sampling was carried out from a station approximately 20 meters east and 20 meters south of the intersection of the Pohoiki Bay Road and the Leilani Road, about 60 meters -- downwind, during most of that hour -- from the emission pipe at the wellhead.

Triplicate samples of air were taken for SO_2, H_2S, and CO; each sample volume being in the range of approximately 0.75-1.5 liters. Detectors for the three gases were distributed over the 60-minute period, and over an area of approximately 250 square meters.

The results of these measurements were essentially the same as those summarized in Table 6 for the Puna sites on 24-26 June, 1976. That is, the detection thresholds were not exceeded.

Additional tests were carried out on 22 July, using acidified 5% barium chloride as an indicator of atmospheric SO_3 or sulfuric acid aerosols. (The acidification prevents precipitation of the barium by SO_2 or CO_2, hence is a specific indicator.) A one-hour, 30 liter air sample produced no turbidity in the solution, a clear negative finding. A similar H S detection trap was set up containing saturated, aqueous lead chloride. Again, no precipitation (of brown PbS) was observed when ca 30 liters of air were drawn into the solution.

We conclude that no significant changes in the levels of atmospheric SO_2, H_2S and other possible toxic emissions occurred during the first (and presumably most intensive) hour of flushing.

However the situation with respect to mercury appears to be different (Table 10). The total air mercury collected during the first hour of well flushing, 9.9 $\mu g \cdot m^{-3}$, is about 10-fold greater than the three values obtained at the Puna site during the previous 14 months. The sample is approximately 17% elemental Hg, the remainder consisting of oxidized forms.

The fallout level found, 1260 $\mu g \cdot m^{-2}$, did not increase as dramatically, but was, nevertheless, substantially higher than in previous determinations. Elemental mercury accounted for about one-third of the total fallout.

In 1971 (Eshleman, Siegel and Siegel, Nature 233:471) it was reported that ca 2% of the fumarolic Hg emitted at HVNP sites was in the form of particles >0.3 μm in size. Our current findings show that ca 9% of the Hg released into the atmosphere during flashing took the form of particulates >0.22 μm in size. The significance of this difference is not now apparent, but particulate Hg again appears to a minor component.

The open Puna reservoir was again sampled, and the total Hg content of 4.6 $\mu g \cdot \ell^{-1}$ agrees well with previous determinations.

TABLE 10. AEROMETRIC MERCURY DATA FOR THE HGP-PUNA DRILLSITE ON JULY 22, 1976

Air	Hg Level
	Average $\mu g \cdot m^{-3}$
Elemental Hg (based upon Au trap)	1.7
Total Hg (based upon Au/HNO_3 trap)	9.9
Particulate Hg (based upon 0.22 µm millipore filter)	0.9
Fallout	Mean $\mu g \cdot m^{-2}$
Elemental Hg (based upon Au-foil)	450 ± 350
Total Hg (based upon Cu-foil)	1260 ± 824

The sharp rise in air Hg levels suggests that there is in fact an Hg source -- possibly at depth -- not greatly different in content and yield from those associated with natural venting, both in Hawaii and Iceland.

However, the contribution of Hg from deep waters having extended contact with rock and mineral substances cannot be assessed at present. Even if the rise in air Hg does reflect the metal present in recharge water at depth, the first period of flashing, with high initial pressures and flows, may not be representative of output during long-term well flowing.

It is obvious that continuing field measurements coordinated with further well output trials are required, as well as more information about the remarkably consistent high Hg level in the open reservoir.

It is appropriate to conclude with this statement of Sabadell and Axtmann (Environmental Health Perspectives 12,1-1975): "Such considerations emphasize the need for systematic monitoring programs for mercury and other trace heavy metals, as well as radioactive contaminants such as ^{222}Rn and its daughters (8) stage, both before and after preoperational drilling and well-testing, and continuing into the operational phase. Only in this way can the contribution of geothermal exploitation to environmental contamination be determined."

APPENDIX: ARCHAEOLOGICAL SITES NEIGHBORING THE STUDY AREA

(See Figure 1 for approximate locations of the archaeological features. The numbers on the map correspond to the order number of the sites listed below.)

