DOE/EA-0071

ENVIRONMENTAL ASSESSMENT

Hydrothermal Geothermal Subprogram

Hawaii Geothermal Research Station

Hawaii County, Hawaii

DOE/EA--0071

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U.S. DEPARTMENT OF ENERGY
Assistant Secretary for Energy Technology
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MASTER

DISCLAIMER

SUMMARY

This environmental impact assessment addresses the design, construction, and operation of an electric generating plant (3 to 4 MWe) and research station [Hawaii Geothermal Research Station (HGRS)] in the Puna district on the Island of Hawaii. The facility will include control and support buildings, parking lots, cooling towers, settling and seepage ponds, the generating plant, and a visitors center. Research activities at the facility will evaluate the ability of a successfully flow-tested well (42-day flow test) to provide steam for power generation over an extended period of time (two years). In future expansion, research activities may include direct heat applications such as aquaculture and the effects of geothermal fluids on various plant components and specially designed equipment on test modules.

Construction-related impacts would be relatively minor. Construction of the facility will require the disturbance of about 1.7 ha (4.1 acres). No further disturbance is anticipated, unless it becomes necessary to replace the seepage pond with an injection well, because the production well is in service and adjacent roads and transmission lines are adequate. Disruption of competing land uses will be minimal, and loss of wildlife habitat will be acceptable. Noise should not significantly affect wildlife and local residents; the most noisy activities (well drilling and flow testing) have been completed. Water use during construction will not be large, and impacts on competing uses are unlikely. Socioeconomic impacts will be small because the project will not employ a large number of local residents and few construction workers will need to find local housing.

Routine operational effects would also be minor. Air pollution by the facility should not be sufficient to affect humans, plants, or wildlife. Repugnant, odor-producing, hydrogen sulfide (H_2S) emissions would occasionally be detectable to nearby residents, but only under a combination of unfavorable conditions (well venting under poor climatic conditions during downtime when discharged geothermal fluids are required to bypass H_2S abatement equipment). However, under these conditions, the well will

be vented to the emergency H_2S abatement equipment (hydrogen peroxide system). The effects of water withdrawal will be minimal but the effects of injection are more problematical. If necessary, the operators of the research station are prepared to replace their proposed seepage pond with a deep injection well. While there is a remote possibility that seepage through the settling pond could contaminate existing potable water supplies, injection into a deep aquifer would reduce the likelihood of contamination. Shallow aquifers will be monitored for evidence of contamination.

Operation of the facility may bring a few new residents to Hilo, Hawaii, but the impact on the socioeconomic character of the Puna district is not expected to be significant. Some native Hawaiians, however, have an interest in preserving their primitive culture and natural surroundings and may view this project as a potential indirect threat to their environment. Such opposition is not unique to projects such as the HGRS.

The most likely accident resulting from operation of the facility is uncontrolled release of geothermal fluids. Such a release may be due to pipeline rupture, failure of the well casing, or loss of control at the wellhead (blowout). The latter type of release is unlikely because the only planned production well has been successfully completed. The likelihood of destruction of the research station by volcanic eruption during its two-year operating life is believed to be less than 1%.

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1. DESCRIPTION OF THE PROPOSED ACTION

Over 90% of the energy used in Hawaii is supplied by imported petroleum products. Since the oil embargo of 1973, there has been a heightened awareness of Hawaii's dependence on petroleum supplies from unreliable sources and the impact of the increasing cost of those supplies. In response, an effort has been made to identify and develop energy supplies indigenous to Hawaii. These include solar and wind energy, solid waste and biomass fuels, ocean thermal and geothermal energy.

Solar heaters and biomass fuels are now providing limited energy for domestic hot water and process heat, but geothermal electrical power is the largest potential source of energy for Hawaii. Initial exploration on the Island of Hawaii indicates that economically exploitable geothermal reservoirs, characterized by relatively high temperatures and pressures, exist. A test facility is planned that will investigate the potential uses of the geothermal energy by conducting experimental tests of electrical power and nonelectric applications.

The Hawaii Geothermal Project (HGP) is a coordinated research effort of the University of Hawaii. It is funded by the State and County of Hawaii and by the U.S. Department of Energy (DOE). The project was initiated in 1973 in an effort to identify, generate, and promote the use of geothermal energy on the Island of Hawaii.

A number of stages were involved as the project developed: (1) exploration (surface methods), (2) test drilling, (3) well completion, (4) extended flow testing, and (5) construction of the Hawaii Geothermal Research Station (HGRS). The continuous flow-testing stage was completed in the first half of 1977, an action that was the subject of an earlier environmental impact assessment (EIA).[1] The results of these tests indicated that a substantial geothermal resource exists.

Accordingly, funds for construction of the research station were made available, pending the favorable outcome of Federal, State, and County licensing actions. Federal and State EIAs are required because of the commitment of Federal and State funds to the project.

Investigations thus far concluded have provided initial baseline data describing the existing environmental setting of the drilling site and vicinity before drilling was begun. Data gathering continued throughout the drilling phase and flow-testing operations so that changes to the environs of the immediate drilling area could be detected. This type of comparative data is essential to the development of mitigating measures that will provide for environmentally acceptable operations of the HGRS.

The purpose of this DOE-sponsored assessment is to describe the activities and potential impacts associated with the construction and operation of the HGRS (the culminating phase of the HGP).

1.1 SITE LOCATION

The Hawaii Geothermal Project well (HGP-A) is located in the Puna district on the southeast side of the Island of Hawaii (Fig. 1.1). Puna represents about 15% of the land area of the Island. The site (Fig. 1.2) is about 6.4 km (4 miles) east-southeast of the town of Pahoa, adjacent to the Pahoa-Pohoiki Road (19°28'30"N by 154°53'30"W).

The Pu'u Honualoa volcano is about 1.2 km (0.75 mile) northeast of the site and is easily visible from the site; the Pu'ulena, Pawai, and Kahuwai craters are located at about the same distance south of the site. Lava Tree State Park is 1.6 km (1 mile) north of the site, and a University of Hawaii Experimental Station is located 1.6 km (1 mile) south of the site.

1.2 PRIOR GEOTHERMAL DEVELOPMENT

Drilling for geothermal energy began on the Island of Hawaii in the early 1960s. Four wells were drilled in the Puna region, ranging in depth up to 305 m (1000 ft). None of these wells were successful in recovering steam.

The HGP-A well was drilled in April 1976. This well was completed to a depth of 1967 m (6453 ft). A bottom-hole temperature of 358°C (678°F) was recorded, making it one of the hottest geothermal wells in the world. Surface casing was set to a depth of 692 m (2270 ft), and a 19.4-cm (7-5/8-in.) slotted liner was placed from the lower end of the casing to the bottom of the hole.[2]

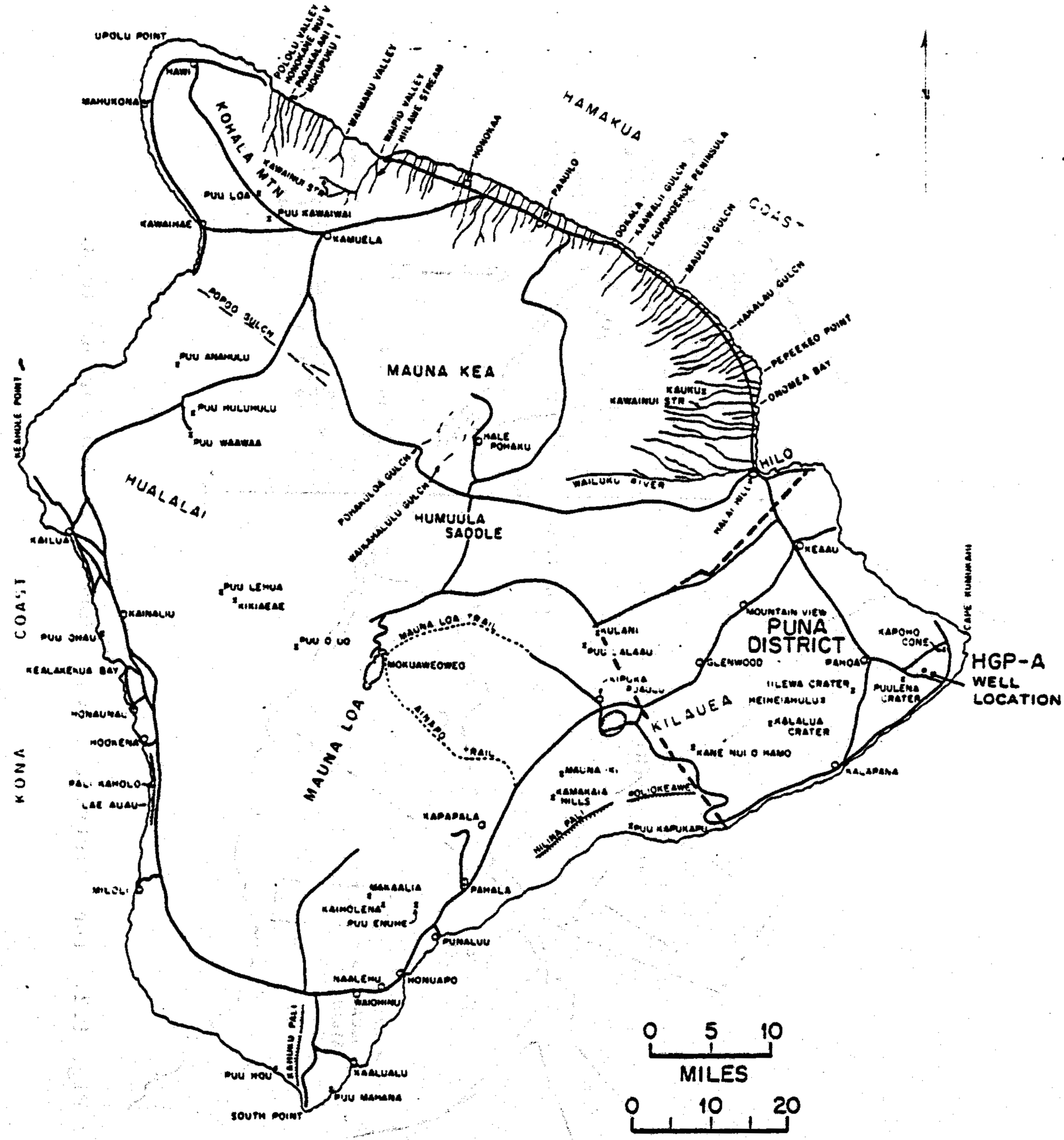

Fig. 1.1. Location of HGP-A well within Puna district of the Island of Hawaii. Source: R. M. Kamins, *Environmental Impact Statement for the Hawaii Geothermal Research Station Utilizing the HGP-A Well at Puna, Island of Hawaii*, prepared for the Department of Planning and Economic Development, State of Hawaii, March 1978.

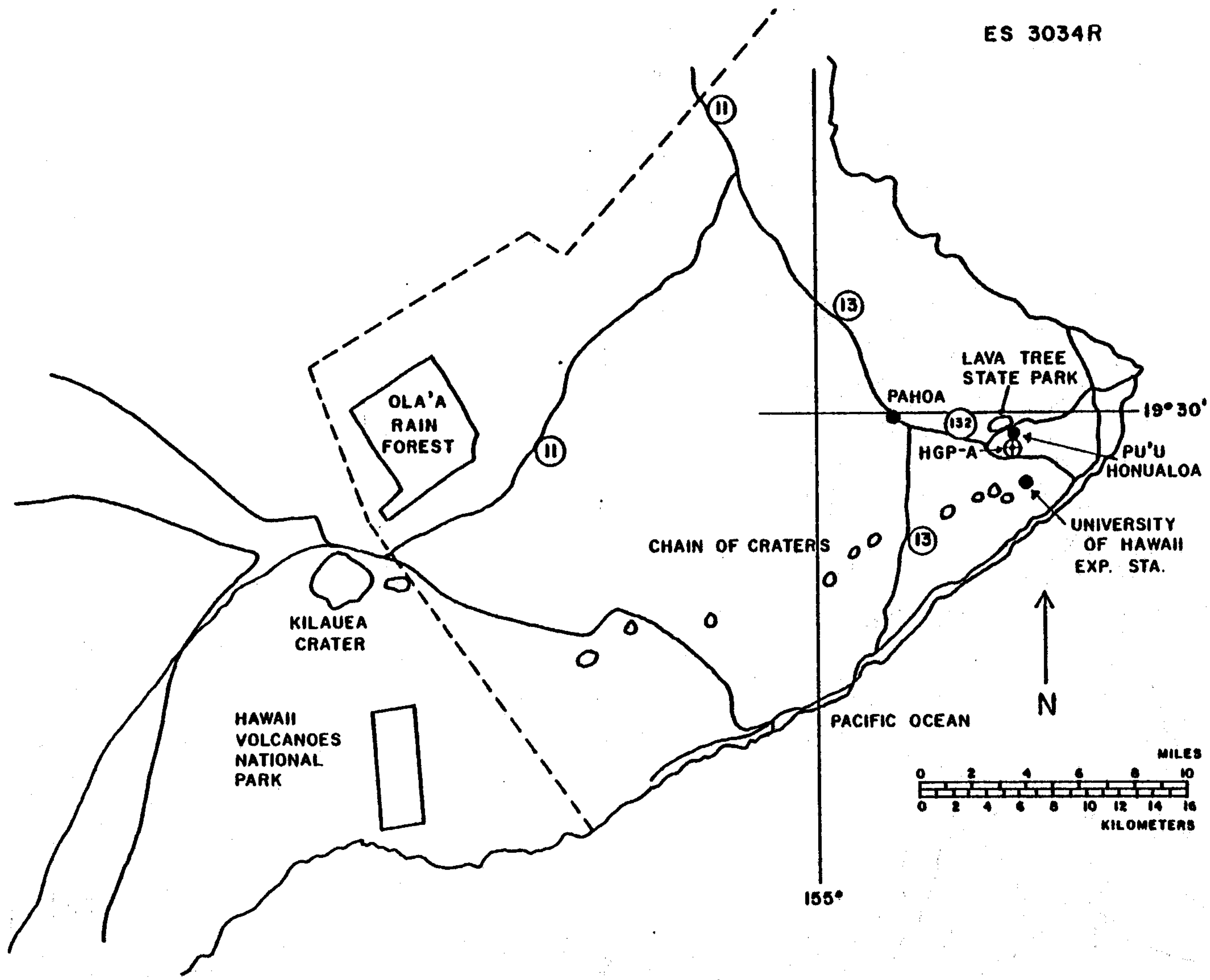

Fig. 1.2. Puna district showing HGP-A well and surroundings.

Initial flow testing of the HGP-A well took place in July 1976, and full-scale flow testing was completed by mid-1977. After 42 days of continuous, wide-open discharge through a 7.6-cm (3-in.) orifice, this well was producing 37,800 kg/hr (83,400 lb/hr) of steam and water at a wellhead pressure of 1.16×10^6 Pa (168 psig) and at a temperature of 190°C (374°F). The enthalpy of the well was 494 cal/g (890 Btu/lb). The steam quality was between 60 and 70%.[2] Approximately 3.5 MW of electrical power (30 MW of thermal power) could be supplied from this well, depending on the size of the orifice. A wide range of operating pressures and temperatures is available (Table 1.1).[3]

The well is located on a 1.7-ha (4.1-acre) site that is virtually undeveloped (except for the well). Figure 1.3 is a diagram of existing facilities that were installed for the flow test. A cyclone fence encloses a small area surrounding these installations, but the rest of the site is not fenced (Fig. 1.4). A small, unlined pit [3×5 m (10×15 ft)] was excavated to a depth of about 1.5 m (5 ft) to collect and dispose of fluid produced during the flow test. Virtually all the fluid was discharged underground by seepage through scoriaceous basalt and lava tubes on and beneath the floor of the pit.[4]

Aside from the well and flow-test equipment, the only remaining evidence of previous activity is a holding pond [0.68×10^6 liter (0.18×10^6 gal)] for drilling fluid (no longer in use). This impoundment has a synthetic (butyl) liner and is surrounded by a dike consisting of earth fill. Although the liner leaks, there is usually a substantial amount of standing rainwater in the impoundment.[4]

1.3 PROJECT DESCRIPTION

A single geothermal well (HGP-A) will provide geothermal fluids to the HGRS. This facility will generate a small amount of electrical power for a local utility and will test experimental power and nonelectrical applications of geothermal fluids.

Recent project schedules call for plant startup in early 1980. The plant is scheduled for shutdown two years after startup. Power plant

Table 1.1. HGP-A wellhead conditions and produced fluid characteristics

Orifice size (cm)	Total mass flow		Steam flow rate		Steam quality (%)	Wellhead pressure		Wellhead temperature [°C (°F)]	Estimated electrical power output MWe
	(10^3 kg/hr)	(10^3 lb/hr)	(10^3 kg/hr)	(10^3 lb/hr)		(10^3 Pa)	(psig)		
20.3	45.9	101	31.8	70	64	352	51	146 (295)	3.3
15.2	44.9	99	31.8	70	66	372	54	149 (300)	3.4
10.2	42.2	93	30.0	66	64	690	100	170 (338)	3.5
7.6	40.4	89	28.1	62	60	1140	165	189 (372)	3.5
6.4	38.1	84	26.3	58	57	1630	236	205 (401)	3.3
5.1	37.0	82	25.0	55	53	2020	293	215 (419)	3.1
4.4	35.0	77	23.0	51	52	2590	376	226 (439)	3.0

Source: Hawaii Natural Energy Institute, *Summary Geothermal Energy in Hawaii – Hawaii Geothermal Project*, University of Hawaii, Honolulu, January 1978.

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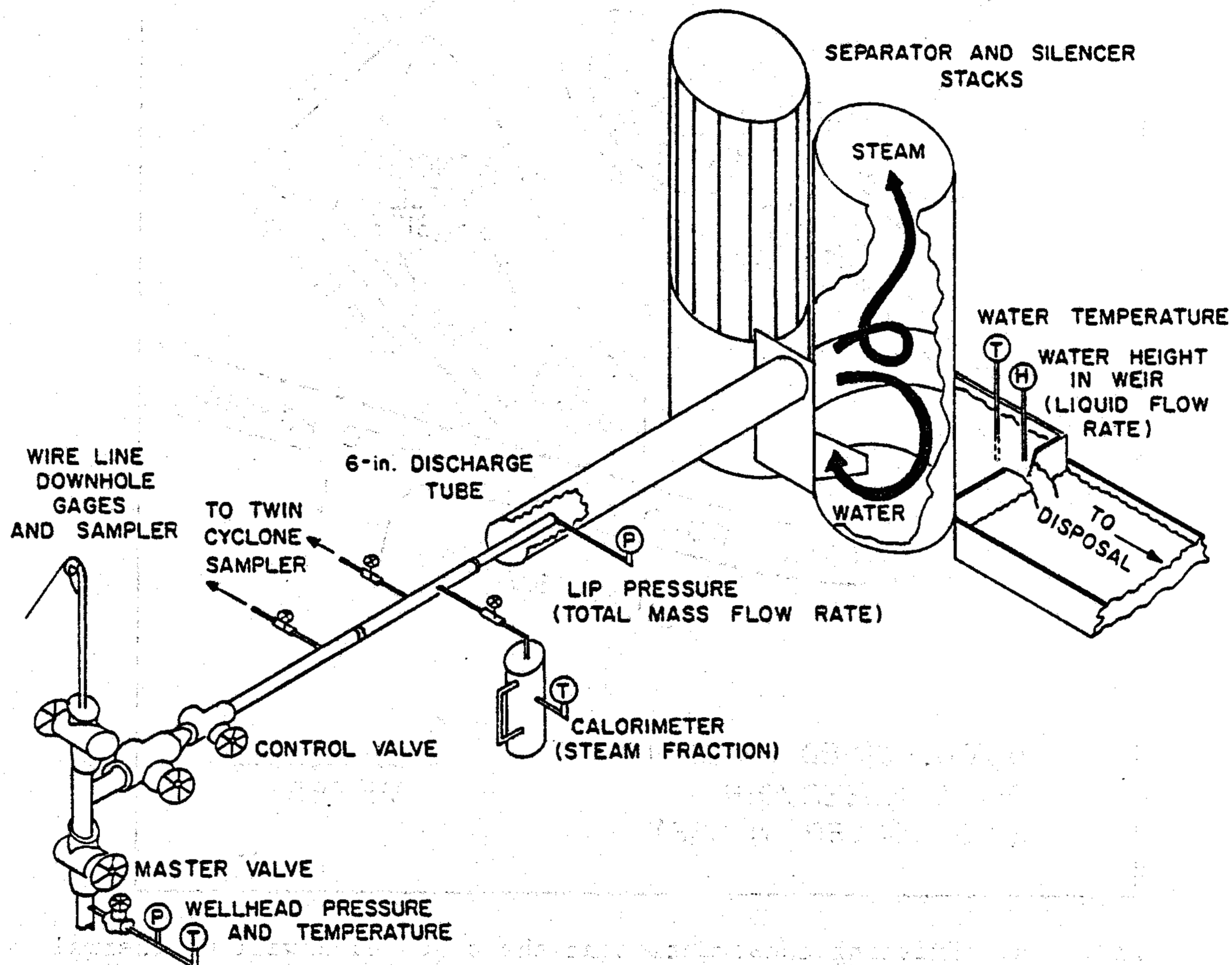

Fig. 1.3. Hawaii Geothermal Project — flow-test equipment and instrumentation. <u>Source</u>: R. M. Kamins, *Environmental Impact Statement for the Hawaii Geothermal Research Station Utilizing the HGP-A Well at Puna, Island of Hawaii*, prepared for the Department of Planning and Economic Development, State of Hawaii, March 1978.

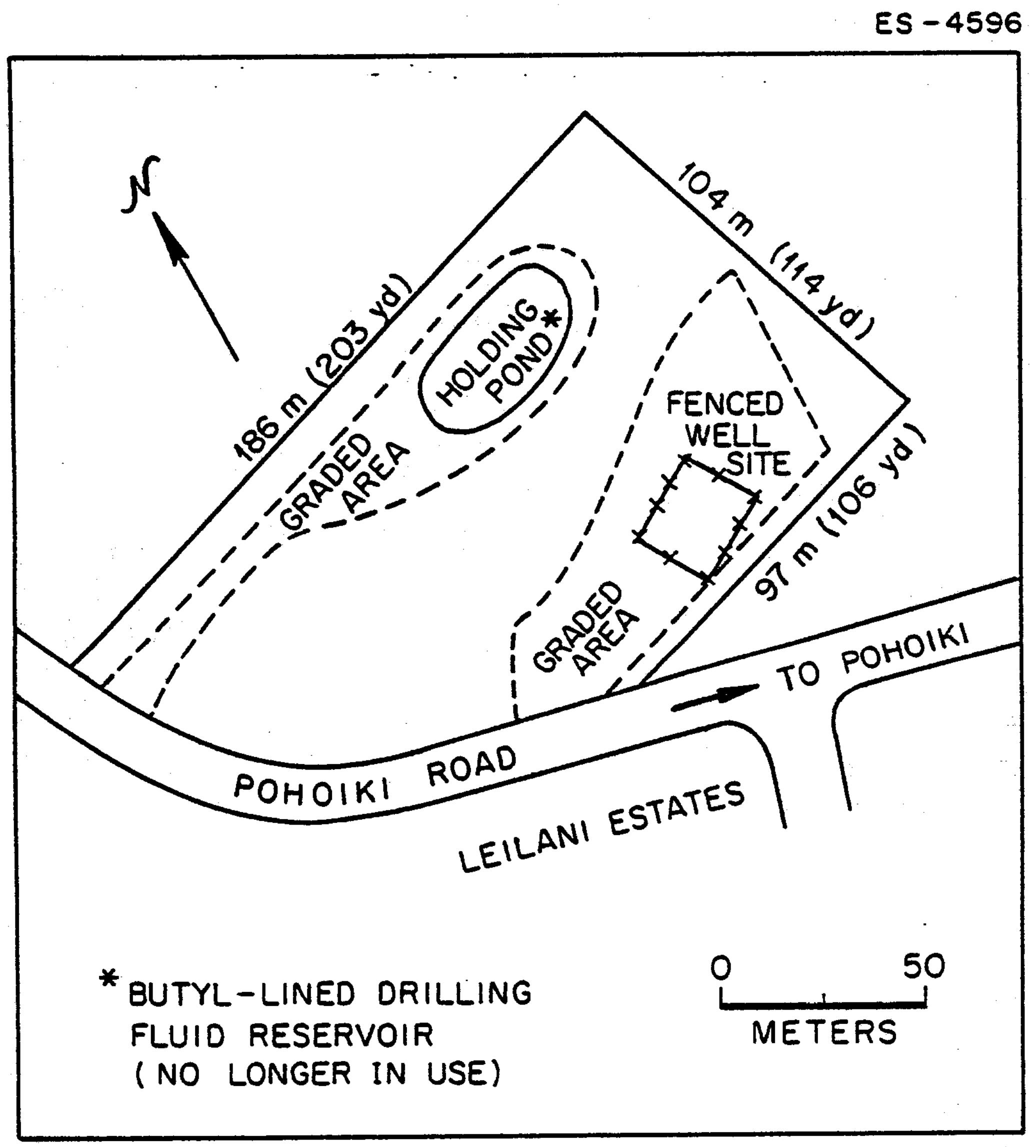

Fig. 1.4. Existing construction at the proposed Hawaii Geothermal Research Station. Source: R. M. Kamins, *Environmental Impact Statement for the Hawaii Geothermal Research Station Utilizing the HGP-A Well at Puna, Island of Hawaii,* prepared for the Department of Planning and Economic Development, State of Hawaii, March 1978.

operations after shutdown could be resumed by the Hawaii Electric Light Company (HELCO), but agreement on this point has not yet been reached. Depending on project funding, a variety of experimental power and non-electrical applications of geothermal fluids will be tested concurrently with power plant operation. Equipment will be designed specifically so that it can be relocated at another site if the project is terminated because of site problems such as lava flows.

1.3.1 Construction

The HGRS will be constructed on a 1.7-ha (4.1-acre) site. A preliminary baseline site plan identifying the major pieces of equipment and connecting piping is shown in Fig. 1.5.

Prominent features of the station include (1) cooling towers, (2) a test-pad shade, (3) support facilities, (4) a low-level-type, direct-contact condenser, (5) a drain field, (6) a steam-water separator, (7) switchgears, (8) transformers, and (9) load banks for dissipating power in excess of that which can be transmitted or used by the station.

The induced-draft, evaporative cooling tower unit will be the most prominent feature of the HGRS and will have overall dimensions of 5.6 m (height), 8.8 m (inside), and 19 m (length) (19 × 29 × 62 ft).

The injection well (Fig. 1.5) will be replaced by a 9.1 × 12.2 m (30 × 40 ft) retention pond and an equally sized seepage pond. From the site access road, the two ponds will be hidden from view behind the cooling towers.

As depicted by Fig. 1.5, a perimeter fence will enclose 0.77 ha (1.9 acres); paved areas will cover 0.37 ha (0.91 acres), including 0.10 ha (0.24 acres) of parking and turnaround areas; and crushed stone around the plant equipment should cover 0.26 ha (0.65 acres).

During construction, the paved roads accessing the site should be capable of sustaining the expected traffic and loads. Based on a rough estimate of $0.4 million for onsite labor, an average of eight to ten workers will be on the site.[5] During peak work periods, the number of workers on the site might exceed 20. Drinking water and portable toilets will have to be brought on site during construction.

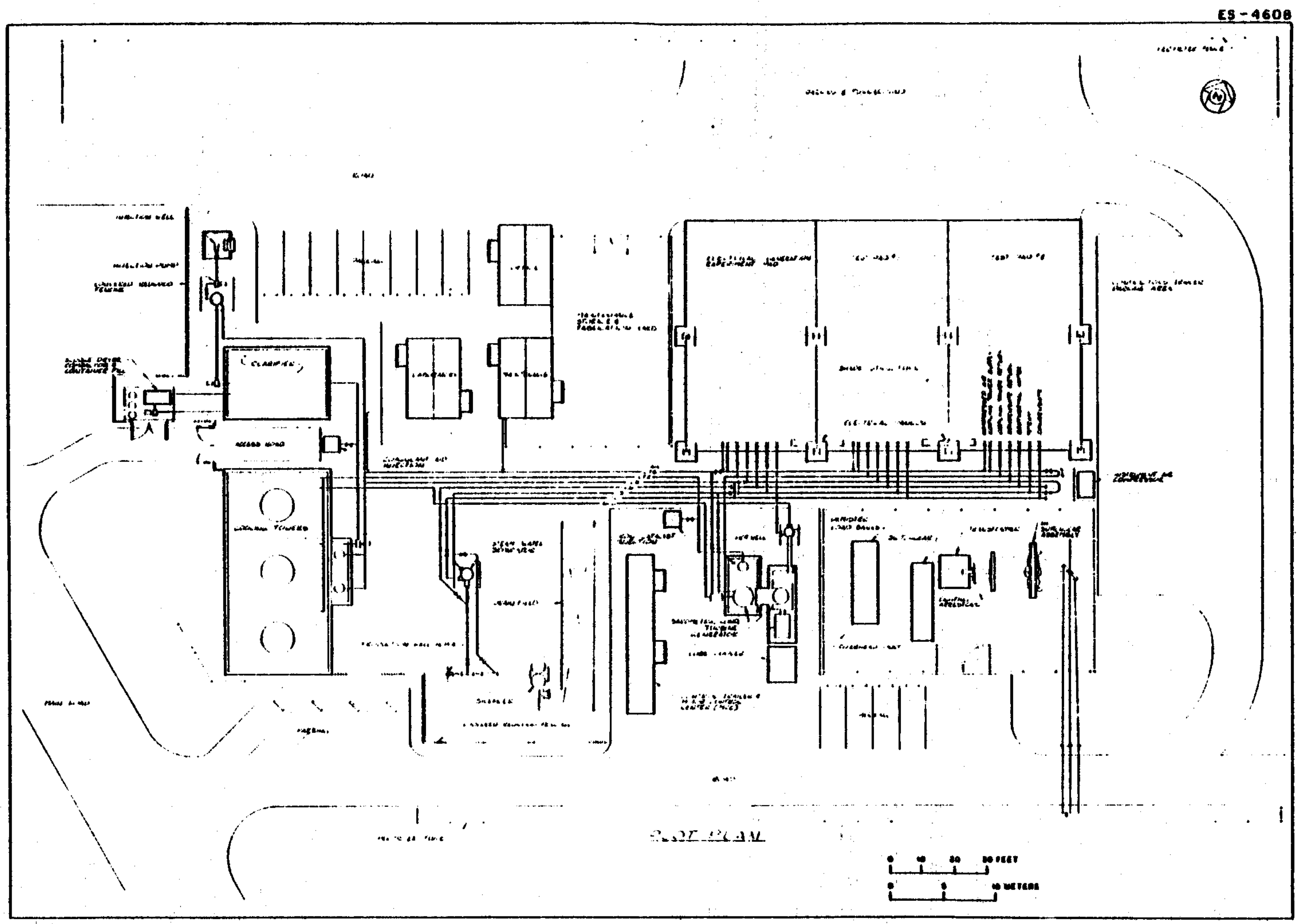

Fig. 1.5. Hawaii Geothermal Research Station facility site plan. <u>Source</u>: Research Corporation of the University of Hawaii, *A Geothermal Electric and Nonelectric Research Facility Utilizing the HGP-A Well on the Island of Hawaii*, vol. I, *Technical*, prepared for the U.S. Energy Research and Development Administration, Division of Geothermal Research, April 1977.

An artist's conception of the HGRS is presented in Fig. 1.6. Possible alternatives to this baseline HGRS design are discussed in Sect. 5.2. Figure 1.6 does not show a visitor information center building [297 m^2 (3200 ft^2)] that will be built on the 1.7-ha (4.1-acre) site adjacent to the HGRS.

Net electrical power generated by the HGRS will be transmitted by a 34.5-km (21.4-mile) transmission line to the Kapoho Substation (Fig. 2.7). The line will run along Pahoa-Pohoiki Road and Pahoa-Kapoho Road for a total of about 2 km (1.2 miles). It will run parallel to an existing residential delivery line but will occupy a new right-of-way extending 9.1 m (30 ft) from the road center. The line will be strung on single poles set 0.3 m (1 ft) from the edge of the right-of-way. The line will be financed and constructed by HELCO.

1.3.2 Operation

Operation of the HGRS will normally consist of electrical power production and experimental testing of process and power equipment. After a recent 42-day, 7.6-cm (3-in.) throttled flow test,[6] the HGP-A well produced 37,860 kg/hr (83,400 lb/hr) of a 64/36% steam/water mixture at a temperature of 190°C (374°F).

Using the steam fraction of this wellhead flow, the proposed power plant should be capable of generating a minimum gross electrical output of 3.3 MWe. A simplified flow chart of the proposed power plant is presented in Fig. 1.7. Mass flow rates of the major constituents in the numbered streams (Fig. 1.7) are summarized in Table 1.2.

1.3.2.1 Equipment selections

The basic equipment selections of primary concern will be the condenser, cooling tower, and hydrogen sulfide (H_2S) abatement subsystems. The ultimate choice will be complicated by the interdependence of these subsystems and by the economic trade-offs.

There are two types of condensers available in the market: (1) contact condensers and (2) surface condensers. In contact condensers, the vapor (steam) and the cooling liquid (water) come in direct contact with each other and are mixed in the condensing process. This is a disadvantage

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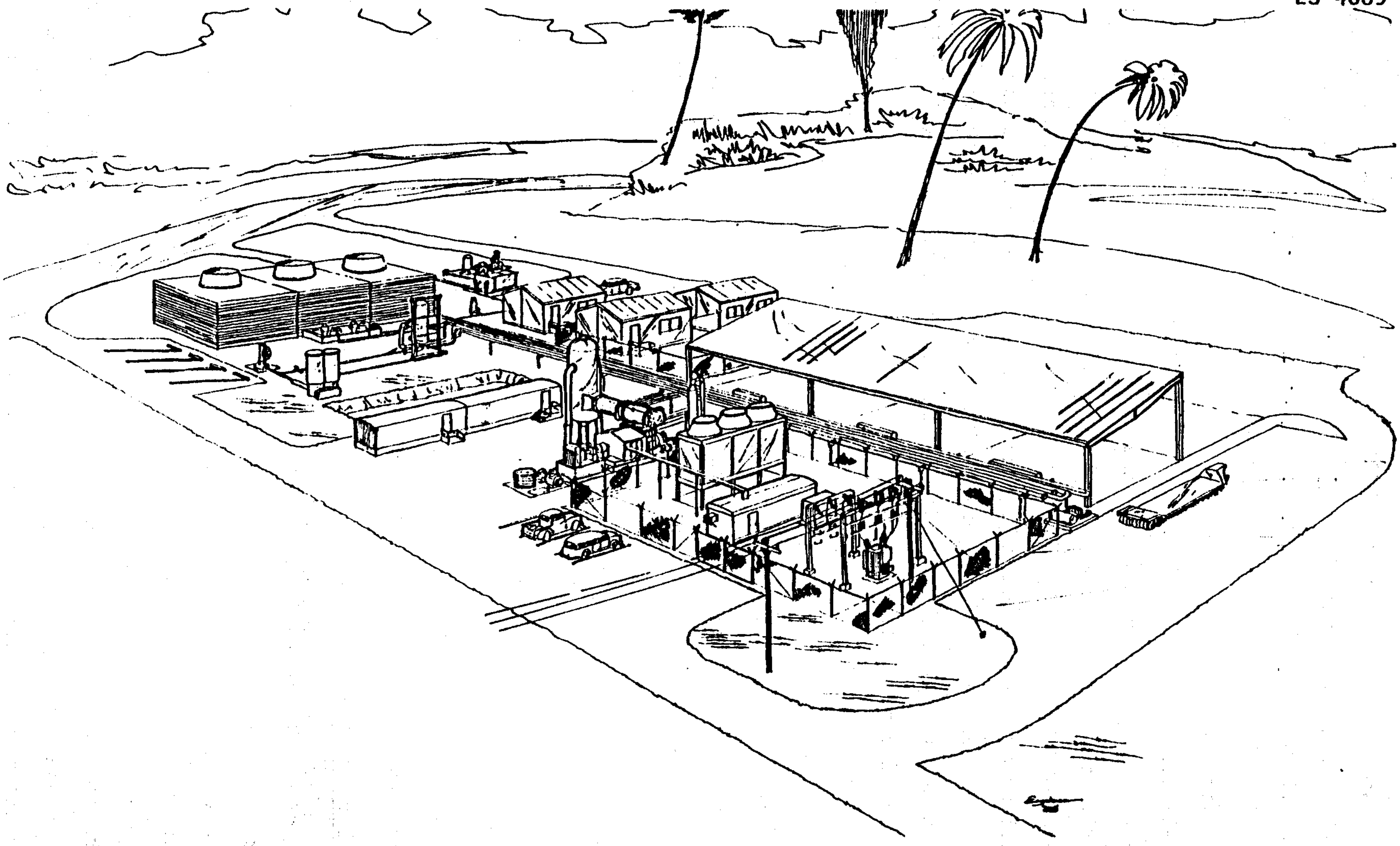

Fig. 1.6. Artist's conception of the Hawaii Geothermal Research Station at Puna, Hawaii. <u>Source</u>: Research Corporation of the University of Hawaii, *A Geothermal Electric and Nonelectric Research Facility Utilizing the HGP-A Well on the Island of Hawaii*, vol. I, *Technical*, prepared for the U.S. Energy Research and Development Administration, Division of Geothermal Research, April 1977.

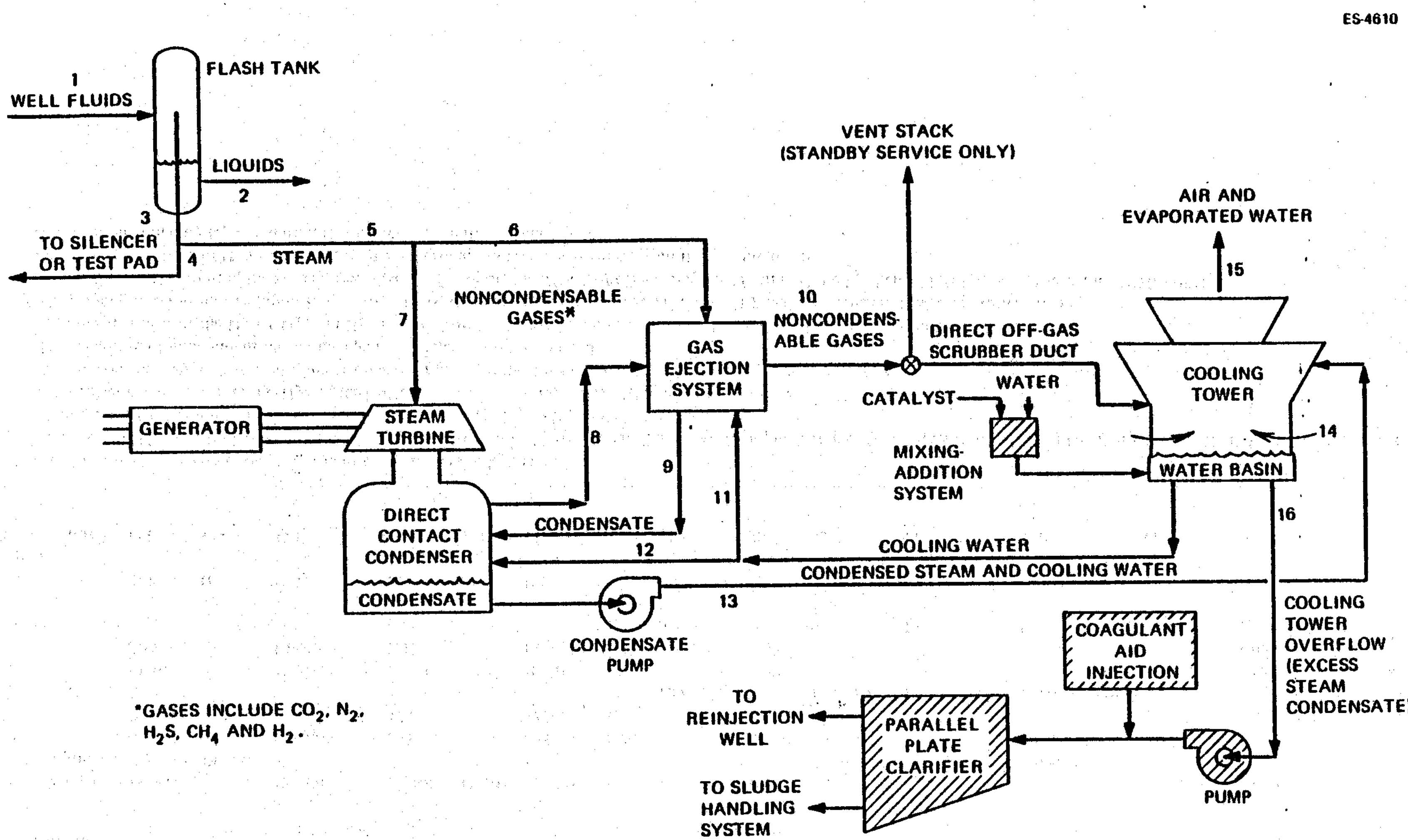

Fig. 1.7. Baseline power plant using iron catalyst H_2S abatement system. Source: Research Corporation of the University of Hawaii, *A Geothermal Electric and Nonelectric Research Facility Utilizing the HGP-A Well on the Island of Hawaii*, vol. I: Technical, prepared for the U.S. Energy Research and Development Administration, Division of Geothermal Research, April 1977.