Site	Tax Key No.	Locality
1. Kehena Beach Trail	1-2-09:22	Keekee

This section of trail is part of the coastal trail which once encircled the Island of Hawaii. Additional portions of this same trail may be seen in the MacKenzie State Park. Large waterworn stones mark the trail and an explanatory sign has been posted not far from the coastal road. The Kehena Beach Trail is an excellent example of Apple's (1965) Type A trail.

2. Ancient Burial Ground	1-3-04:71	Opihikao

The platform type of construction of these graves suggest a post-historic origin for these structures.

3. Housesites, Trail, Petroglyphs	1-3-07:27	Malama-ki

The section of coastal trail in the MacKenzie State Park is well maintained. Here it shows the Kerbstone type of construction, classifying it as being in the period 1820-1840.

Neither the home sites nor the petroglyphs in the area could be located during the field check, although the latter were noted over 15 years ago.

4. Mahinaakaka Heiau	1-3-08:15	Keahialaka

Mahinaakaka Heiau is located back of the beach front, approximately 1,000 feet to the south of Lae o Kahuna point, near Isaac Hale Park. It is easily accessible by a private road.

It is of the platform type of heiau and in good condition, though the sea has eroded its eastern side. Nonetheless, it is still possible to distinguish its shape, features and size: north-south width of approximately 40 feet, a maximum east-west length of 120 feet, maximum height about 12 feet.

The north wall of the heiau has two levels. The first is approximately four feet high and no more than two feet wide. The second level rises another four feet. The western end has crumbled and as a result it is difficult to distinguish height along this side. The southern wall rises perpendicularly, without terracing, and shows crumbling at its seaward end.

The eastern or seaward portion of the heiau seems to have had three levels. The first is at ground level and shows paving; though its length cannot be accurately measured, it can be distinguished by an alignment of waterworn stones along its northern side. From what remains of this level we can say that it was at least four feet wide. The second level, is, in terms of height and width, much like the first level of terracing along the northern wall of the heiau. The third, or highest level, on the sea side of the site, corresponds to the second level of the northern wall, although it is not as high.

The central or top portion of the heiau could not be examined as a dense growth of young coconut trees covers this area. It is said to have been paved, though already disturbed by 1931. (Hudson: 1932, p. 78).

Although there are no written sources specifying its class, function or age, it is one of the better preserved heiaus of the Puna area. A local informant mentioned the finding of various artifacts while clearing land to the west of this site, and the presence of a plot of native Hawaiian pineapple to the north of the heiau support the belief of a sizeable prehistoric population in the area.

5. Keahialaka Spring and Pond 1-3-08:15 Keahialaka

This brackish water pond is located immediately to the south of Mahinaakaka Heiau. A retaining wall along the edge of the pond was noted, and from this another low wall extends up a gradual slope to pass within approximately 25 feet from the western end of the heiau.

6. Housesites, Trail, Petroglyphs 1-3-08:1 Kaukulau

A few petroglyphs are scattered on the pahoehoe near the trail that runs along the coast north of MacKenzie State Park. These and a few scattered house foundations should be archaeologically examined and perhaps preserved by an expansion of the present boundary of the Park.

7. Warm Springs 1-3-08:5 Pohoiki

The tiny pool of warm water is located on the Kalapana side of the gravel beach at Isaac Hale Park. It cannot really be classified as a "historic site" as there is little to indicate man-made changes on this natural phenomena, but it is a place of interest and natural charm.

8. Old Coffee Mill 1-3-08:5 Pohoiki

This large two-story structure is located along an old jeep trail between Isaac Hale Park and the coastal road. It is in excellent condition, and is a unique architectural piece, worthy of protection and reconstruction as a relique of an older Hawaii. The concrete walls are approximately two feet thick. There are no windows on the first or ground floor of the building.

9. Petroglyphs 1-4-2:31 Kapoho

Petroglyphs are carved in the large vertical basaltic slabs that make up the face of the old Kapoho dome to the east of Green Lake. At least six clusters of figures were located under the heavy undergrowth, trees and moss coating that ring the base of the Kapoho cone. Most of the figures represent men in the common stick or triangular bodied forms. Some show the "ear plug" feature, a fairly uncommon trait seen in but a few other locations in Hawaii. It is highly likely that there are many more of these petroglyphs than were seen by our field party, for we have descriptions of other figures, such as what may be carvings of crossed spears and men with clubs over their heads.