Table 1.2. Estimated Hawaii power plant steam compositions[a,b]

Constituent	Stream															
	1	2	3	4[c]	5	6[d]	7	8	9[e]	10[f]	11	12	13	14	15[g]	16
H_2O (vapor)	53,400		53,400		53,400	1,120	52,280	71.6		3.7				36,608	76,492	
H_2O (liquid)	30,000	30,000							54,093		53,080	1,875,433	1,981,734			13,516
CO_2	105.78	0.12	105.66		105.66		105.66	31.70		31.70				(805)[h]	(911)	
H_2S	38.01	0.15	37.86		37.86		37.86	11.36		11.36					2.27–3.03	
S° (note *i*)									129–132		129–132	4,550–4,650	4,810–4,910			32.8–33.5[j]
N_2	30.30		30.30		30.30		30.30	9.09		9.09					30.30	
H_2	1.05		1.05		1.05		1.05	0.32		0.32					1.05	
Dry air								52.2	0.2	53.1	0.9	39.3	0.2	2,440,559	2,440,559	0.3
$Fe(OH)_3$									1.59		1.59	56.3	57.9			0.4
Pressure, psia	183	183	183		183	183	180	1.42	7.1	15				14.7	14.7	
Temperature, °F	374	374	374		374	374	373	90	110	90	85	85	110	83	100	85

[a] All flow rates are given in pounds per hour (1 lb/hr = 0.454 kg/hr).

[b] Noncondensible mass flow rates entering the plant are based on a "best estimate" in: P. M. Kroopnick et al., "Geochemistry of a Hawaii Geothermal Well: HGP-A," in *Geothermal Resources Council's 1978 Annual Meeting Transactions*, vol. 2, Sect. 2, p. 375, Table 1.

[c] Intermittent source; will release H_2S in flashed steam at a concentration of 710 ppmw or 375 ppmv.

[d] All noncondensibles are assumed to be ejected from the low-level-type condenser.

[e] The solubility of noncondensibles in the ejector system are not considered.

[f] Assumes that 30% of the H_2S, CO_2, and H_2 and 100% of the air and N_2 entering the condenser-ejector system are ejected.

[g] The cooling tower assumes a liquid-to-gas ratio of 0.8, the heat of vaporization at 41°C (105°F), and 20% sensible/80% evaporative cooling.

[h] Atmospheric CO_2 entering the cooling tower (see R. C. Weast, *Handbook of Chemistry and Physics*, 51st ed., Chemical Rubber Co., Cleveland, 1970–1971).

[i] Range of free sulfur and H_2S values reflects the uncertainty in H_2S release rates from the cooling tower.

[j] Hydrogen liberated by H_2S oxidation is consumed in catalyst regeneration.

in the usual steam power plant, in which treated water is used to produce steam, because of the relatively large volume of the cooling water that must be treated if part of it is to be returned to the boiler. However, in a geothermal power plant, the condensate is not returned to a boiler because new steam is obtained continuously from a geothermal well. Direct-contact condensers are recommended whenever feasible because they are lower in cost, more efficient, and use less water than surface condensers.

The selection of the H_2S abatement method may dictate the type of condenser to be used. The Stretford process requires the use of a surface condenser to isolate the noncondensible gas stream from the cooling water. Alternatively, the "iron catalyst" system of H_2S abatement treats cooling water and can handle the large volume of flow from a barometric condenser.

As currently conceived, the condenser for HGP-A is the direct-contact barometric or low-level jet type. Because the cooling water must be pumped back to a cooling tower with the condensate, it may be desirable to use the low-level jet pump for this function. This would reduce the size of the condenser and also the length of ducting between the turbine exhaust and the condenser.

1.3.2.2 H_2S abatement system

Ideally, an upstream (between the wellhead and the user) H_2S removal system would be desirable because it would offer, in addition to H_2S abatement for the user, abatement of H_2S released when steam is vented upstream of the user. It also would reduce corrosiveness of the steam condensate and thus permit wider scale use of standard construction materials in the resource user's facilities. To date, unfortunately, no such abatement method is available or projected for the near term. Abatement methods must be employed downstream (i.e., after the steam is used).

Although the iron catalyst system is indicated (Fig. 1.7) in the preliminary design configuration, both the iron catalyst and Stretford process abatement systems are candidates that will be evaluated during the detailed design phases. Table 1.3 lists some of the merits and disadvantages associated with these systems.

Other H_2S abatement processes will be given further consideration to determine which would be most effective from an operational and

Table 1.3. Summary of major features of the candidate H_2S abatement methods

Iron catalyst system	Stretford process
Advantages	
Typical water treatment process equipment can be utilized. Equipment required is relatively simple. Use of barometric condenser in power plant is possible. Procurement cost is lower relative to Stretford process. Procurement lead times are shorter than in Stretford process.	Process is independent of basic power cycle and can be an independent facility. Process is well established; although the process has yet to demonstrate performance for H_2S abatement at a geothermal power plant, confidence in its success is high. Inherent corrosion problem of iron catalyst system is eliminated. Commercially pure sulfur is produced.
Disadvantages	
Chemistry is not fully understood; system requires tune-up and trial to establish proper injection rates and additives (catalyst and coagulant aids) during system startup. Cooling water is very corrosive necessitating special construction materials. Potential settling of precipitates and attendant plugging of cooling loop condenser hotwell, cooling tower sump, valves, pipes, etc., necessitate special attention in equipment and system design. Sludge disposal is a consideration; although the H_2S in the steam is two orders of magnitude less (~3 compared with 222 ppm) at Puna than at the Geysers, resulting in significantly less sludge production, sludge dewatering, handling, and disposal may still be a problem.	Process is complex relative to iron catalyst system. Cost is high. Use of surface condenser in power plant is required. Procurement lead times are longer than in iron catalyst system. Effectiveness is dependent on condensate pH in the condenser.

economical viewpoint under the specific conditions at the HGRS. Incineration processes and a number of chemical extraction processes are commercially available. The factors affecting process selection are H_2S concentration, operating pressure and temperature, and the presence of large concentrations of carbon dioxide that may drastically affect the selectivity and absorption efficiency of the chemical removal processes.

Although the research power plant design considerations will significantly influence the abatement method selected, other considerations, including compatability of the candidate systems with the overall research facility; H_2S abatement requirements; and the comparative operating and maintenance costs, reliabilities, and procurement lead times of the systems, will weigh heavily in the selection process.

Iron catalyst system

In this system, approximately 70% of the noncondensables in the steam dissolve in the cooling water and steam condensate mixture in the condenser hotwell; the balance is removed from the condenser by the noncondensables ejector system and is ducted to the cooling tower airstream. In plants not equipped for H_2S abatement, the gases dissolved (including H_2S) in the cooling water/condensate are air stripped from solution in the cooling tower and released to the atmosphere.

To prevent the emission of H_2S, the cooling water is dosed with ferric ions via injection of ferric sulfate. The ferric ions react with the dissolved H_2S to yield elemental sulfur, water, and ferrous ions. As the cooling water is aerated in the cooling tower, the ferrous ions react with oxygen to re-form ferric ions; continuous regeneration of ferric ions is thus provided to sustain the H_2S reactions, which repeat continuously to yield sulfur. The sulfur thus formed is removed from the system via clarifiers (after flocculation) as a sludge and dumped at an approved site. The H_2S ducted to the cooling tower as part of the condenser vent gases is similarly treated after the H_2S is scrubbed from the airstream by the falling water, which is high in ferric-ion content. Overall H_2S abatement efficiencies of up to 92% have been reported.

The basic elements of a typical iron catalyst system include the catalyst injection system, the clarifier, transfer pumps, the flocculator/clarifier, and the sludge-handling system. Note that this method of abating H_2S emissions is used only with power plants employing direct-contact condensers or processes in general in which H_2S is dissolved in the cooling water and released by air stripping in cooling towers. The system has the advantage of being inherently simple and utilizes conventional in-water treatment systems. It has some disadvantages, including increased corrosiveness of the cooling water/condensate, potential plugging of the cooling water/condensate piping, and the need for removal and handling of the sulfur sludge produced by the process.

Stretford process

In the power plant configuration incorporating the Stretford process the direct-contact condenser of Fig. 1.7 is replaced by a surface condenser, thus precluding release of H_2S via the cooling water.

The Stretford process is a proprietary process widely used to desulfurize process gas streams. As typically applied to geothermal steam power plants, the noncondensable gas purged from the condenser is washed with an aqueous solution of sodium carbonate, sodium ammonium polyvanadate, and anthraquinone disulfonic acid. The H_2S in the purge gas is absorbed in the solution and reacts with the sodium carbonate to yield sodium bisulfide, which is subsequently oxidized in the process to elemental sulfur. Following oxidation, the solution is recirculated to the absorber column, and a sulfur-bearing froth is separated, filtered or centrifuged, washed, and melted to produce commercially pure sulfur. Oxidation of the sodium bisulfide is effected by the vanadate, which is reduced from a 5-valent to a 4-valent state. The vanadate is, however, later regenerated to a 5-valent state through a mechanism involving oxygen transfer through the anthraquinone disulfuric acid.

The Stretford process is essentially an independent facility collocated with the power plant and has no direct influence on the power cycle. It thus does not have the added corrosion problem associated with the iron catalyst system. It has, in addition, the advantage of producing a commercially saleable product in lieu of a sludge requiring disposal. It does, however, have the disadvantage of being more complex and costly than the iron catalyst system.

1.3.2.3 System description

Of the total wellhead steam, approximately 98% will pass through the plant's turbine, and the remaining 2% will be needed by the ejector system to remove small amounts of noncondensibles (i.e., air, carbon dioxide, H_2S, etc.) from the low-level-type barometric condenser. About 70% of the noncondensibles in the geothermal steam will dissolve in the cooling water and condensate mixture stream leaving the condenser system. The remaining 30% of the geothermal noncondensibles and air entering the condenser system (by leakage and with the cooling water) will be ejected to the evaporative cooling towers. Catalytic oxidation of the H_2S in the plant's cooling water will result in an H_2S release in the cooling tower exhausts of 1.0 to 1.4 kg/hr (2.3 to 3.1 lb/hr) at a concentration of 0.9 to 1.2 ppmw (0.7 to 1.0 ppmv).

Condensed geothermal steam from the condenser supplies the makeup water for the evaporative cooling towers. These towers will evaporate 18,144 kg/hr (40,000 lb/hr) of water and will release 6124 kg/hr (13,500 lb/hr) of blowdown liquids.

Blowdown from the cooling towers will contain elemental sulfur, iron hydroxide, atmospheric dust, trace elements, and other extraneous substances. These solids are separated from the blowdown as a 90% (by weight) water sludge. This sludge is then dried for disposal and will contain 12.7 to 15 kg/hr (28 to 34 lb/hr) of elemental sulfur, depending on the efficiency of the H_2S abatement system (in the range 78 to 94%). The clarified blowdown [6000 kg/hr (13,200 lb/hr)] and flashed separator liquids from the steam-water separator [11,250 kg (24,800 lb)] are sent to a retention pond to allow any precipitates and wellbore solids to settle out. The precipitates will consist largely of silicates and smaller amounts of carbonates and sulfates. Clarified water from the retention pond is then sent to a separate seepage pond for disposal by percolation. An injection well is not required because of the excellent permeability of the surrounding lava. Also, because the groundwater is brackish in this area, the disposal of geothermal fluids does not present a problem. The temperature of the liquids in the two ponds will not exceed 75°C (167°F). Flashing the separator liquids to atmospheric pressure will generate 2345 kg/hr (5170 lb/hr) of steam containing 0.07 kg (0.15 lb) of H_2S.

Based on operating experiences with Unit 11 at the Geysers,[7] only 6 to 8% of the H_2S entering the proposed power plant will be released. The final design of the HGRS power plant, however, may specify the Stretford process for H_2S abatement. With this process, less than 4% of the H_2S entering the plant is expected to be released.[8] For the proposed power plant, this level of H_2S abatement would correspond to a normal release rate of 0.7 kg/hr (1.5 lb/hr) of H_2S in the cooling tower exhausts.

In addition to normal power plant operations, equipment failures and other causes of power plant downtime can affect the release of geothermal fluids to the environment. Based on operating experiences with Unit 11 at the Geysers, the HGRS power plant should have an availability factor of 76 to 87%.[9]

Much of the H_2S released to the environment by the HGRS could occur during downtimes. During these downtimes, the HGP-A well flow must be maintained at a significant level to avoid unstable well operation and thermal stresses in the wellbore. During turbine downtimes, geothermal steam from the steam-water separator will be condensed by the plant's cooling system. Both cooling water flow and evaporative rates will increase by 24% during turbine downtimes.

Operating experience with Unit 11 at the Geysers indicates that the HGRS power plant can expect 10% cooling system downtime. This is due to the corrosive nature and solids content of the plant cooling water. If the HGRS power plant used a Stretford process for H_2S abatement, cooling system downtimes would be significantly reduced. During cooling system downtimes, the HGP-A well will either be shut in or the well flow will be diverted to the silencer.

HGRS power plant designers have indicated that they plan to allow less than 1 hr of silencer operation each month. During silencer operation, approximately 27,700 kg/hr (61,000 lb/hr) of steam and

10,160 kg/hr (22,400 lb/hr) of geothermal liquids will be released. Silencer steam should contain 620 ppmw (330 ppmv) H_2S, and the flashed geothermal liquids should contain 5 ppmw H_2S.

Since specific planned activities for the experimental power and nonelectrical research facility have not been outlined, their operation cannot be elucidated in this assessment.

It is anticipated that two workers will normally be required to operate the HGRS power plant.

1.4 KNOWN ENVIRONMENTAL ISSUES

The State of Hawaii has prepared and issued a Final Environmental Impact Statement on the HGP-A power plant. The known environmental issues include potential nuisance noise and H_2S odor at nearby residences. Native Hawaiian groups have expressed interest and concern regarding the development of geothermal resources in Hawaii. These and other potential environmental impacts are discussed in Sect. 3 of this assessment.

REFERENCES FOR SECTION 1

1. *Environmental Assessment of the Hawaii Geothermal Project Well Flow Test Program*, prepared for the U.S. Energy Research and Development Administration, Washington, D.C., November 1976.

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3. Hawaii Natural Energy Institute, *Summary, Geothermal Energy in Hawaii — Hawaii Geothermal Project*, University of Hawaii, Honolulu, January 1978.

4. R. M. Kamins, *Environmental Impact Statement for the Hawaii Geothermal Research Station Utilizing the HGP-A Well at Puna, Island of Hawaii*, prepared for the Department of Planning and Economic Development, State of Hawaii, March 1978.

5. A. Adduci, U.S. Department of Energy, San Francisco, personal communication, September 1978.

6. P. C. Yuen et al., "Well Test and Reservoir Engineering," in *Hawaii Geothermal Project Phase III Quarterly Progress Report*, Apr. 1 – June 30, 1977, p. 29.

7. O. Weres, K. Tsao, and B. Wood, *Resource, Technology, and Environment at the Geysers*, LBL-5231, June 1977, p. XI-35.

8. Ref. 7, p. XI-28.

9. Ref. 7, p. VIII-28.

2. DESCRIPTION OF THE EXISTING ENVIRONMENT

The following sections constitute a description of the existing environment in the Puna district. Subjects to be covered include geology, soils, geothermal resources, atmospheric characteristics, hydrology, water quality and use, land use, historic and archaeologic sites, landmarks, noise, ecology, demography, socioeconomics, and cultural values.

2.1 GEOLOGY, SOILS, AND GEOTHERMAL RESOURCES

2.1.1 Geology

The southeastern part of the Island of Hawaii is dominated by an asymmetrical shield volcano (Kilauea) and its associated rift zones (Fig. 2.1). The east rift zone is of particular interest because it passes through the Puna district and the geothermal well is located within it.[1] The southwest rift zone extends into the Ka'u district — 50 km (30 miles) or more west of the well site.[2] The Hilina and Koae fault systems (Fig. 2.1) are also related to Kilauea.

Two centers of eruption of lava at the surface have been active in the past two centuries — Kilauea and its larger neighbor to the west, Mauna Loa. Mauna Loa was more active throughout the nineteenth and the first half of the twentieth centuries, but Kilauea has been more active since the 1950s. A third volcano, Hualalai, has been dormant since 1801. Mauna Loa achieved its present size by the end of the Ice Age, but Kilauea is probably still in its growth stage.[2]

Major eruptions of Kilauea occur as flank eruptions. As Kilauea begins to swell, lava wells up in the caldera. Then flank eruptions burst through the surface along one or both of the principal rift zones. As the flank eruptions take place, the caldera at Kilauea subsides.

Earthquakes always accompany the eruptions. Earthquake precursors increase in frequency and intensity as Kilauea swells over a period of several months preceding a flank eruption. Seismicity reaches a peak as eruption commences and continues sporadically as long as Kilauea continues to subside and the flank eruptions persist.

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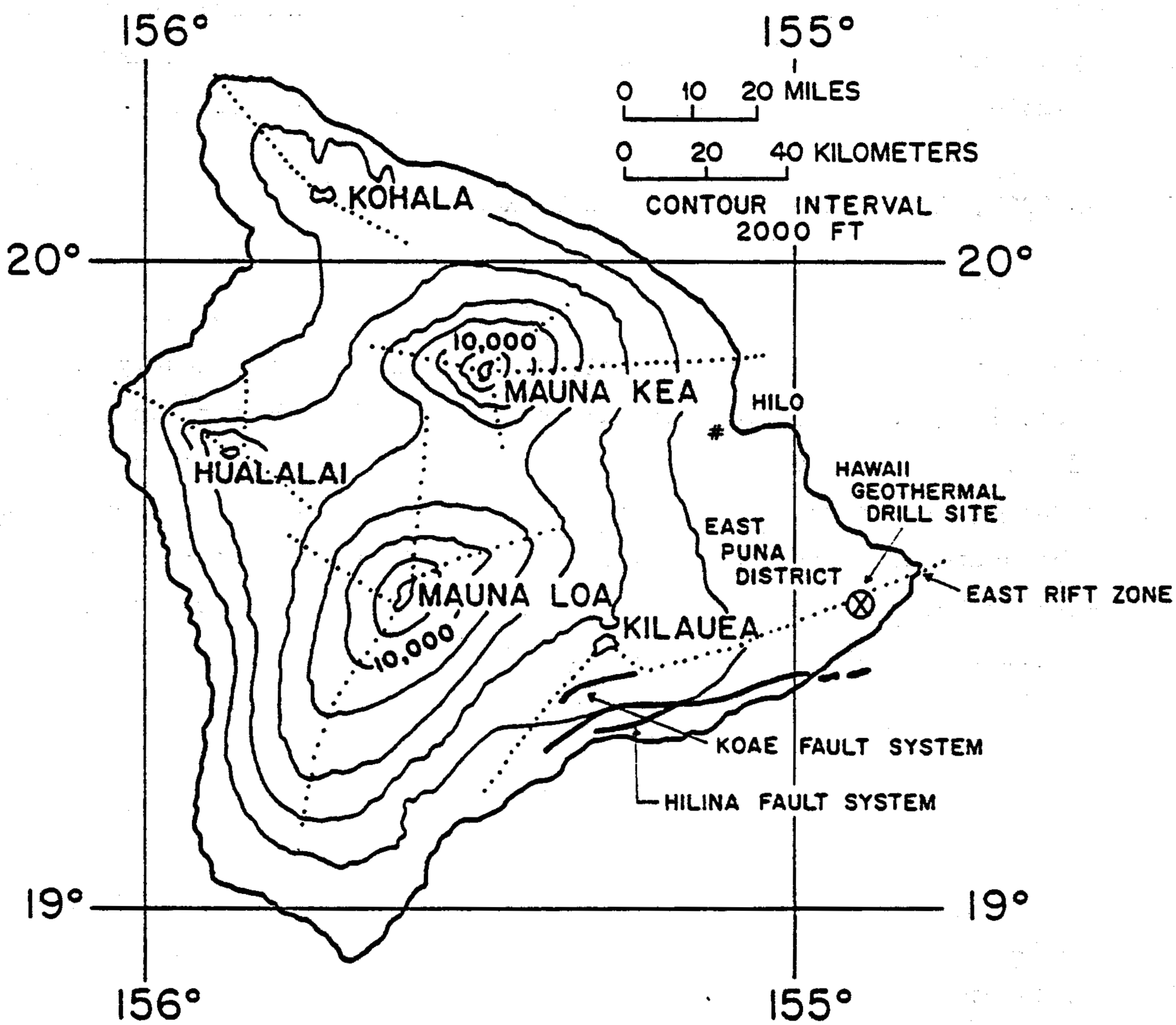

Fig. 2.1. Relationship of the geothermal well site to the east rift zone of Kilauea. Source: R. M. Kamins et al., *Environmental Baseline Study for Geothermal Development in Puna, Hawaii*, Hawaii Geothermal Project, University of Hawaii, Honolulu, September 1976.

Earthquake activity does not always culminate in volcanic eruption. An earthquake swarm took place in the Puna district in 1924 without the occurrence of volcanism. This led the residents of the community into a false sense of security when, in 1955, earthquake swarms were followed by massive eruptions that lasted intermittently for 88 days.[2]

2.1.1.1 Structure, physiography, and stratigraphy

The detailed geologic discussions that follow are largely directed to the east rift zone, where the well site is located. The east rift zone trends 6.4 km (4 miles) southeast from the caldera of Kilauea. It then turns 65° northeast and extends to Cape Kumukahi, the easternmost point of the Puna district. From there, it passes out to sea for a distance of about 115 km (70 miles).[2]

The rift zones of the Hawaiian volcanoes are not believed to extend below the ocean floor; the lava migrates laterally from the shield volcano (e.g., Kilauea), producing flank eruptions up to 160 km (100 miles) away.

The east rift zone has several distinctive physiographic features. It is linked to the caldera of Kilauea by a series of pit craters, which are rather unevenly distributed. Within 1.2 km (0.75 mile) south of the well site are located three pit craters — Pu'ulena, Pawai, and Kahuwai. About sixty spatter and cinder cones and two parasitic shield volcanoes are also found along the east rift zone. A 45-m (150-ft) cinder cone, Pu'u Honualoa, lies about 1 km (0.6 mile) northeast of the well site (Fig. 1.2). Finally, there are a number of slightly eroded fault scarps. Older lava flows are truncated by these scarps, which are in turn covered by more recent lava flows.[2,3]

The stratigraphic section exposed in the Ka'u and Puna districts is divided into two volcanic series. The lower (older) series is called the Hilina and is separated from the upper series (Puna) by the Pahala ash, a sandy-to-silty vitric yellow ash. Both series consist of oceanic basalt lava flows, together with cinder cones and ash deposits. The Hilina volcanic series is a succession of thin lava flows with a cumulative thickness of at least 305 m (1000 ft). The overlying Puna series ranges from one or two thin flows to a thickness of more than 128 m (420 ft). The Puna series has been erupted entirely from Kilauea caldera and the rift zones radiating from it.[3]

The stratigraphy at the HGP-A well is relatively simple (Fig. 2.2). An upper unit extends from the surface to a depth of about 550 m (1800 ft). This unit consists of subaerial volcanics (aa and pahoehoe flows, ash, and cinders). The lower unit consists entirely of pillow lavas (erupted on the sea floor).[4]

The geothermal reservoir may be isolated from the shallow part of the section by an impermeable cap. Between depths of 670 and 1100 m (2200 and 3500 ft), fractures are filled by secondary mineralization, and the basalt is highly altered by migrating fluids of volcanic origin. This mineralization may have produced an impermeable seal over the reservoir rock that contains open fractures between depths of 1100 and 1400 m (3500 and 4500 ft).[4] A second producing zone lies below 1800 m (6000 ft).

It has also been suggested that circulation of shallow, cold water prevents the upward movement of hot reservoir water. Although the nature of the reservoir cap is uncertain, it is evident from the temperature curve of Fig. 2.3 that convective circulation of the reservoir water is inhibited.

Intrusive rocks are also exposed in the rift zones of Kilauea. These rock bodies are mainly vertical dikes that are a few centimeters to a few meters wide, and some of them are clustered in zones that are several hundred meters wide. They are well exposed in the walls of the caldera, and many of them strike parallel to the east rift zone.[3,4]

Fracture porosity (essential to many geothermal reservoirs) bears a spatial relationship to the vertical dikes and their associated fissures. The rift zones are long, narrow features bounded by dikes. Clusters of dikes are formed by upward movement of magma along parallel fissures within the rift zone. Fissures re-form repeatedly due to (1) deformational adjustments during volcanic episodes and (2) cooling after the termination of each eruption. Transverse fractures or faults crossing the rift zone may result in unusually high fracture porosity where they intersect longitudinal fissures.

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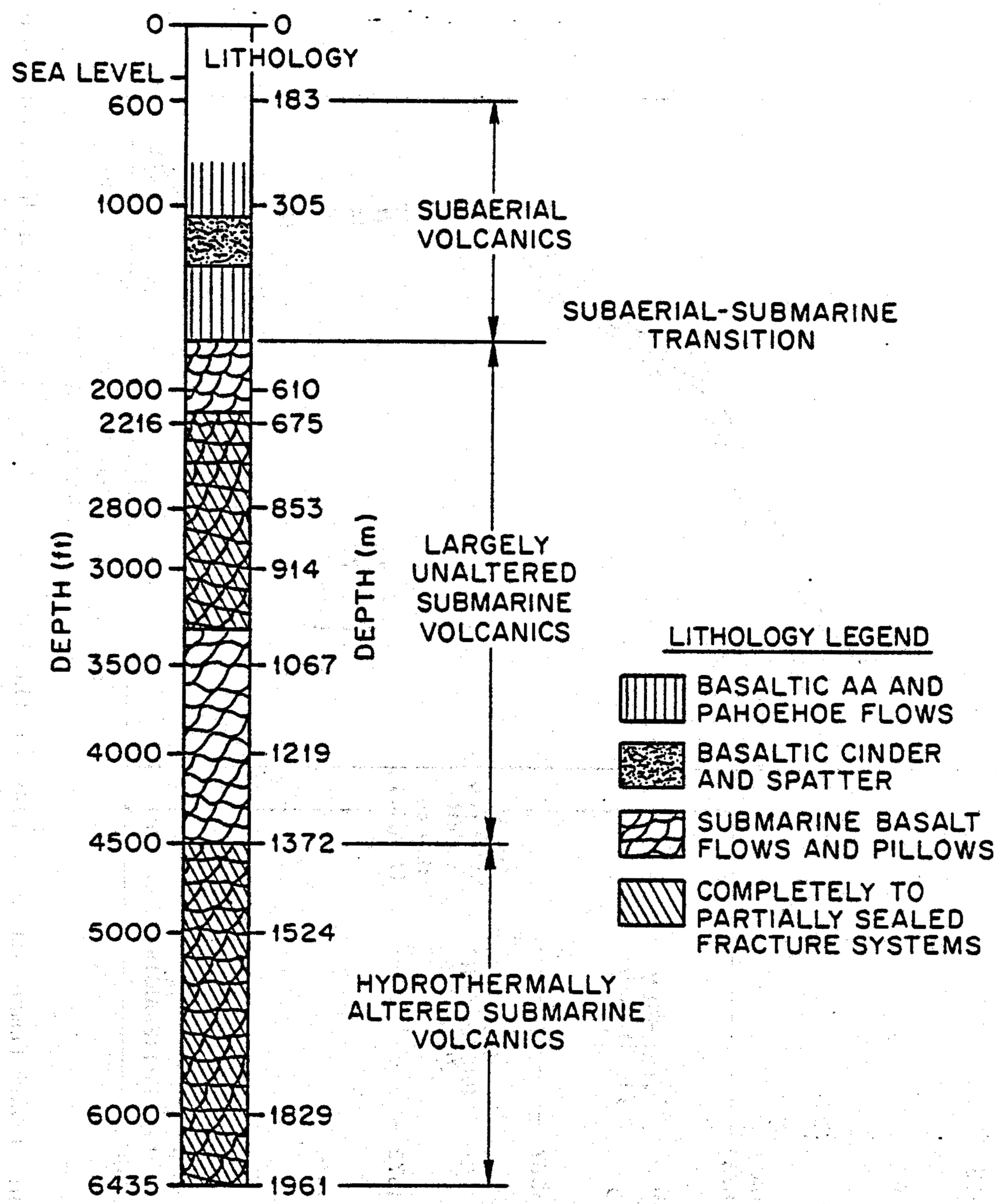

Fig. 2.2. Generalized stratigraphic section of the HGP-A well. <u>Source</u>: Research Corporation of the University of Hawaii, *A Geothermal Electric and Nonelectric Research Facility Utilizing the HGP-A Well on the Island of Hawaii*, vol. I, *Technical*, prepared for the U.S. Energy Research and Development Administration, Division of Geothermal Research, April 1977.

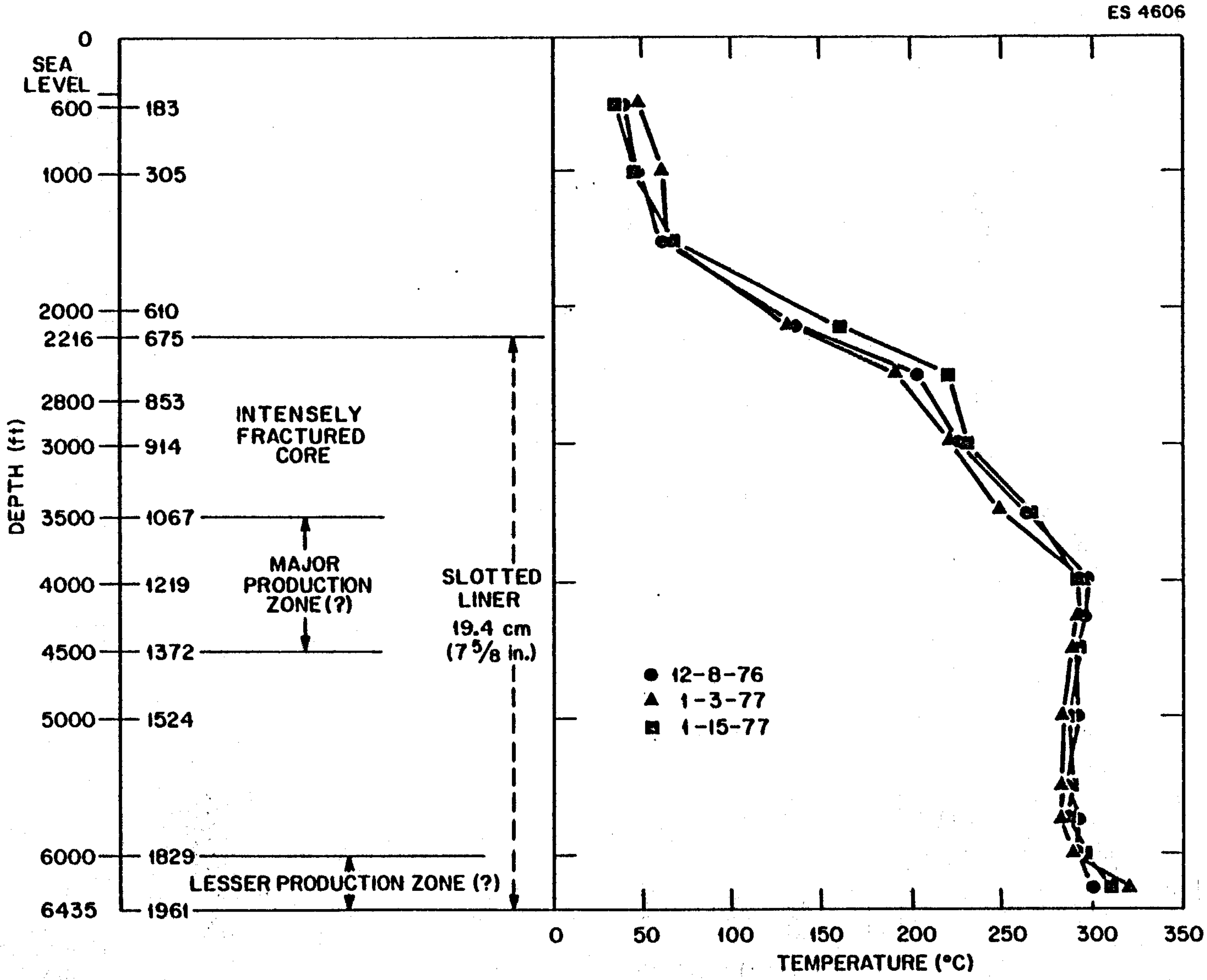

Fig. 2.3. Generalized temperature profile of the HGP-A well. Source: Research Corporation of the University of Hawaii, *A Geothermal Electric and Nonelectric Research Facility Utilizing the HGP-A Well on the Island of Hawaii*, vol. I, *Technical*, prepared for the U.S. Energy Research and Development Administration, Division of Geothermal Research, April 1977.

2.1.1.2 Tectonic history

The Hawaiian Islands chain is very young by geologic standards. The oldest rocks of the major islands exposed above sea level are believed to have formed during the Pliocene epoch (3 to 12 million years ago). On the basis of radioactive age dates and other evidence, the rocks of Oahu and islands further south are believed to be no older than Pleistocene (15 thousand to 3 million years).

The Island of Hawaii is the youngest of all the islands. It is the only island having an extensive historic record of volcanic activity (a single eruption occurred on Maui in the eighteenth century) and the only island considered to be seismically active. All the lava flows of the Island have normal magnetic polarities, suggesting that they belong to the Bruhnes paleomagnetic epoch (less than 800 thousand years old).

The rocks of Kilauea and Mauna Loa are the youngest of all. The oldest members of the Hilina volcanic series of Kilauea interfinger with the youngest Ninole series of Mauna Loa; therefore, the oldest rocks exposed at Kilauea are probably about 100 thousand years old. The Puna volcanic series, which overlies the Hilina, is subdivided into two members: (1) a prehistoric late Pleistocene member, which in places is capped by sand dunes, and (2) a historic member that is still accumulating. Table 2.1 is a record of eruptions on the east rift of Kilauea that have occurred in the historic period.

Fault movement is also still taking place. Many Puna lava flows of recent age cascaded over older fault scarps but were themselves displaced by subsequent movement.

2.1.1.3 Seismicity

The Island of Hawaii is the only island in the Hawaiian chain that could be characterized as a seismically active region.[2] Although earthquakes occasionally occur on the other islands, the great majority take place on Hawaii; most of the earthquakes are small and do little or no damage.

The U.S. National Oceanic and Atmospheric Administration (NOAA) provides a more or less complete list of earthquakes (modified Mercalli intensity $\geqslant$ V) in the Hawaiian Islands, beginning with a major earthquake

Table 2.1. Historic eruptions of the east rift of Kilauea, 1750–1969

Year	Duration (days)	Area		Volume	
		(sq miles)	(sq km)	(10^6 yd^3)	(10^6 m^3)
1750(?)		1.57	4.07	19.5	14.9
1790(?)		3.04	7.87	37.7	28.8
1840[a]	26	6.60	17.09	281.0	214.8
1884	1	At sea	At sea		
1923	1	0.20	0.52	0.1	0.08
1955[b]	88	6.1	15.8	120.0	91.8
1960[c]	36	4.1	10.6	155	118.5
1961	3	0.3	0.8	3.0	2.3
1962	2	0.02	0.05	0.4	0.3
1963	3	0.06	0.16	1.1	0.8
1963	2	1.3	3.4	9.1	7.0
1965	10	3.0	7.8	23.0	17.6
1965	1	0.23	0.60	1.2	0.9
1968	5	0.01	0.03	0.1	0.08
1968	15	0.8	2.1	9.0	6.9
1969	6	2.3	6.0	22.0	16.8
1969[d]	May 24–Nov. 20	4.8	12.4	71.0	54.3

[a]Broad zone along the east rift, including the well site.

[b]Includes the immediate area of the well site.

[c]Four miles east of well site.

[d]Still in progress on date of recording; this eruption occurred 10 to 15 miles west of the well site.

Source: G. A. Macdonald and A. T. Abbott, *Volcanoes in the Sea – The Geology of Hawaii*, University of Hawaii Press, Honolulu, 1970.

in 1868 and extending through 1970.[5] Between 1834 and 1868, two other earthquakes are also listed by NOAA. The geologic-geographic distribution of these earthquakes is shown in Table 2.2.

Although there is no published record of earthquakes in Hawaii for the first half of the 1970s, a particularly strong earthquake (7.2 on the Richter scale) occurred immediately offshore of Kaimu Beach on the south coast of the Puna district in November 1975. If it had occurred on land, it would have been capable of causing nearly total destruction in the epicentral area and extensive damage in immediately adjacent regions.

The earthquake of 1868, which also occurred near the south coast of the Island of Hawaii, had an estimated intensity $\geq$ X (modified Mercalli). This earthquake caused nearly complete destruction of wooden structures at Keiawa, Punaliu, and Ninole, located near the terminus of the southwest rift zone of Kilauea, and it caused landslides beyond Hilo on the east coast as far as Waipio and Hamakua. Fissures extended along the southwest rift zone from Pahala to Kilauea. At Kohuku, volcanic eruptions accompanied the opening of a fissure 4.8 km (3 miles) long. Ground swells of 0.3 to 0.6 m (1 to 2 ft) occurred, and a *tsunami* wave exceeding 18 m (60 ft) in height struck the Ka'u-Puna coast, sweeping structures off the beach.[2,5]

The year of 1868 is the only historic period in which Mauna Loa and Kilauea erupted simultaneously.[3]

In addition to the fissure eruption on the southwest rift zone of Kilauea, an offshore eruption occurred on the seaward extension of the east rift zone.

Since 1834, at least 5 intermediate-intensity (Mercalli VI and VII) and 16 minor-intensity (Mercalli V) earthquakes have been experienced at Kilauea and its associated rift zones. All the intermediate shocks were capable of causing light to moderate damage to wooden structures. Three of the intermediate shocks took place along the east rift zone of Kilauea in the Puna district, two occurred a few months before the extensive volcanic eruptions of 1955, and the third occurred during that eruption.[5]

Table 2.2. Distribution of earthquakes, 1834–1970[a]

Location	Number			
Hawaiian Island chain				102
Island of Hawaii			85	
Volcanoes and associated rifts		47		
Kilauea	21			
Mauna Loa	20			
Hualalai	6			
Faults subparallel to rifts		6		
Kaoiki (Mauna Loa)	5			
Kealakekua (Mauna Loa)	1			
South and south coast		2		
Other locales[b]		12		
Unidentified by locale		18		
Other islands			13	
Unidentified by locale			4	

[a]There may be minor errors in the classification due to uncertainty of epicenter locations.

[b]Uncertain association with volcanoes, rift zones, and subparallel fault systems. For example, two earthquakes have been identified as having occurred at Hilo, on the east coast. They could have been placed in either the Mauna Kea or Mauna Loa rift zones. Perhaps, on the other hand, they are unrelated to volcanism.

Source: J. L. Coffman and C. A. von Hake, Eds., *Earthquake History of the United States*, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, U.S. Government Printing Office, Washington, D.C., 1973.

2.1.2 Soils

Much of the Puna district has a thin covering of histosols (sparse, well-drained, organic soils) that commonly occur on geologically young lava flows. Entisols (weakly developed soils found on old beach sands and volcanic ash) are found west of the well site. The older histosols are very fertile, supporting lush vegetation, papaya orchards, and sugarcane.[6]

At the well site, however, lava flows are so recent (1955) that soil has not had sufficient time to develop. Fresh cinders and aa lava are abundantly evident within the 1.7-ha (4.1-acre) well site and its immediate surroundings. The area is in the initial stage of revegetation.

2.1.3 Known geothermal resources

Although a number of potential geothermal resource sites probably exist in the various rift zones of the Island of Hawaii, the only known geothermal resource area is the site for which this assessment was prepared. The Pahoa site of the east rift zone of Kilauea was selected on the basis of a geophysical (self-potential) anomaly, together with other evidence. Two other self-potential anomalies are located on the east rift of Kilauea, and although the presence of a geothermal resource has not been demonstrated, the potential exists.[7] Research scientists involved in this project believed that the Pahoa site offered the best chance for recovering geothermal fluid. Their optimism was rewarded by the successful flow test of the HGP-A well. The estimated 3.5-MWe electrical generating capacity clearly demonstrates that commercial development of geothermal energy is feasible on the Island of Hawaii. Had the casing been extended through the impermeable zone [to 1070 m (3500 ft)] before installing the slotted liner, the performance of the well might have been even better. The inadequate casing procedure allows cooler, shallower water to mix with the hot reservoir water.[8]

G. A. Macdonald appraised the likelihood for geothermal development in all six major rift zones of the Island of Hawaii.[9] He concluded that only two of these zones (the southwest rifts of Mauna Loa and Kilauea) are perhaps as promising as targets for geothermal exploration as the east rift of Kilauea. While each of these rift zones may have geothermal energy potential throughout its length, the resources are expected to be most promising near the center of volcanic activity (the summit of Mauna Loa and the craters of Kilauea). Unfortunately for geothermal energy development, much of this land lies within Hawaii Volcanoes National Park, where development is not permitted. Furthermore, if a proposed natural area reserve is established, it will limit the development of the geothermal resources of the east rift zone of Kilauea to a length of 13 km (8.1 miles) southwest from the HGP-A well site. Although the other three major rift zones should be explored for geothermal energy, they are not as promising as resource regions. The northeast rift zone of Mauna Loa has been inactive for a very long time, and petrologic evidence suggests that rapidly rising magma has transferred little heat to the surrounding country rock in the two major rift zones of Hualalai.