These petroglyphs are cut into the face of the large upright segments of stone instead of the usual smooth, flat pahoehoe. In this, they resemble, at least in environmental context, the Nuuanu carvings on Oahu. They generally are in excellent condition, perhaps protected from erosive action by the heavy vegetative cover. In size, they range from one foot to two and a half feet high.

This series of petroglyphs around the base of this volcanic dome should be preserved, for they are well made, they are unique in their local placement on upright basaltic slabs, and they exhibit the "ear plug" feature which may be illustrative of a Marquesan trait and hence may support the hypothesis that the early Polynesian migrants left from the Marquesas on their primary voyage to Hawaii.

10. Kumakahi Grave Sites 1-4-02:1 Kapoho

The type of construction associated with these graves indicates a post-historic date. As with other grave sites, these structures must be preserved in accordance with provisions of the National Historic Landmarks program.

11. Kukii Heiau Ruins 1-4-02:2 Kapoho

Kukii heiau is reputed to have been built by King Umi after his ascension to power and to have served with minor importance as a fishing shrine. However, the original construction is said to have employed cut stone, a distinguishing feature of the heiaus built by Umi and which undoubtedly took much time and effort. In this case, however, it may be that the hewn stones were flat land slabs which may have been fitted together.

Certainly by 1931 the heiau was in a state of ruins, and as Hudson says it, "apparently consisted of a platform built up on the sides to a level with the top of the hill and with a wall along its west side. There may also have been a wall on the north but the present condition is too dilapidated to give an accurate idea.... No trace at all remains of stonework on the east end; at this point the hillside drops very sharply and it may have been considered too difficult or unnecessary to build it up" (Hudson: 1932, p. 67). No interior features are presently discernible and the paving has been destroyed or disrupted by the heavy growth of vegetation.

In addition the heiau has been robbed of stone, once in 1879 by Kalakaua, for use in the foundation walls of Iolani Palace, and again in the building of Kapiolani's residence. More recently, some of the remaining stones may also have been "removed to the Lyman house in Kapoho." (*Loc. cit.*)

This site cannot be preserved because of its poor condition. However, additional data should be gathered by careful excavation and study before any further disturbance and destruction takes place.

12. Kahuwai Village 1-4-03:13 Kahuwai

This interesting and extensive coastal villages lies in the ahupua'a of Kahuwai. It covers an area of approximately 100 acres, extending southward from Makaukiu Point. Contained within this village are at least 45 house platforms, four canoe sheds, two possible heiau structures, numerous walls, trails and what might be agricultural plots. The condition of these structures range from excellent to poor. A thick layer of soil is present, covered by a thin layer of cinder that covered the region during the 1960 eruption at Kapoho. Systematic tests in pits made by the leasee in one of the platforms has yielded fishhooks, obsidian chips and adzes. Further, other artifacts including an adze have been found on the sandy surface near the coast.

In age, the structures range from pre-historic through the post-historic period. Ellis, during his journey around the island in 1823, mentions his stop at Kahuwai Village where he "sat down and took some refreshment, while Makoa was engaged in bringing the people of the place together. About one hundred and fifty assembled around the door,..." (Ellis: 1917, p. 223). A Bishop Estate survey in 1895 by an A. R. Loebenstein showed agricultural workings in the area.

The village is now under heavy forestation of guava, hau, 'ulu, coconut, castor bean trees, and this growth has destroyed and is continuing to destroy the structures, although at one time the area was classified as grassland or meadow.

Kahuwai Village has the potentiality to offer much information pertaining to ancient Hawaiian life and the changes which resulted from contact with foreign sources. Initial excavations indicate that the site is capable of producing valuable archaeological information.

13. Early Hawaiian Well 1-4-03:20 Honolulu

This site is of no real significance and field investigation did not produce sufficient data to warrant protection.

14. Kamehameha Crevice 1-6-01:3 Keeau

While it may be true that Kamehameha I invoked his famous Mamalahoa law as a result of his getting his foot caught in some crevice of in the Papai Bay area, and then while helpless being hit over the head by a man with a paddle, it would be asking too much to expect anyone, Kamehameha I included, to be able to locate that particular crevice.