It is less likely that geothermal development will occur in the near future on the other islands of the Hawaiian chain. Nevertheless, hot water resources are known to exist on Molokai and Oahu. Haleakala on the Island of Maui erupted during the eighteenth century (geothermal resources occur in association with recent volcanism).[7]

According to Macdonald, "At the present state of knowledge, it is difficult to make a worthwhile appraisal of the island's geothermal resources and impossible to make a reliable one."[9] Macdonald summarized the estimates provided by others (Helsley and Furumoto), and he concluded that potentially there are perhaps 60 and 360 megawatt centuries of electrical power available from geothermal resources in the Kapoho Geothermal Field (KGF), where the HGP-A well is located, and for the Island of Hawaii, respectively. Macdonald's estimates for the KGF are perhaps conservative, combining Furumoto's lower estimate of reservoir volumes (6 km^3) with Helsley's lower estimates for permeability [1 millidarcy (averaged over a 1-km-thick production zone)] and assuming an energy conversion efficiency of 12%. According to others, the KGF reservoir volume may be as high as 9.5 km^3.

There are two principal impediments to the development of geothermal energy in Hawaii: (1) the location of the most likely resources are separated from major population centers by open sea, and (2) there is a higher element of financial risk associated with long-term development where frequent (in the geologic time sense) seismic and volcanic activity constitutes a hazard. The remoteness of the resource to population centers is probably the more formidable obstacle to geothermal development. An analysis of the risks associated with seismic and volcanic activity is presented in Sect. 3.2.1.

2.2 ATMOSPHERIC CHARACTERISTICS

2.2.1 Climate

Except for the highest elevations, the Hawaiian Islands are typified by a mild oceanic climate. Because of their location in the tropics, solar radiation and daily temperatures vary little seasonally. The weather pattern of the Islands is dominated by the almost constant northeast tradewinds. Local weather conditions are determined by the surrounding topography, as Hawaii's mountains intercept the moist tradewinds and obstruct, accelerate, or deflect the winds. Precipitation varies greatly within short distances or rises in elevation. The windward (northeast) side of an island receives much more rain than the leeward (southwest) side. Because the tradewinds lose moisture as they rise over the mountains, the greatest amount of precipitation in the Islands generally occurs in the higher elevations.

Major storm fronts do occur, predominantly in the winter, when the tradewinds occasionally slacken and bring *kona* storms (so called because they usually come from the south, *kona*). The *kona* storms are often accompanied by thunder and lightning and may result in a large amount of rainfall in a short time.

Temperatures along the Puna coast vary little seasonally or diurnally. Nearby Hilo is 12.2 m (40 ft) above sea level and experiences a range of only 2.7°C (5°F) between monthly means.[10] Daily temperatures along the coast commonly fluctuate by 4.4 to 8.3°C (8 to 15°F) between early morning and late afternoon extremes.[2] By comparison, the elevation of the project site is 175 m (574 ft) above sea level; temperatures on site will be similar to those in Hilo. Annual temperature ranges around the Puna district are listed in Table 2.3.

Average annual rainfall in Puna ranges from a low of 190 cm (75 in.), along the south coast, to more than 500 cm (200 in.) on the low flanks of Mauna Loa, along Puna's northern margin. Kapoho, located nearer the coast [approximately 6.5 km (4 miles) from the HGP-A site], records an average of 250 cm (98 in.) of rain annually.[10] The project site, inland, receives about 290 cm (115 in.) of rain per year.[10] The precipitation is relatively evenly distributed throughout the year, with a slight peak during the winter *kona* storm season.

Humidity at the site is moderate to high. Windward areas such as Puna tend to be cloudy (8/10 or more cloud cover) 40 to 60% of the daylight hours and clear (3/10 or less cloud cover) 15 to 20% of the time.[11]

Wind patterns are dominated by the northeast tradewinds, which frequently exceed 5.5 m/sec (12 mph).[10] Strongest during the afternoons, the tradewinds are dominant during 90% of the summer and 50% of the winter.[10] The frequent tradewinds tend to readily disperse any airborne pollutants. However, topography can exert a marked influence on local wind patterns by deflecting and obstructing the tradewinds.

2.2.2 Air quality

Because of its location, remote from industrial and urban emission sources, concentrations of the primary air pollutants (those for which ambient standards have been promulgated) are expected to be quite low. Prior to drilling, air samples were collected at the HGP-A site and analyzed for some of these pollutants, as well as for hydrogen sulfide. Table 2.4 presents the results of this sampling at the site and at Sulfur Banks, a site of considerable volcanic activity, for comparison. The applicable State of Hawaii ambient air quality standards are also presented. In all cases, the State standards are more stringent than Federal ambient standards.

Table 2.3. Temperature ranges in and around Puna district

Station	Elevation above sea level [m (ft)]	Mean temperature [°C (°F)] January	Mean temperature [°C (°F)] August
Hilo	12 (40)	22 (71)	24 (76)
Mountain View	466 (1530)	18 (65)	21 (70)
Hawaii Volcanoes National Park	1210 (3971)	14 (58)	18 (64)

Source: D. Blumenstock and S. Price, "The Climate of Hawaii," in *Climates of the States*, vol. 2, Water Information Center, Inc., Port Washington, N.Y., 1974.

Table 2.4. Predrilling air quality measurement at the HGP-A site and at a site of volcanic activity for comparison

Air quality measurement should represent background concentrations.

Gas	Concentration of gases from measurements between 1971 and 1975		State of Hawaii[a] ambient air quality standard (ppm)
	HGP-A site (ppm)	Sulfur Banks (ppm)	
Sulfur dioxide (SO_2)	<0.5	Up to 25	0.01 (24-hr average annual arithmetic mean)
Hydrogen sulfide (H_2S)	<0.5	Up to 5	No standard – odor threshold ≈0.03
Nitrogen dioxide (NO_2)		<0.2	0.08 (24-hr average annual arithmetic mean) 0.04
Carbon monoxide (CO)	<0.5	Up to 3	9.0 (1-hr average) (8-hr average)

[a]In all cases, the State of Hawaii Ambient Air Quality Standard is more stringent than the Federal standard (Hawaii Environmental Laws and Regulations, Department of Health, Chap. 43, amended Feb. 13, 1976, effective May 13, 1976).

From Table 2.4, it may be observed that, excepting carbon monoxide, the sensitivity of the sampling methods was not sufficiently low to determine whether the concentrations of the pollutants at the project site were below the State ambient standards. The sampling results and later sampling during intense volcanic activity suggest that nearby volcanism does not apparently affect concentrations of sulfur dioxide, carbon monoxide, and hydrogen sulfide at the project site.[12,13]

Such is not the case, however, for atmospheric mercury. Atmospheric mercury has been measured at the HGP-A site on numerous occasions, including before drilling, during drilling, during well testing, and during periods of intense volcanic activity nearby when the well was shut in.[12-14] These measurements indicate that atmospheric mercury at the site is extremely variable and directly correlated with volcanic activity along the nearby east rift zone. Atmospheric mercury at the site has been recorded at 16 to 18 $\mu g/m^3$ and at 4.9 $\mu g/m^3$ during two periods of volcanic activity. Even during periods of relatively little activity, background atmospheric mercury levels at the project site ranged between 0.2 and 1.5 $\mu g/m^3$ of total mercury. These concentrations may be compared to atmospheric mercury levels ranging from 0.001 to 0.03 $\mu g/m^3$ reported from nonvolcanic regions.[14,15]

2.3 HYDROLOGY, WATER QUALITY, AND WATER USE

Because surface water is nearly absent a short distance inland from the coast, this section is primarily devoted to groundwater. A substantial amount of baseline groundwater data has been collected from nearby wells and springs that could be affected by geothermal resource development. Enough data have also been collected from the HGP-A well to formulate some tentative conclusions regarding relationships between geothermal water on the one hand and shallow aquifer waters and seawaters on the other.[16]

2.3.1 Surface water

Surface-water sources in the Puna district are nearly nonexistent, except for isolated ponds, springs, or reservoirs. Most of the area consists of undissected uplands displaying few established stream channels. Although stream channels became established on the northeast coast of Mauna Kea (Fig. 1.1), where volcanic activity has ceased, recurring eruptions in the Puna district prevent the development of an integrated drainage pattern. Streams are intermittent and ponds or lakes do not develop due to limited watersheds and the high permeability of Quaternary basalt and soil that lie at the surface throughout the Puna district.[6] At its nearest point, the Pacific Ocean lies about 5 km (3 miles) southeast of the HGP-A well. Groundwater reaches the surface, discharging as a spring (Isaac Hale Park) on the steep, rocky slope adjacent to the south coast. This surface water travels only a short distance before reaching the sea.

Household water supplies in the rural areas of Puna are obtained largely through roof catchment and storage in cisterns.[16] The more developed areas such as Pahoa are supplied with water pumped from the South Hilo district by the County public water supply. Wells in the vicinity of the project site generally produce water that is too brackish for either domestic or agricultural use.

2.3.2 Groundwater

Groundwater resources in Hawaii's Puna district occur in both confined and unconfined aquifers.[3] A portion of the water may be confined within porous compartments bounded by relatively impermeable dikes. These dikes are commonly vertical or steeply dipping. Regionally, fresh water occurs as a broad, lens-shaped, unconfined groundwater body, commonly called a Ghyben-Herzberg lens, which floats on the denser salt water beneath the Island. A typical Ghyben-Herzberg lens may not be present in the shallow aquifers that surround the HGP-A well site. Chemical analyses of well water suggest that a barrier (possibly dikes) prevents normal interaction with seawater.[4]

Eight sites have been used to evaluate the groundwater quality of Puna.[16] The location of each well and spring is illustrated in Fig. 2.4. Table 2.5 lists the chemical analyses for each site. In general, water samples from wells within 4.8 km (3 miles) of HGP-A are brackish and unusable as potable water. Although it does not quite meet U.S. Environmental Protection Agency (EPA) water quality standards (Table 2.6), water from the Allison and Airstrip wells could be considered potable for private use. Potable water is available from wells at Pahoa Station and Kalopana Station, which are 5.5 km (3.4 miles) and 9.0 km (5.6 miles) from the HGP-A well, respectively.

The mean residence time for waters from shallow wells does not exceed a few years.[16] Tritium concentrations (Table 2.5) and oxygen isotope ratios compare with those of local rainwater. These data suggest local recharge and short residence times.

Fecal coliform analyses (Table 2.7) indicate generally pollution-free reservoirs.[11] The high coliform concentrations in the Allison well are believed to be associated with local contamination during sampling.

Chemical analyses of downhole samples from the HGP-A well indicate that the geothermal reservoir water differs from shallow well water in several important respects.[16] Table 2.8 lists a summary of geochemical data for the HGP-A well. While the water is brackish (nonpotable), it differs from shallow aquifer water in the following respects: (1) high acidity (pH value of $\sim$3, compared to pH of >7 for shallow wells), (2) high silica content (440 mg/liter, compared to a maximum of 80 mg/liter for shallow wells), and (3) very low tritium content. High acidity and silica content are normal characteristics of geothermal water.

The low tritium content is significant because it indicates a relatively long residence time compared to water in shallow aquifers. The tritium content [<0.1 tritium units (TU)] suggests that geothermal water has a residence time exceeding 50 years.[16] This indicates that there is little hydraulic communication with shallow aquifers where

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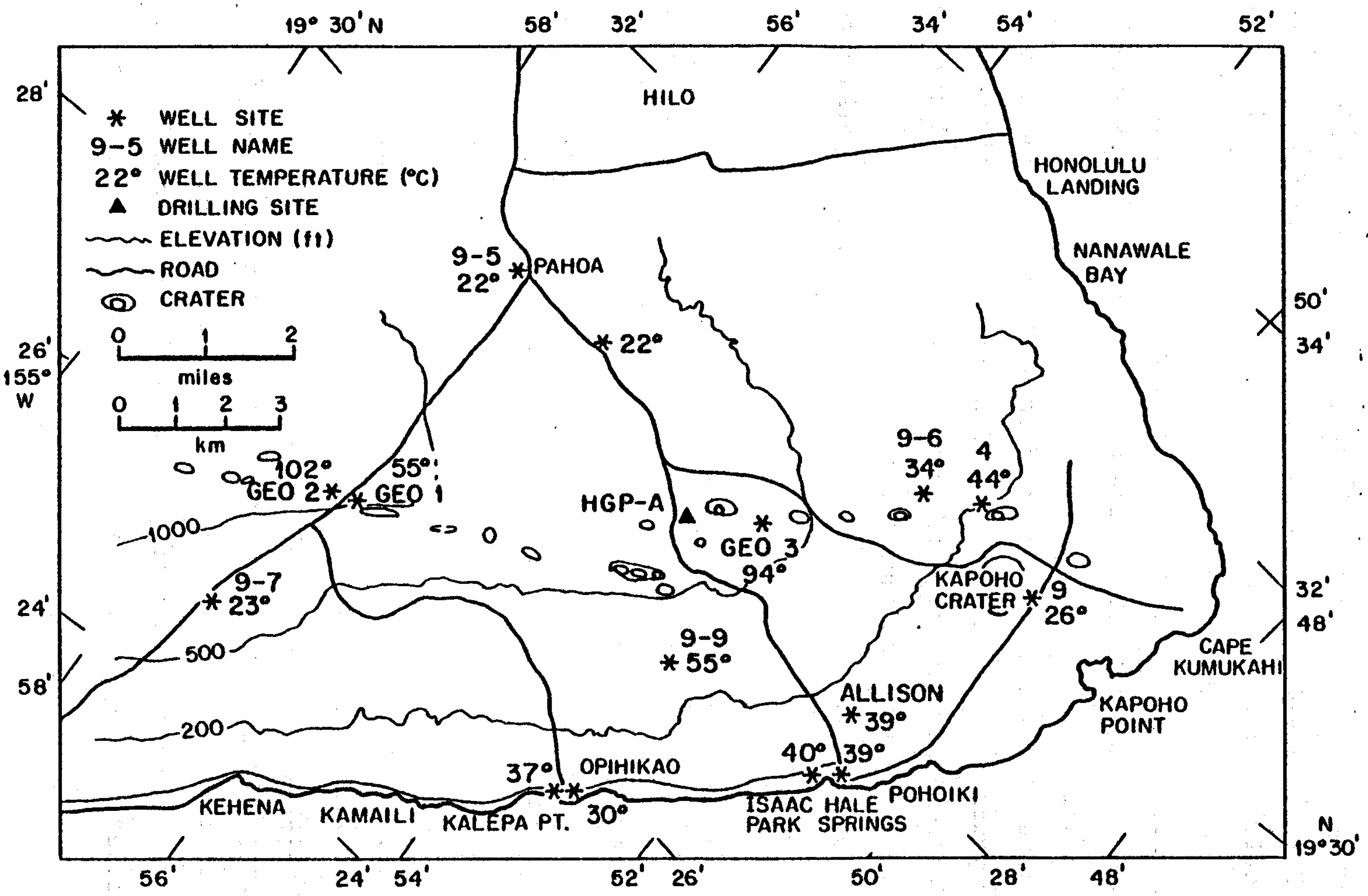

Fig. 2.4. Location of sampled wells and spring, Puna, Hawaii. Source: P. M. Kroopnick et al., *Hydrology and Geochemistry of a Hawaiian Geothermal System: HGP-A*, HIG-78-6, No. 4, prepared for the National Science Foundation, Grant GI-38319, and the Energy Research and Development Agency, Grant EY-76-C-03-1093, May 1978.

Table 2.5. Chemical data for Puna area wells

All concentrations are in milligrams per liter.

USGS/BWS No.	Name	Distance from HGP-A [km (miles)]	Date	Temperature [°C (°F)]	pH	Na	K	Ca	Mg	Cl	HCO_3	SO_4	SiO_2	TU[a]
2986-01	Pahoa Station	5.5 (3.4)	01-06-76		7.30	36.0	2.72	1.58	2.7	13.5	48	21.1	50.0	9.9
9-5	[elev. 215 m (705 ft); pumped]		07-21-75	23.3 (73.9)	6.65	19.3	2.7	1.6	1.9	9.8	44	27.3		10.6
2487-01	Kalapana Station	9.0 (5.6)	01-06-75	28.5 (83.3)	7.68	89.6	5.20	5.30	6.6	132.2	38	37.2	44.5	16.7
9-7	[elev. 229 m (752 ft); pumped]		07-21-75	20.8 (69.4)	7.05	78.8	5.0	5.9	5.6	120	36.8	28.6		18.0
3080-02	Kapoho Shaft	6.5 (4.1)	01-06-75	25.5 (77.9)	7.80	85.8	6.60	42.4	37	16.9[b]	372	20	53.6	14.1
9	[elev. 12 m (38 ft)]		07-21-75	22.1 (71.8)	7.10	86.5	6.2	23.2	25.7	95.7	328	22.7		10.5
			10-27-75			92.0	5.8	32.0	27.8	105	330	23.0		
3081-01	Airstrip Well	4.3 (2.7)	01-06-75	36.8 (98.2)	7.42	238	13.6	23.0	28	303.5	48	204	71.3	
9-6	[elev. 88 m (287 ft); depth 87 m (285 ft)]		07-22-75	33.5 (92.3)	7.75	223	16.8	12.5	27.2	316	44	211		11.1
2881	Allison Well [elev. 43 m (140 ft); depth 44 m (144 ft)]	4.6 (2.9)	01-07-75	37.8 (100.0)	7.35	216	10.8	13.4	15	281	132	69.2	24.1	12.9
	Isaac Hale Park Spring	5.3 (3.3)	01-07-75	36.0 (96.8)	7.75	2020	86.0	32.4	200	3534	56	507	81.5	8.5
			10-27-75			2140	87.5	98.0[b]	239	3660	61.0	552		
2783-01	Malama Ki Well	2.7 (1.7)	01-07-75	52.2 (126.0)	7.02	2105	109	66.8	210	3811	144	471	100.7	15.6
9-9	[elev. 83 m (274 ft); depth 84 m (276 ft)]		07-22-75		7.45	2890	149	117	293	5120	128	598		8.6
G3	Geothermal No. 3	1.3 (0.8)	01-07-75	93.0 (199.4)	6.85	2050	190	76.8	52	3274	30	314	96.6	10.3
	[elev. 183 m (600 ft); depth 168 to 183 m (550 to 600 ft)]		07-21-75			2000	195	81	59	3410		335		7.3
G3-T	Geothermal No. 3[c] (Thief)	1.3 (0.8)	07-21-75	74.0 (165.2)	1.4	1740	158	71	62.5	2980	20	317		9.1

[a] Tritium reported in tritium units (TU).
[b] Suspect data.
[c] This sample taken 15 to 18 m (50 to 60 ft) below water surface.

Source: P.M. Kroopnick et al., *Hydrology and Geochemistry of a Hawaiian Geothermal System: HGP-A*, HIG-78-6, No. 4, prepared for the National Science Foundation, Grant GI-38319, and the Energy Research and Development Agency, Grant EY-76-C-03-1093, May 1978.

Table 2.6. U.S. Environmental Protection Agency drinking water standards for potential HGP-A contaminants

Parameter	Drinking water standard (ppm)
Total dissolved solids (TDS)	500[a]
Cadmium (Cd)	0.010[a]
Copper (Cu)	1[b]
Chromium (Cr)	0.05[a]
Mercury (Hg)	0.002[a]
Manganese (Mn)	0.05[b]
Lead (Pb)	0.05[a]
Sulfate (SO_4)	250[b]
Zinc (Zn)	5[b]

[a]Source: "National Interim Primary Drinking Water Regulations," *Fed. Regist.* 40(248): 59566–59588 (1975).

[b]Source: "National Secondary Drinking Water Regulations," *Fed. Regist.* 42(62): 17143–17146 (1977).

Table 2.7. Microbiological quality of groundwater, Puna, Hawaii

Well/shaft number	State number	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	1,500	7	
	2881	Allison	1-7-75	≥24,000	93	Well bottom mud in sample

Source: R. M. Kamins et al., *Environmental Baseline Study for Geothermal Development in Puna, Hawaii*, Hawaii Geothermal Project, University of Hawaii, Honolulu, September 1976.

Table 2.8. HGP-A geochemical summary

All concentrations in milligrams per liter of total discharge.

	Cl	Na	K	Ca	Mg	SiO_2	$S^{=}$	pH	Tritium
Downhole	1040	730	123	53.8	1.0	440	135	3	<0.1
Nonflowing (average of five profiles)									
Mean	1040	730	123	53.8	1.0	440	135	3	0.1
Standard deviation	465	270	46	49.5	0.7	230	96		
692 m (2270 ft) (2-14-77)	4720	2008	245	445	14.0	432	0.66	3	
Low flow (average of four samples)	1040	480	103	22.6	0.25	710		2.5	
Weir box									
Approximate steady state (1-30-77)	780	390	68	24	0.11	41		8.5	

Source: P.M. Kroopnick et al., *Hydrology and Geochemistry of a Hawaiian Geothermal System: HPG-A*, HIG-78-6, No. 4, prepared for the National Science Foundation, Grant GI-38319, and the Energy Research and Development Agency, Grant EY-76-C-02-1093, May 1978.

tritium levels* are high (between 7.3 and 18.0 TU) and that recharge probably takes place from a more distant source. Although no evidence is available, it has been suggested that the slopes of Mauna Loa may be the recharge area for the geothermal reservoir.

Chemical analyses for trace elements produced the following results: (1) copper, chromium, and nickel concentrations were below the threshold of detection (0.1 mg/liter), (2) cadmium and lead concentrations were barely detectable (∿0.01 mg/liter), (3) zinc and manganese concentrations were ∿0.20 mg/liter. A significant concentration of mercury [in particulate form (cinnabar)] was present, ranging from several hundred micrograms per liter at the beginning of the flow test to less than 50 μg/liter at the end,[16] suggesting that most trace-element concentrations (mercury is a notable exception) are below EPA-recommended maximum concentrations (Table 2.6).

P. M. Kroopnick et al. suggest that impermeable vertical dikes may form a barrier between the geothermal water and the ocean water on the south side of the rift zone.[16] The measured chemical parameters of the well under no-flow conditions do not vary appreciably as a function of depth. The HGP-A well water is only slightly saline (∿5 to 10% seawater) despite its origin at great depth where typical seawater would normally be present.[16]

The chloride concentration steadily increased from 2500 mg/liter at the beginning of the 42-day flow test to 3200 mg/liter at the end of the test.[16] This suggests that saltwater encroachment may take place as reservoir water is withdrawn over an extended period of time.

Water from an intermediate-depth aquifer evidently mixes with geothermal reservoir water during continuous discharge. Figure 2.5 illustrates water temperature as a function of depth under no-flow

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*Natural tritium concentration in rainwater before 1952 (pre-bomb) was 8 tritium units (TU), and the half-life of tritium is 12.33 years.[17] A concentration of 0.1 TU (decay through 6 half-lives) implies a groundwater age of at least 74 years before atmospheric testing of hydrogen bombs began (1952). Tritium levels in excess of 8 TU indicate that groundwater was produced by rain that fell more recently than 1952.

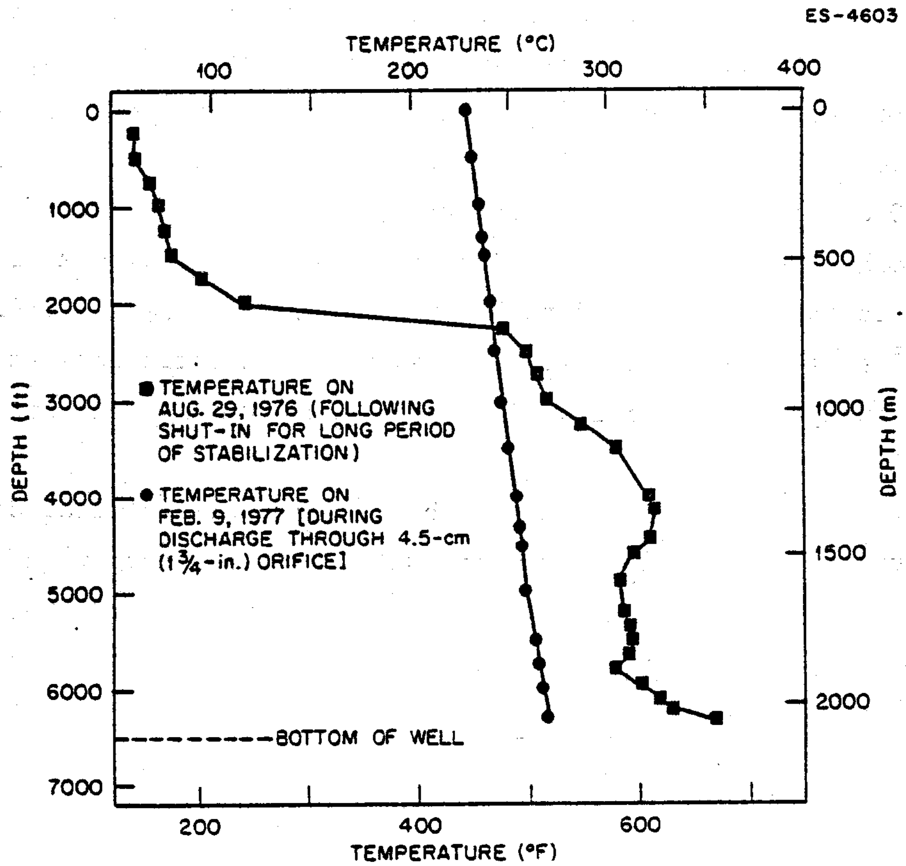

Fig. 2.5. Downhole temperature for HGP-A. Source: P. M. Kroopnick et al., *Hydrology and Geochemistry of a Hawaiian Geothermal System: HGP-A*, HIG-78-6, No. 4, prepared for the National Science Foundation, Grant GI-38319, and the Energy Research and Development Agency, Grant EY-76-C-03-1093, May 1978.

conditions with a long period of temperature stabilization and for a short-duration flow test. The temperature curves suggest that the more shallow water source is having a cooling effect upon the geothermal reservoir water during flow testing.

A probable cause of this mixing is the manner in which the HGP-A well was completed.[17] The intermediate-depth interval was completed with slotted liner rather than with cemented casing. While this completion method may reduce the generating capacity of the well, it should have little or no effect on shallow aquifers having potential potable water resources.

2.4 LAND USE

Land use on the Island of Hawaii is about evenly divided between agricultural and forested land (Table 2.9). The third-ranking category is recreational use, primarily because of the Hawaii Volcanoes National Park surrounding Kilauea (Fig. 1.2).

The Puna district is primarily forest (commercial and noncommercial open land). Other large land categories are conservation (forest reserves) and agriculture. The soils of the Puna district are well drained, and they are relatively young soils that have developed on lava (histosols) and weakly developed soils that have developed on volcanic ash (entisols). Therefore, the potential for large-scale, highly productive agriculture is limited. Table 2.10 lists existing land-use acreage in the Puna district. Open land (75% of the land area) dominates in this category. Recreation includes part of the Hawaii Volcanoes National Park and State land.

The area surrounding the project site is predominantly open land of *ohia* forests of various ages. (The *ohia* tree commonly colonizes recent lava flows in Hawaii.) There are two forest reserves within a few kilometers of the site — Malama Ki and Nanewale (Fig. 2.6). About 4.5 km (2.8 miles) west of the site, land is cultivated for sugar. Papaya orchards lie a similar distance east of the site. Because it is covered by a 1955 lava flow, the entire project site and much of the area immediately surrounding it is not valuable agricultural land. According to the Hawaii State Conservationist (Appendix A), there is no unique farmland near the project site. The nearest prime farmland is close to Pahoa, approximately

Table 2.9. Land use – Island of Hawaii

Land use	Land area (acre)	Land area (ha)
Sugar cane	114,775	46,449.4
Vegetable	1,916	775.4
Orchard	21,529	8,712.8
Grazing	794,629	321,586.4
Dairy	3	1.2
Poultry	7	2.8
Idle agriculture	0	0.0
Forest	197,823	80,059.0
Forest reserve	710,260	287,442.2
Recreation	794	321.3
Game management	19,288	7,805.8
National park	211,688	85,670.1
Urban		
Undeveloped residential	74,429	30,121.4
Developed	12,146	4,915.5
Pali and barren land	421,945	170,761.1
Water	101	40.9
	2,581,333	1,044,665.4

Source: University of Hawaii, *Atlas of Hawaii*, Department of Geography, University of Hawaii Press, Honolulu, 1974.

Table 2.10. Existing land use in Puna district

Existing land use	Land area (acre)	Land area (ha)
Residential	2,219.3	898.15
Manufacturing	32.1	12.99
Nonmanufacturing	391.6	158.48
Retail	28.8	11.66
Services	124.1	50.22
Social	42.2	17.08
Recreation	52,095.1	21,082.89
Agriculture	27,748.1	11,229.66
Transportation (non-road)	0.0	0.00
Open (forest)	237,370.3	96,063.76
	320,051.6[a]	129,524.88

[a]Total does not include roads.

Source: Hawaii County Research and Development Department, unpublished data, 1976.

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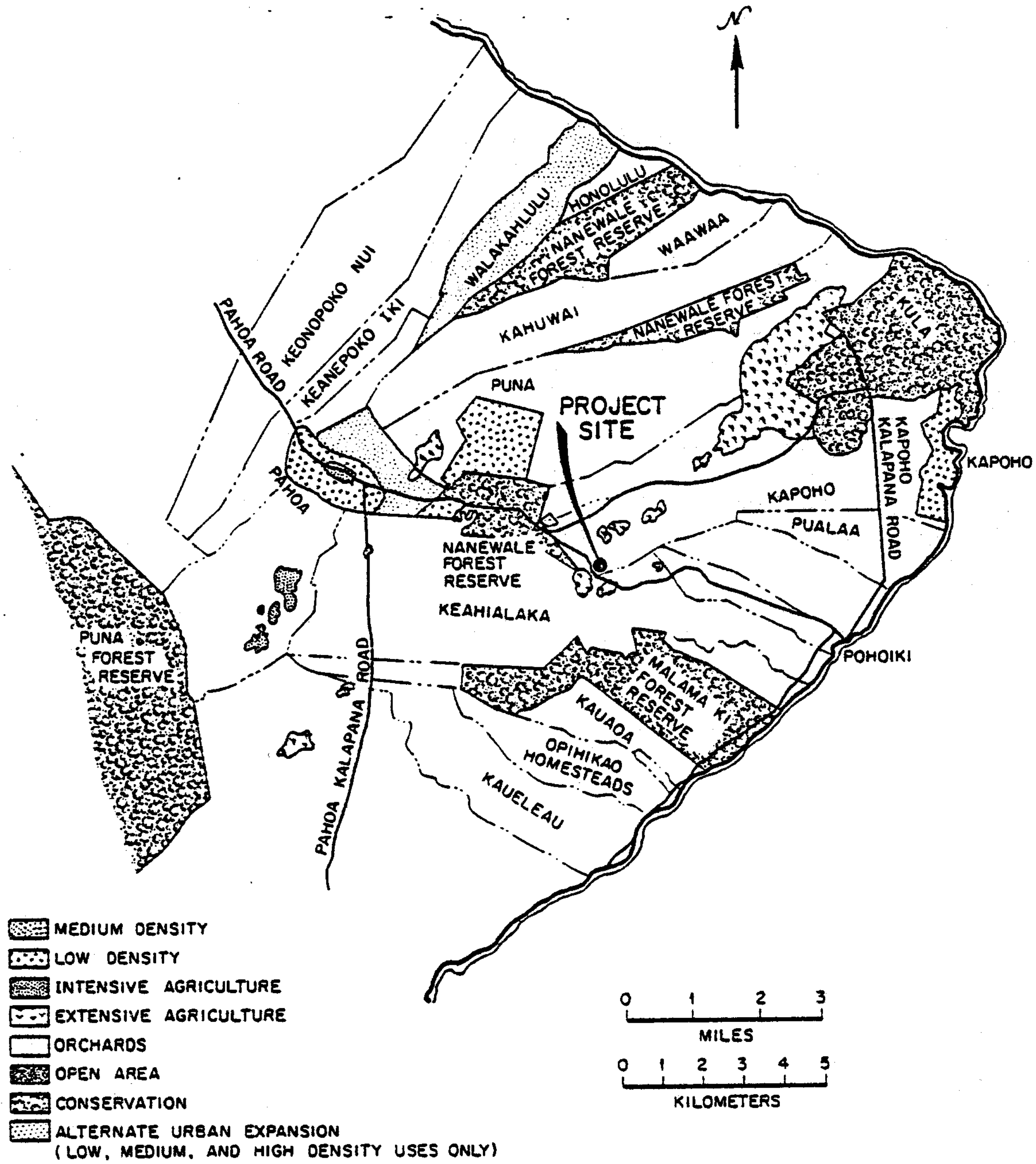

Fig. 2.6. Land-use map of the Puna district. Source: R. M. Kamins, *Environmental Impact Statement for the Hawaii Geothermal Research Station Utilizing the HGP-A Well at Puna, Island of Hawaii*, prepared for the Department of Planning and Economic Development, State of Hawaii, March 1978.

5 km (3 miles) northwest of the site. The University of Hawaii Agricultural Experiment Station is over 0.8 km (0.5 mile) from the site.

Directly adjacent to the site (to the south across the Pohoiki Road), land that was covered by the 1955 lava flow has been subdivided into 0.4-ha (1-acre) homesites (Fig. 2.7). The majority of these lots are vacant; there are only about one dozen residences within a 1.6-km (1-mile) radius of the site.[6] The nearest occupied residence is 1.1 km (0.7 mile) from the site and is located in the Leilani Estates (Fig. 2.7). The Nanewale Estates, a subdivision with a number of occupied residences, is about 2.5 km (1.6 miles) northwest of the site.

2.5 HISTORIC AND ARCHAEOLOGIC SITES AND NATURAL LANDMARKS

2.5.1 Historic

The Puna district has played a relatively insignificant role in Hawaiian history; it has produced no important family or chief. Consequently, there are few historic or archaeologic sites in the district. Table 2.11 lists all the sites on the "National Register of Historic Places"[18] that are located in the southeastern half of the Island of Hawaii. No site is less than 40 km (25 miles) from the project site.

2.5.2 Archaeologic

The few archaeologic sites that exist in Puna are along the coast, some distance from the project site. The petroglyphs at Kapoho (Fig. 1.2) are approximately 6.9 km (4.3 miles) northeast of the well site and constitute the nearest archaeologic site.[6] The well site is covered by a 1955 lava flow that has buried any archaeologic remains that may have existed at the site. An area within a 1.6-km (1-mile) radius of the project site was studied for evidence of any material of archaeologic importance.[19] The area studied consisted of both recent and prehistoric lava flows, as well as a few areas that were untouched by lava for many centuries. No evidence of archaeologic material was found that would indicate prehistoric human occupation in the immediate vicinity of the project site.[12]

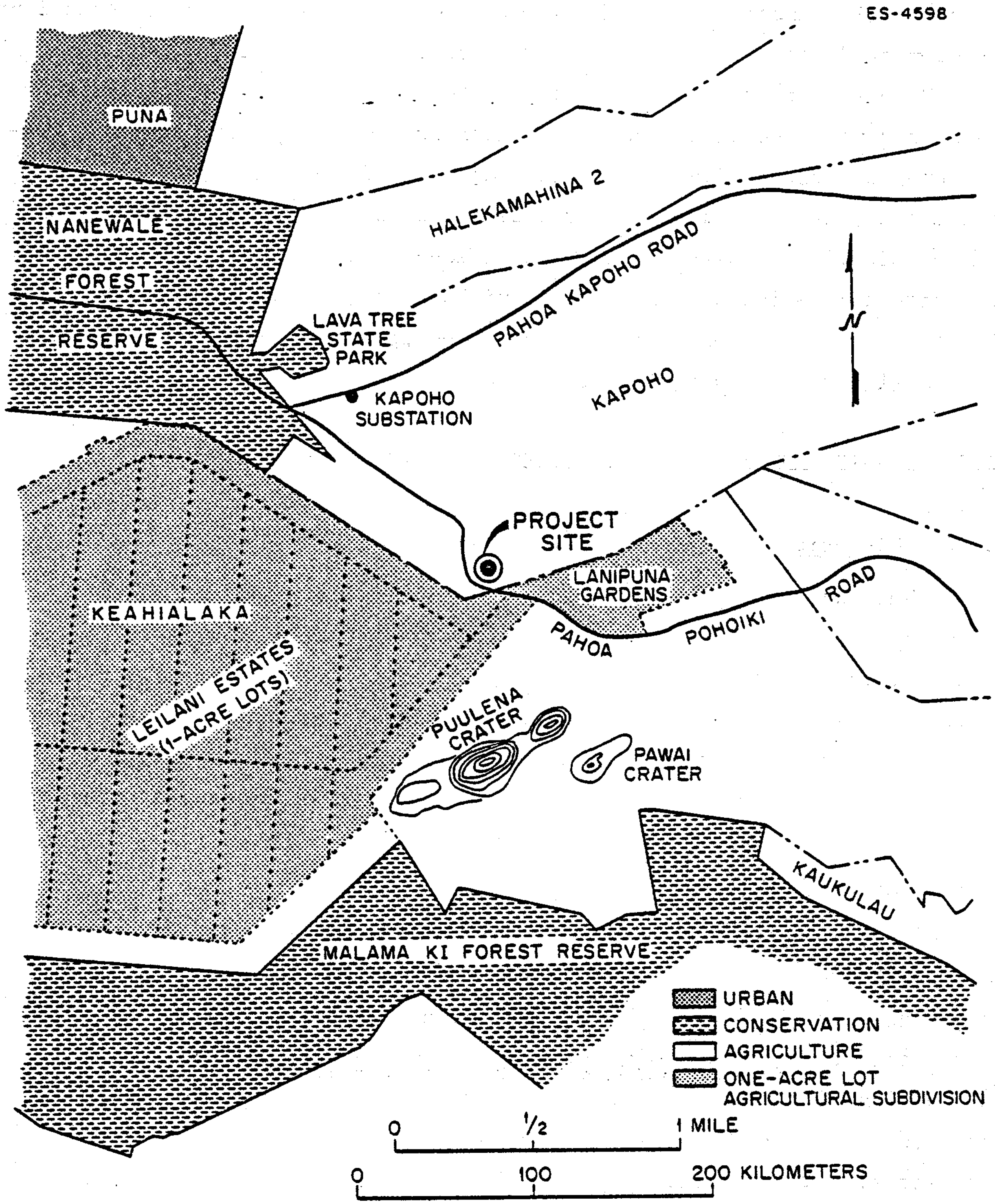

Fig. 2.7. Land use in the immediate vicinity of the project site. Source: R. M. Kamins, *Environmental Impact Statement for the Hawaii Geothermal Research Station Utilizing the HGP-A Well at Puna, Island of Hawaii*, prepared for the Department of Planning and Economic Development, State of Hawaii, March 1978.

Table 2.11. National historic sites in the southeastern half of the Island of Hawaii

Name	Location	Distance from well site (km)	Distance from well site (mile)	Comment
U.S. Post Office building	Kinoule and Waianuenue Streets, Hilo	>40	>24.8	Dates from 1937 to 1938.
Footprints – 1790	Hawaii Volcanoes National Park (HVNP)	>40	>24.8	Footprints of ancient, native Hawaiians, preserved in volcanic ash.
Kilauea crater	HVNP	40	24.8	Volcanic crater, roughly 3 km in diameter.
Old Volcano House No. 42	HVNP	40	24.8	Original tourist hotel, dates from 1877.
Whitney Seismograph Vault No. 29	HVNP	40	24.8	Contains early (1961) equipment to record volcanic activity.
Wilkes campsite	Mauna Loa volcano in HVNP	>70	>43.5	Camp of U.S. Exploratory Expedition, 1840–1841.
Ainapo Trail (Menzies trail)	Mauna Loa volcano in HVNP	>40	>24.8	Customary route to summit (prehistoric to 1961).
Ahole Holua Complex	South of Milolii on Ahole Bay	≅100	≅62.1	Remains of ancient structures.
South Point Complex	Southern tip of island	≅100	≅62.1	Archaeological site – provides most complete record of Hawaiian occupation on the island.
Puna-Kau'a Historic District	HVNP – Pahala vicinity	70	43.5	Prehistoric village and temple sites; petroglyphs.
Manuka Bay Petroglyphs	Southwest of Waiohinu at Manuka Bay	>100	>62.1	Petroglyphs in *pahoe hoe* lava.

Source: U.S. Department of the Interior, *The National Register of Historic Places*, 1976; and "Annual Listing of National Register of Historic Places," *Fed. Regist.* 43(26): 5163–5345 (1978).

2.5.3 Natural landmarks

Two locations on the Island of Hawaii (Mauna Kea and Makalawena Marsh) are located on the "National Registry of Natural Landmarks."[19] Both sites are over 80 km (50 miles) northwest of the project site.

Although it is not on the Registry, Lava Tree State Park, located 1.6 km (1 mile) north of the project site, is an area of considerable natural interest. It consists of a number of standing tree molds of cooled lava and some *kipukas* (densely forested and isolated parcels of land untouched by recent volcanism).

2.6 NOISE

2.6.1 Noise characteristics of the site

There have been no measurements of background noise at the HGP-A site. Because of its rural setting, noise levels are expected to be low [probably less than 45 dB(A)]. The major source of noise in the site vicinity is infrequent traffic on the adjacent Pohoiki Road.

2.6.2 Noise regulations

There are no specific State or County regulations that apply to noise.

2.7 ECOLOGY

This section addresses terrestrial ecology and endangered species. There are no aquatic species because there are no natural surface waters in the project area (HGP-A well site).

The Hawaiian Islands are removed from mainland plant and animal populations by 3220 to 6440 km (2000 to 4000 miles) of open ocean. The native flora and fauna of Hawaii developed from the relatively few species of plants and animals that were able to successfully colonize the Islands. The isolated populations evolved into races and species quite different from their mainland ancestors. Much of the Hawaiian native flora and fauna, therefore, is unique.

Since the arrival of man on the Islands, two factors have contributed to the decline of the native Hawaiian biota: (1) the introduction of exotic species and (2) habitat destruction. Hundreds of species of European and Asian plants and animals have become established as reproducing populations on the Islands and have replaced much of the endemic biota through competition and predation. Western man's encroachments on the Islands have increased pressure on native biota through habitat destruction. Consequently, many of Hawaii's endemic species are now extinct and many are currently on the Federal list of endangered species. Relic populations of the native Hawaiian flora and fauna exist primarily on high mountain slopes and in other areas not amenable to man's activities.

2.7.1 Terrestrial ecology of the site and environs

2.7.1.1 Vegetation

The project site and its immediate vicinity was covered by a 1955 lava flow. The plant and animal communities represented on site are those typical of the earliest stages of primary succession on lava flows in Hawaii. The undisturbed portions of the flow consist of barren aa lava (blocky lava) covered by a dense growth of lichens, with scattered ferns and *ohia lehua* (*Metrosideros collina*) saplings less than 1 m (3.3 ft) in height.

The region surrounding the site consists of forests dominated by *ohia*. Since most of the flows are relatively recent, the forests are mostly small. Near Lava Tree State Park [about 1 km (0.6 mile) from the site] are a few *kipukas* (small "islands" not covered by recent flows) on which the *ohia* trees reach 30 m (98.4 ft) in height. The ground cover in all the *ohia* forests consists largely of false staghorn ferns (*Dicranopteris linearis*), grasses, and several species of wild orchids (common in Hawaii). Treeferns (*Cibotium* sp.) and *ieie* vines (*Freycinetia arborea*) occur in the more mature forests of the *kipukas*. All the endemic plant species found in the *ohia* forests in the region of the site are common in Hawaii on recent lava flows.

In disturbed areas near the site, the vegetation consists predominantly of introduced trees, shrubs, vines, and grasses. Such exotic vegetation is found along roads, in the vicinity of Lava Tree State Park, and in most areas downslope of the drilling site. Exotic vegetation along the roads and trails consists of such plants as mango (*Mangifera indica*), papaya (*Carica* sp.), guava (*Psidium guajava)*, bamboo (*Bambusa* spp.), kukui (*Aleurites moluccana*), sugarcane (*Saccharum officinarum*), bana (*Musa* sp.), Indian pluchea (*Pluchea indica*), Jamaica vervain (*Stachytarpheta jamaicensis*), and sensitive plant (*Mimosa pudica*). A plantation of Norfolk Island pines (*Araucara excelsa*) occurs between Lava Tree State Park and the drilling site, and there are groves of albizia (*Albizia falcataria*) along the road and at the park.

2.7.1.2 Fauna

The only native Hawaiian mammals are the Hawaiian hoary bat (*Lasiurus cinereus semotus*) and the Hawaiian monk seal (*Monaccus schauinslandi*). Both are listed as endangered by the U.S. Department of the Interior.[20] Only the bat potentially occurs in the region surrounding the site. The bats require relatively dense sheltering tree or shrub growth for roosting habitat.[21] Thus, bats would not utilize the relatively barren site, but they may occur in *ohia* forests on surrounding lands. Introduced mammals such as rats (*Rattus* sp.) and mongooses (*Herpestes auropunctatus*) may also be expected to occur in surrounding lands, especially in the agricultural areas within a few kilometers of the site.

Land birds of eight families have populated Hawaii without known help from man.[22] These colonizers evolved into many unique species, endemic to the Islands. Of the 66 endemic Hawaiian land birds that were known during the nineteenth century, about 35% are now extinct and over 40% are considered rare or endangered.[11] The endangered Hawaiian birds account for about half of all the birds of the United States listed on the endangered species list.[20]

Although *ohia* forests provide habitat for the majority of native forest birds on Hawaii, most species occur only at higher elevations. Of the native Hawaiian birds, only two species would be expected in the young *ohia* forests near the low-elevation [175 m (574 ft)] project site: (1) the Hawaiian hawk (*Buteo solitarius*) and (2) the Hawaiian short-eared owl or *pueo* (*Asio flammeus sandwichensis*). The habitats within a 1.6-km (1-mile) radius of the site are not suitable for these species; individuals would be expected to occur only in passage. Birds observed at the site by a noted ornithologist were all introduced species and include the spotted dove, melodious laughing thrush, Japanese white-eye, common myna, house finch, ricebird, and cardinal.[23]

2.7.2 Endangered species

2.7.2.1 Plants

The Puna district is not an area of potential endangered plant species. Apparently, the naturally induced disturbance and the history of human use have eliminated rare endemics. Field surveys[12] and consultation with local authorities have failed to reveal any evidence of rare or endangered plant species in the vicinity of the site.

2.7.2.2 Animals

There are 12 land animal species on the Island of Hawaii that are listed by the Federal government as endangered with extinction.[20] Table 2.12 lists these species and their preferred habitats. The only species that could occur near the site (the Hawaiian hoary bat and the Hawaiian hawk) would only occur as transients (Sect. 2.7.1.2).

2.8 DEMOGRAPHY, SOCIOECONOMICS, AND CULTURAL VALUES

The Puna district (estimated 1976 population of 7800) is the second most populous of the nine districts on the Island of Hawaii. Only the South Hilo district has a larger population (39,600 in 1976). Nevertheless, the Puna district is sparsely populated. The agricultural town of Pahoa (1970 population of 924) is the population center nearest the site [about 5.6 km (3.5 miles) northwest]. Hilo, the largest city on the Island (1970 population of 26,353), is about 24 km (15 miles) north of

Table 2.12. Endangered wildlife of the Island of Hawaii

Name	Habitat	Present distribution
Hawaiian dark-rumped petral (*uau*) (*Pterodroma phaeopygia sandwichensis*)	Oceanic, nests on walls of craters	Flanks of Mauna Kea and Mauna Loa
Hawaiian goose (*nene*) (*Branta sandvicensis*)	Lava flows 5000–8500 ft away from water	Slopes of Mauna Loa and Hualalai; reintroduction on Maui
Hawaiian duck (*koloa*) (*Anas wyvilliana*)	Coastal lagoons, marshes, and mountain streams	Reintroduced experimentally
Hawaiian hawk (*io*) (*Buteo solitarius*)	Widespread, open forest, agricultural land, grassland	Slopes of Mauna Loa, windward and Kona coasts
Hawaiian coot (*alae keokeo*) (*Fulica americana alai*)	Ponds and lagoons	Migrates between islands
Hawaiian stilt (*aeo*) (*Himantopus himantopus Knudseni*)	Ponds, lagoons, marshes	Coastal shoreline
Hawaiian crow (*alala*) (*Corvus tropicus*)	1000–8000 ft, forested and ranching areas	Higher elevations on north and south Kona and Kau districts
Akiapolaau (*Hemignathus wilsoni*)	Upper mountain forests, tall kau, mamane	Upper forests of Mauna Kea and Mauna Loa
Hawaii akepa (*akepa*) (*Loxops coccinea coccinea*)	Native forests	Widely scattered on Mauna Kea, Mauna Loa, and Hualalai
Ou (*Psittirostra psittacea*)	Dense mountain rain forest with fern understory	
Palila (*Psittirostra bailleui*)	Mamane-naio forests, 7000–9000 ft	Mauna Kea
Hawaiian hoary bat (*Lasiurus cinereus semotus*)	Mature ohia-lehua and koa forests	

the site. The 1976 population of the Island of Hawaii was 76,600, which is equivalent to an overall population density of 7.5 persons per square kilometer (19 persons per square mile), while the population density for the Puna district was 6.4 persons per square kilometer (17 persons per square mile).[6,12]

Residential areas are under development immediately to the west of the project site and also about 1.6 km (1 mile) north of the site. The nearest occupied dwelling is in the former development (Leilani Estates) and is located approximately 1.1 km (0.7 mile) southwest of the site (Fig. 2.7). There are a dozen houses within 1.6 km (1 mile) of the project site.[6]

The largest employment sector in the Puna district is agriculture (Table 2.13). The manufacturing sector includes processing of agricultural products such as sugar, papaya, and macadamia nuts. Within the agricultural sector, the sugar industry is the largest full-time employer, with papaya second. Significant seasonal or part-time employment is provided by the papaya, macadamia nut, and anthurium industries (Table 2.14). Unemployment rates in the Puna district have been about 10% in recent years,[6] compared with a statewide figure of 7.4% in 1975.[24]

Projections to 1990 indicate that the population of the County of Hawaii will increase to 115,000 to 137,000 (a 50 to 79% increase over 1976 totals) and that the Puna district will increase to 8,400 to 13,000 (an 8 to 67% increase over 1976). Among other factors, the range of projections reflects uncertainty of the future of agriculture and tourism. The ability of existing services to handle projected growth will depend largely on the geographical distribution of the growth, whether in population centers such as Pahoa or in more remote areas. More centralized growth is expected to require expansion of municipal water supplies and initiation of sewage treatment, while other services (e.g., schools, fire and police services, and recreation facilities) are considered adequate in such places as Pahoa.[6]

Table 2.13. Employment (by sector) of Puna district residents

Sector	Employment (No.)	Employment (%)
Agriculture	718	24.9
Retail/wholesale trade	548	19.0
Construction	502	17.4
Service (including government)	467	16.2
Manufacturing (including agricultural processing)	309	10.7
Transportation, communications, utilities	228	7.9
Finance, insurance, real estate	101	3.5
Fishing, hunting	12	0.4
	2885	100.0

Source: R.M. Kamins, *Environmental Impact Statement for the Hawaii Geothermal Research Station, Utilizing the HGP-A Well at Puna, Island of Hawaii*, prepared for the Department of Planning and Economic Development, State of Hawaii, March 1978.

Table 2.14. Summary of employment statistics for major agricultural activities in Puna

Crop	Employment	
	Full-time	Seasonal or part-time
Sugar	428	
Papaya	265	227
Macadamia	81	205
Anthurium	95	235
Other flowers	116 (County)	67 (County)
Truck farming	30	

Source: County of Hawaii Research and Development Department and State of Hawaii Department of Agriculture, unpublished data, 1976.

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3. POTENTIAL ENVIRONMENTAL IMPACTS

The potential environmental impacts of the proposed action during the construction and operation phases are evaluated as they relate to geology, water and air quality, water and land use, historic and archaeologic resources and natural landmarks, noise, ecology, and socioeconomics.

3.1 IMPACTS OF CONSTRUCTION

The following sections consider the environmental impacts of construction of the power plant, a power line, and various research modules.

3.1.1 Geological impacts

There will be no geological impacts during plant construction. The lone production well has been completed and flow tested. It will usually be shut in during construction. The site is in a relatively flat area so that excavation activities will not lead to massive slope failure.

3.1.2 Impacts on air quality

Air emissions during the construction phase of the project will consist of exhaust emissions from diesel machinery and some fugitive dust. Diesel emissions will be minor, intermittent, and of short duration. They should be readily dispersed and should have no effect on air quality. The high precipitation and humidity should hold fugitive dust and releases to a minimum.

3.1.3 Impacts on water quality and use

No fresh surface water or groundwater exist at the site; hence, no potable water of local origin will be consumed during construction. Water for construction purposes will be obtained from the County public water supply system. A distribution line serving the Pahoa community presently ends near Lava Tree State Park, about 0.4 km (0.25 mile) from the construction area,[1] and water will be hauled from there by truck.

There should be no significant effect on groundwater quality, and there will be no surface discharge during construction. Sanitary and construction waste fluids will be discharged in an approved septic tank. Recent-age lava flows are highly suited for use as septic tank drain fields. Measurable degradation of water quality is not expected because of (1) the relatively low rate of liquid-waste discharge and its dilution by infiltration of a substantial amount of rainwater and (2) the brackish nature of local groundwater.

3.1.4 Impacts on land use

The HGP-A well site consists of 1.7 ha (4.1 acres) of land that is currently occupied by a holding pond, a parking lot, a geothermal well, and associated testing and muffling equipment. Because all onsite construction activities will disturb ground that was covered by a 1955 lava flow (Sect. 2.4), there will be no encroachment on valuable agricultural land. The project site is not visible from the nearby Lava Tree State Park; therefore, conflicts with recreational uses of the park are not anticipated.

The land directly across the Pohoiki Road from the HGP-A well site is zoned residential and has been subdivided into home lots (Fig. 2.7); however, there are few residences within the subdivision. The closest house is 1.1 km (0.7 mile) from the project site. Construction activities and the attendant increase in traffic on the Pohoiki Road could affect nearby residents. Presently planned public information meetings involving the communities near the well site should serve to minimize potential conflicts.

The entire Puna district is sparsely populated and essentially rural. The HGP-A well has already somewhat changed the rural or "natural" setting of the immediate area. Even with mitigating measures such as attractive fencing and landscaping, construction of a pilot power plant at the site will further change the character of the area. The effects of commercial development of the geothermal resource would be even greater. How the HGP-A well power plant and geothermal energy in Puna are perceived will depend upon the individual viewer. Public meetings involving the local populace in the early stages of this geothermal project should help to ensure as few conflicts as possible.

Construction of the new power line will require extension of the utility right-of-way to 5.15 m (17 ft) beyond the edges of the roads. Loss of developed residential land will be avoided by stringing the lines on the north side of the Pohoiki Road across from the Leilani Estates lots adjoining the road. Approximately 120 m (400 ft) of right-of-way will be taken from the Nanewale Forest Reserve.

3.1.5 Impacts on historic and archaeologic resources and natural landmarks

There are no sites of historic or archaeologic value near enough to the project site to be affected by project activities (Sect. 2.5). Since the project site is situated on a 1955 lava flow, construction activities are not likely to disturb any archaeologic resources. There are no natural landmarks near the site (Sect. 2.5).

3.1.6 Noise-related impacts

There will be no additional well drilling at the HGP site unless the seepage pond's performance is unsatisfactory. The major source of noise during the construction phase of the project will be the diesel construction machinery that will be operated during normal working hours. Noise levels from heavy diesel equipment generally reach 85 to 90 dB(A) at 15 m (50 ft) from the source.[2] Based on physical laws of wave propagation, sound attenuation by distance should reduce these noise levels to 49 to 54 dB(A) at the nearest residence [1.1 km (0.7 mile) from the site]. Deflection by vegetation between the well site and the residences and atmospheric absorption should further reduce these noise levels.

The U.S. Department of Housing and Urban Development rating system for residential noise levels categorizes as "normally acceptable" noise levels in excess of 65 dB(A) for less than 8 hr in a 24-hr period.[3]

The U.S. Environmental Protection Agency recommended maximum outdoor residential day/night noise level is 55 dB(A).[3] At the nearest residence, the estimated noise levels resulting from construction activities will be lower than 55 dB(A) and thus will fall within both criteria. Because the noise levels are suitably low and because construction activities at the site are expected to last only a few months, noise from projected construction is not expected to produce any long-term effects on nearby residents.

3.1.7 Ecological impacts

For the most part, project construction activities will disturb only terrestrial areas of the project site that have already been cleared. Vegetation that may be destroyed by additional clearing, if any, will consist of lichens and small *ohia* saplings on the 1955 lava flow. The early successional habitat surrounding the site is not suitable for endemic wildlife. Construction of the new transmission line will involve a small loss of roadside vegetation consisting of mixed *ohia* woodland and numerous introduced weedy species. Construction activities and noise may displace a few individuals of the nearby introduced wildlife species, but the total number displaced will be small in relation to the populations present in the surrounding habitats. Critical habitat for endangered species does not occur on or near the site (Sect. 2.7.2); therefore, the project will not affect these species.

3.1.8 Socioeconomic impacts

Total construction employment is not expected to exceed 25 persons at any one time, with eight to ten persons being a more typical figure (Sect. 1.3.1). Most of this construction force will be skilled labor (employees of the HGRS project participants). A few unskilled laborers may be required, but the Puna district labor pool, with its relatively high unemployment rate (Sect. 2.8), is expected to accommodate this demand. Construction personnel not already residents of the Puna district will probably commute from Hilo, the nearest major city. A slight increase in local spending may result (e.g., for groceries or automobile fuel), but the Hilo area would be expected to benefit primarily from any employee spending. Thus, project construction employment will likely represent a negligible socioeconomic impact.

3.2 IMPACTS OF OPERATION

The following sections consider the environmental impacts of power generation and of the operation of various research modules.

3.2.1 Geological impacts

Induced seismicity, subsidence, and groundwater degradation are the principal geologically related operational impacts. Impacts on groundwater are considered separately in Sect. 3.2.3. Natural geological phenomena such as earthquakes and volcanic eruptions are unplanned events and are considered in Sect. 3.4.

The operation of the HGRS is not likely to cause induced seismicity. It is generally recognized that induced seismicity is caused by reinjection of waste fluid at high pressure and high discharge rate.[4] Combined discharge from the well and cooling tower, however, is relatively small [3.8 to 6.3 liter/sec (60 to 100 gpm)] and will infiltrate through the floor of a seepage pond by gravity flow.

Subsidence is not expected to have a substantial environmental impact. The low production rate [10.5 liter/sec (166 gpm)] from a single well and the nature of the reservoir[5] (pillow lava with fracture porosity and hydropressure, as opposed to interbedded sedimentary rock with primary porosity and geopressure) suggest that subsidence will be minimal.

Even if subsidence did occur, there would be no significant effect on the environment beyond the HGRS boundary. Possible effects of subsidence on HGRS facilities are treated as accidents (Sect. 3.4). Subsidence would not be harmful to the surroundings because there is no surface drainage that could conceivably be disrupted or ponded.

3.2.2 Impacts on air quality

During project operation, air quality could be affected by releases of noncondensible gases or other constituents of geothermal fluids into the atmosphere. Due to the moderate and humid climate, water vapor released from the cooling towers should not significantly affect local air quality. Chemical analyses of the geothermal fluids were obtained during earlier flow tests at the HGP-A site. These analyses indicate that hydrogen sulfide (H_2S) is the only noncondensible gas present that has a potential for adverse effects on local air quality. Mercury, which is closely associated with volcanic activity on the Island of Hawaii, is also present in the geothermal fluids at the HGP-A site. No other constituents of the geothermal fluids that could potentially affect air quality have been identified.

3.2.2.1 Hydrogen sulfide

Air quality effects of H_2S are of concern at the HGP-A site only in relation to its potential for nuisance odor. Adverse human health effects from H_2S occur only above 100 ppm.[6] However, the characteristic and unpleasant odor of H_2S is detectable at atmospheric concentrations of approximately 30 ppb. The recommended maximum atmospheric concentration for exposure to H_2S during an 8-hr working day is 10 ppm.[6] Adverse effects on sensitive species of plants have been demonstrated at H_2S concentrations above 300 ppb.[7]

The predrilling air quality measurements at the HGP-A site are detailed in Table 2.4. The odor of H_2S was not detectable prior to drilling, nor is the odor detectable (at present) when the well is shut in. However, during well flow tests, H_2S odor is prevalent near the well, and nearby residents have complained of odor during some well tests. Because of these complaints, an H_2S abatement system is planned. With abatement, H_2S emissions resulting from normal power plant operations will be an order of magnitude less than those resulting from well testing.

Ambient H_2S measurements recorded at the HGP-A site during three previous well flow tests are detailed in Table 3.1. The highest atmospheric concentration measured during flashing flow was 7 ppm (measured

Table 3.1. Results of atmospheric H_2S measurements in the HGP-A site vicinity during three flow tests

HGP-A well flow test	Concentration (ppb)	
Flashing flow test (4 hr) on Nov. 3, 1976[a]		
In plume [10 m (33 ft) from wellhead]	3100	
In plume [100 m (328 ft) from wellhead]	800	
Outside plume [10 m (33 ft) from wellhead]	600	
Flashing flow test on Apr. 22–23, 1977[b,c]		
Directly over water outfall at well	7000	
Upwind [3 m (10 ft) from well]	1000	
Downwind [30 m (98 ft) from well]	600	
Downwind [110 m (361 ft) from well]	300	
Preflashing flow test on Feb. 2, 1978[d]		
Steam over weir box at well	1700	
Well platform (in steam plume)	1300	
Downwind +90° [20 m (66 ft) from well]	15	
Downwind [100 m (328 ft) from well]		
Flashing flow test on Feb. 2, 1978	**First half hour**	**Second half hour**
Steam over weir box at well	500–700	700–1000
Well platform (in steam plume)	1100	700–900
Downwind [100 m (328 ft) from well]	10–20	5–10

[a]Source: B.Z. Siegel and S.M. Siegel, "Geotoxicology, Task 4.1," in *Phase III – Well Testing and Analysis, Progress Report for the First Quarter of Federal FY77*, Hawaii Geothermal Project, University of Hawaii, Honolulu, 1977.

[b]Source: B.Z. Siegel and S.M. Siegel, unpublished memorandum to Dr. John Shupe, Director, Hawaii Geothermal Project, Apr. 28, 1977.

[c]Ambient concentrations were also measured in over 20 locations along the roads and in nearby subdivisions. All measurements were below 200 ppb, which was the sensitivity limit of the instrumentation. The odor of H_2S was detectable along the road to Cape Kumuhaki up to 0.5 km (0.3 mile) from the site and along the Pahoa Road up to 0.8 km (0.5 mile) downwind of the site.

[d]Source: B.Z. Siegel and S.M. Siegel, *Aerometry of the February 2, 1978 Flashing*, Geotoxicity Phase III, Supplement No. 5, Hawaii Geothermal Project, University of Hawaii, Honolulu, Feb. 8, 1978.

just above the wellhead), which is below the recommended concentration for industrial exposure to H_2S. Atmospheric concentrations of H_2S fall off rapidly with increasing distance from the well. During flow tests, ambient H_2S concentrations generally fell below 200 ppb beyond a few hundred meters from the well. During the April flow tests, ambient H_2S concentrations were determined at 20 locations in the community surrounding the well site. Except in the immediate vicinity of the well, ambient H_2S concentrations were between 30 ppb (odor threshold) and 200 ppb within 0.8 km (0.5 mile) of the well. During normal power plant operations, H_2S abatement should reduce these ambient levels by an order of magnitude [3 to 20 ppb within 0.8 km (0.5 mile) of the site]. Except in the immediate vicinity of the power plant, atmospheric H_2S concentrations should not exceed the odor threshold of 30 ppb. Normal power plant operations should definitely not cause a nuisance odor at the nearest residence [1.1 km (0.7 mile) from the site]. Only when both the turbine and the abatement system are off line will H_2S emissions approach the levels that occur during well testing. At these times and with the appropriate weather conditions, H_2S odor may be detectable at nearby residences. This set of circumstances is not expected to occur often, and it is possible to partially shut in the well for extended power plant downtime.

3.2.2.2 Mercury

Environmental sampling for mercury was initiated in the earliest stages of the HGP-A project because of the toxicity of mercury and its known association with regions of volcanic activity. There are no Federal ambient air quality standards for mercury. The U.S. Environmental Protection Agency has suggested a maximum concentration of 1 $\mu g/m^3$ for long-term exposure of the general public to atmospheric mercury.[8] The American Conference of Governmental Hygenists has adopted a standard for the workplace environment of 50 $\mu g/m^3$ of inorganic mercury in the atmosphere.[9] The only point-source emission standard for mercury is 2300 g/day, established for the chloro-alkali and mercury ore processing industries.[8]

Natural thermal and volcanic sites on the Island of Hawaii have been shown to exhibit elevated atmospheric mercury concentrations.[10,11] From 1971 to 1976, atmospheric mercury was measured at a number of active volcanic sites in Hawaii Volcanoes National Park. The average mercury concentration in 80 samples from these sites was 15 $\mu g/m^3$ (refs. 12 and 13). By contrast, ambient atmospheric mercury concentrations in nonthermal regions of the world are generally well below 0.1 $\mu g/m^3$ (refs. 14 and 15). Atmospheric mercury concentrations in excess of 40 $\mu g/m^3$ have been recorded at two sites in Hawaii Volcanoes National Park.[11] During a recent eruption at Kalalua, along the east rift zone in Puna, 200 $\mu g/m^3$ of mercury was measured (the highest atmospheric concentration of mercury ever recorded on the Island of Hawaii).[13]

Sampling for ambient atmospheric mercury was initiated at the HGP-A site prior to drilling the well and has continued during well testing (Table 3.1). Even though the HGP-A site is at least 10 km (6.2 miles) from any known active volcanic site along the east rift zone, the HGP-A site has a high mercury background. Prior to any well-drilling activity at the site, atmospheric mercury levels of 1 $\mu g/m^3$ recorded on site were well above those expected in nonvolcanic regions of the world. In July 1976, atmospheric mercury concentrations of 9.9 $\mu g/m^3$ were recorded at the site during a well flashing test (Table 3.2). Although these high values were initially attributed to the release of geothermal fluids containing mercury, it was later discovered that intense volcanic activity had been occurring at that time along the east rift zone. From the results provided in Table 3.2, it is evident that the well was shut in on many occasions when high atmospheric mercury levels were recorded at the HGP-A site. The high levels could not be attributed to release of geothermal fluids into the atmosphere. All indications are that atmospheric mercury levels at the HGP-A site are determined by events that occur along the east rift zone. The results of extensive aerial and ground-level sampling along the east rift zone during the eruption of Kalalua have been reported by B. Z. Siegel and S. M. Siegel.[13] Their study substantiates the theory that volcanic activity in Hawaii affects atmospheric mercury levels at sites far from the eruption.

Table 3.2. Results of ambient atmospheric mercury sampling at the HGP-A site and at Sulfur Banks

Date	Well activity	Total atmospheric mercury ($\mu g/m^3$)	
		HGP-A	Sulfur Banks[a]
5-75[b]	Predrilling	1.1 ± 0.58	2.6 ± 0.51
5-76[b]	Postdrilling	1.2	5.3–10.0
6-24/25-76[c]	Well flowing	<1.0	47.5
7-22-76[c]	Flashing (first hour)	9.9	
10-21-76[c]	Well shut-in	16.1	
11-2-76[c]	Warmup phase of flow test	16–18	
11-3-76[c]	Flashing flow (first two hours)	18.0	
11-3-76[c]	Flashing flow (second two hours)	7.0	
11-76[c]	Two weeks after well shut-in	13–29	
7-77[c]	Well shut-in (45 days before Kalalua eruption)	0.8	1.4
8-12-77[d]	Well shut-in (30 days before Kalalua eruption)	0.5	0.2
9-15-77[d]	Well shut-in (36 hr after Kalalua eruption)	0.2	1.1
9-30-77[d]	Well shut-in (17 days after Kalalua eruption)	4.5	11.3
2-2-78[e]	Well shut-in	1.5	
2-2-78[e]	Well flashing	1.6	

[a] Sulfur Banks is an active, thermal site in Hawaii Volcanoes National Park.

[b] Source: R.M. Kamins et al., *Environmental Baseline Study for Geothermal Development in Puna, Hawaii*, Hawaii Geothermal Project, University of Hawaii, Honolulu, September 1976.

[c] Source: B.Z. Siegel and S.M. Siegel, "Geotoxicology, Task 4.1," in *Phase III – Well Testing and Analysis, Progress Report for the First Quarter of Federal FY77*, Hawaii Geothermal Project, University of Hawaii, Honolulu, 1977.

[d] Source: B.Z. Siegel and S.M. Siegel, *Measurements at HGP-A During the Kalalua Eruption of September 1977*, Hawaii Geothermal Project Supplement, University of Hawaii, Honolulu, 1977.

[e] Source: B.Z. Siegel and S.M. Siegel, *Aerometry of the February 2, 1978 Flashing*, Geotoxicity Phase III, Supplement No. 5, Hawaii Geothermal Project, University of Hawaii, Feb. 8, 1978.

Initial analyses of geothermal fluids brought to the surface at the HGP-A site yielded an average mercury content of 1.0 μg/liter, with a maximum of 6.0 μg/liter. Later sampling of the geothermal reservoir, at various depths, measured total mercury concentrations averaging less than 10.0 μg/liter at all depths except 305 m (1000 ft), where total mercury was recorded at 44.4 μg/liter. Using the highest concentration of 44.4 μg/liter as a worst-case assumption and assuming that all mercury in the geothermal fluids would be released to the atmosphere, normal power plant operations would result in release of approximately 40 g/day of mercury. This is less than 2% of the mercury point-source emission standard set by the U.S. Environmental Protection Agency for the mercury industry.[8] Considering even the most conservative meteorologic conditions, the release of 40 g/day of mercury would not increase the ambient atmospheric mercury levels at the HGP-A site sufficiently to be distinguishable above the existing background mercury levels. Release of mercury during operation of the project will not affect air quality.

3.2.2.3 Postoperational ambient air quality monitoring

Monitoring of the ambient air for H_2S and mercury as well as for sulfuric acid (H_2SO_4), sulfur dioxide (SO_2), and arsenic will be conducted after project operations commence. Continuous monitoring of H_2S will be done at the project boundary and at the nearest residence. The sensitivity of the instrumentation will be 10 ppb of atmospheric H_2S, which is sufficient to detect H_2S before nuisance odor levels are reached. In addition, H_2S will be monitored on a weekly basis at 30 sites in the area surrounding the project sites. Disposable or mobile detectors capable of detecting concentrations as low as 30 ppb (near the nuisance odor threshold) will be used.

Ambient measurements of atmospheric concentrations of mercury, arsenic, H_2SO_4, and SO_2 will be made weekly at the project boundary (an 8-hr sample). The detection limits will be as follows:

SO_2	10 ppb
H_2SO_4	0.1 mg/m^3
Total mercury	0.1 $\mu g/m^3$
Arsenic (III)	5 ppb

3.2.3 Impacts on water quality and use

This section addresses the impact of production and injection of geothermal fluid. Production takes place from a deep, confined aquifer, whereas injection takes place in a shallow, unconfined aquifer. Production only reduces the quantity of available groundwater supplies, but injection affects the quality of those supplies.

Production of geothermal fluid will have no effect on water use in the Puna district. It is evident from the geochemical investigations of P. M. Kroopnick et al. that shallow aquifers (potential suppliers of potable or agricultural water) are not hydraulically connected with the geothermal reservoir.[16] Furthermore, groundwater resources in the area are underutilized at present. Lack of demand for groundwater may continue because of low population density, high rainfall, and generally poor-to-marginal groundwater quality (as determined from nearby wells).

Injection of geothermal fluid will take place in a shallow aquifer where groundwater resources could conceivably occur. The analysis that follows considers the impact on water quality of (1) possible nearby, undiscovered potable groundwater and (2) downgradient existing wells that are suitable for limited water uses.

If there is any potable or agricultural groundwater in the immediate vicinity of the seepage pond, it will be degraded. Marginally suitable groundwater is present within a 4.8-km (3-mile) radius,[1] and its presence nearer the site cannot be definitely excluded. Several additional shallow test holes could be drilled to evaluate the potential for degrading groundwater sources near the site.

The potential for contaminating the nearby existing wells cannot be assessed with the information presently available. If the chemical composition of the geothermal fluid does not change during the operation of the HGRS, dispersion through the aquifer (unquantified at present) and infiltrating rainwater may adequately dilute the relatively small discharge from the seepage pond [4.8 liter/sec (76 gpm)]. The results of the 42-day flow test, however, showed that the concentration of chloride ion in the geothermal fluid increased by about 25%,[16] implying that saltwater encroachment may be taking place during reservoir drawdown. Uncertainty concerning the chemical characteristics of the geothermal discharge after prolonged flow and lack of data related to dispersion characteristics prevent an adequate analysis of the potential degradation of water quality in existing wells.

Periodic monitoring of water wells should be required as long as the HGRS is operating. Baseline data for the water wells are already available (Table 2.5 and Fig. 2.4). Increase in chloride concentration would be an excellent indicator of contamination.

Groundwater quality could be protected by substituting an injection well for the seepage pond so that geothermal fluid would be discharged to a deeper and more brackish aquifer. An injection well is actually being considered for the HGRS in case the seepage pond proves to be inadequate for handling the geothermal discharge. (Overflow from the seepage pond is considered in greater detail in Sect. 3.4.) Future commercial-scale development of the Kapoho Geothermal Field (KGF) by private interests would require the installation of one or more injection wells.[1]

3.2.4 Impacts on land use

It is unavoidable that construction and operation of a geothermal power plant will somewhat alter the rural nature of the surrounding region. Land-use conflicts with nearby residential areas have occurred during well testing as a result of increased noise levels and H_2S odor. As discussed in Sects. 3.2.2 and 3.2.6, normal power plant operation will greatly reduce both noise and release of H_2S over the levels experienced during well testing. Noise and H_2S levels approaching those during testing would occur only when the well is venting to the atmosphere as a result of both the H_2S abatement system and the turbine being off line. Major conflicts with nearby residents are not anticipated as a result of power plant operation.

There are no prime or unique farmlands near the project site that could be affected by operation of the power plant (Sect. 2.4). Agricultural land at the Hawaii Experimental Station [0.8 km (0.5 mile) from the site] will not be affected by cooling tower drift or H_2S (Sect. 3.2.2).

The power plant will not be visible from the nearby Lava Tree State Park. Normally, a plume from the cooling tower should not be visible. Only during unusually cool weather should a plume be evident, but topography and vegetation should hide the plume from park visitors. The construction of a new transmission line, parallel to an existing line and crossing the Pohoiki Road five times, will create a visual clutter that will degrade the area's aesthetic character but should not affect use of the area.

3.2.5 Impacts on historic and archaeologic resources

As discussed in Sect. 3.1.5, the proposed project will have no impacts on historic or archaeologic resources.

3.2.6 Noise-related impacts

To date, the major source of noise at the HGP-A project site has been venting of the well during well tests. Initial well tests resulted in measured noise levels of 98 to 101 dB(A) at 15 m (50 ft) from the venting well.[17] Equipment modifications and mufflers have reduced noise levels recorded during well venting to approximately 85 dB(A) at 15 m (50 ft) from the well and to 74 dB(A) at the Pohoiki Road, 50 m (165 ft) from the well.[17] Attenuation by distance should reduce well venting noise to less than 50 dB(A) at the nearest residence. However, complaints of the low "jet roar" noise during well venting are still made by nearby residents. These complaints probably arise from the fact that the low-frequency noise resulting from well venting is readily discernible over the low background noise [probably less than 45 dB(A) in this rural area] that consists primarily of high-frequency sounds (e.g., birds and insects singing and wind blowing).

Because well venting will be eliminated, noise levels during normal power plant operation will be considerably lower than those produced during well flow tests. The well will be venting full to the atmosphere only during periods when both the turbine and the H_2S abatement system are off line. When this circumstance occurs, full well venting should last less than one day until the well can be partially shut in.

The major source of noise during normal power plant operation will be the cooling towers, which produce much lower sound levels than a venting well. A typical cooling tower is expected to produce noise levels of about 80 dB(A) at 3 m (10 ft) from the towers.[18] This should attenuate to less than 45 dB(A) at the nearest residence. Noise produced by the cooling tower is also different from that produced by a venting well, in that cooling tower noise consists primarily of high-frequency "white" noise. At the nearest residence, noise from the cooling towers [at less than 45 dB(A)] is not likely to be discernible above normal background noise.

3.2.7 Ecological impacts

Habitat for endangered and/or endemic species does not occur on or near the site. Collisions with the new transmission line by transient Hawaiian hoary bats or Hawaiian hawks are unlikely. Project operations will not affect these important wildlife species. Noise and activity associated with the project operation could cause displacement of a few individuals of the introduced wildlife species that occur near the site. The number displaced will be small in relation to the populations in nearby habitat and should be of no significance.

Analyses of the geothermal waters at the HGP-A site indicate that the water is of relatively good quality. The total dissolved-solids content is approximately 2500 ppm. This fact, combined with the efficiency of drift eliminators on modern cooling towers, contributes to the conclusion that salt drift from the cooling towers will be insignificant. In any case, drift effects from the cooling towers would be limited to within a few hundred meters of the towers, thereby affecting only the early successional vegetation on the recent lava flow. Mercury releases from the cooling tower should not cause a detectable increase in ambient mercury over the present high background concentrations caused by volcanic activity on the nearby east rift zone (Sect. 3.2.2). Hydrogen sulfide emissions from power plant operations will be well below the 300-ppb threshold concentration for effects on sensitive vegetation (Sect. 3.2.2).

3.2.8 Socioeconomic impacts

Total employment during operation of the research station is not expected to exceed two persons at any one time (Sect. 1.3.2). This work force will probably consist of persons already employed by the HGRS project participants and will not represent a demand on the Puna district labor pool. Members of the small operation staff, if not already residents of the Puna district, will probably commute from Hilo, the nearest major city. A slight increase in local spending may result (e.g., for groceries or automobile fuel), but this would be more likely to occur in the Hilo area. Thus, operation of the research station will likely represent a negligible socioeconomic impact.

The interests of native Hawaiians in geothermal development on the Island of Hawaii are currently being evaluated by DOE with respect to the proposed project. Several discussions have been held between representatives of native Hawaiian groups and DOE in order to ensure that native Hawaiian concerns are known to DOE for project planning purposes. As expressed in formal presentations by native Hawaiian representatives at the Geothermal Resources Council meeting in Hilo (July 1978, unpublished), the principal geothermal issues are associated with a combined set of legal and cultural relationships that determine ownership of the geothermal resource and stewardship of all natural resources. Other native Hawaiian interests center on the question of "What is progress?" and are not unique to geothermal development. The electrical production of the DOE-supported project is relatively small, so that no significant impact on native Hawaiian cultural interests is expected.

A net result of the project is a decrease in the dependence of the Island of Hawaii on fossil fuels, which will potentially manifest itself in small economic savings in electrical uses on the Island.

3.3 SITE RESTORATION

Decommissioning plans have not been included in the proposed action; however, all construction activities are essentially reversible.[1]

If required, the generator could be removed; the cooling tower and research modules could be dismantled; and the well could be plugged and abandoned as in oil well procedures.

In the humid, tropical climate of the Puna district, vegetation would reestablish itself, subject only to the natural constraint of soil development on the recent lava flows.

3.4 ACCIDENTS

The serious accident that is most likely to occur is an uncontrolled release of geothermal fluid. Release of fluid may occur at the wellhead (blowout), in the wellbore, or in pipelines. Blowout-prevention equipment has been installed on the HGP-A well.[1] Nevertheless, malfunctioning equipment, human error in judgment, or negligence occasionally leads to blowouts. A blowout is most likely to occur when a workover rig is being used to replace worn-out casing. Blowout can also occur if the casing ruptures at a shallow depth. A blowout that occurs below ground can be controlled by cement injection through directional relief wells. This procedure, however, is often expensive and time consuming; furthermore, the results may not be satisfactory.

Geothermal blowouts do not carry the risk of fire of oil field blowouts; nevertheless, they are difficult to handle because of the presence of superheated steam or hot water. A blowout may result in (1) surface cratering, (2) contamination of the surface, water, and atmosphere, (3) excessive noise, (4) waste of geothermal energy, and (5) injury to personnel. Because of its high temperature, blowout-released water could destroy vegetation. It is estimated that the largest probable area of direct impact due to any single excursion would be about 4 ha (10 acres). Noise and H_2S nuisance would affect a much wider area.

Casing may rupture during the production stage as a result of (1) subsidence caused by withdrawal of fluid, (2) an earthquake, (3) a landslide, or (4) corrosion. Induced seismicity is unlikely at this site, and a landslide will not occur. Subsidence is unlikely because of the nature and depth of the reservoir. Nevertheless, the installation of a flexible joint between the well casing and the pipeline at the surface will prevent rupture in case subsidence does occur.[18] The most likely causes of casing failure are natural seismicity and corrosion. Cement packing around the casing is intended to contain the fluids in the event of a casing failure; however, large displacement along a fault may rupture the cement packing as well. Furthermore, hot and acidic brackish water will decompose most cements after a period of time. If the casing ruptures in a groundwater aquifer and the reservoir fluid is steam-flashed, groundwater contamination and waste of geothermal energy will occur. If rupture takes place in the cap rock or reservoir, little or no damage to the environment or waste of energy will result, but the well would have to be recompleted.

Ruptured geothermal pipelines may cause intense but brief surface spills. Thermal expansion joints are installed to reduce the possibility of rupturing a pipeline. The more critical lines can be double-walled to prevent escape of fluid in case the inner wall ruptures. Although a blow-out and a ruptured well casing may be difficult to bring under control, pipelines can be isolated by shutting in the well and closing down the generating plant.

Overflow of the seepage pond could result in a temporary surface discharge of geothermal fluid. The affected area would probably be less than 1 ha (2.5 acres) because of the high infiltration and relatively low discharge rates. It is anticipated that silica will precipitate on the bottom of the seepage pond. Periodically, encrusted silica will be removed with a backhoe from the bottom of the basin to prevent the infiltration rate from falling below the discharge rate.[1] If silica deposition proves to be a serious problem, the seepage pond will have to be enlarged or an injection well will be required. While it is generally recognized that an injection well would be required in case of full-scale field development (several production wells), it is believed that a seepage pond will be adequate to handle the low discharge rate from the HGRS.

If a volcanic eruption occurred along the east rift of Kilauea and lava inundated the site, the effects of the lava flow would be far more damaging to the immediate surroundings than an uncontrolled release from the well. There might be a long time interval, however, before the well could be recapped. G. A. Macdonald suggests locating critical wellhead valves below ground level and covering them.[19] Recompleting the HGP-A well in this manner is probably impractical, but a lava-diversion barrier might offer adequate protection against a blowout.

The greatest volcanic risk is the destruction of the research station. Macdonald estimates that the chance of inundation by lava in the east rift of Kilauea is 4% during the operational lifetime of the well (30 years).[19] While the wellhead can be protected, the generating plant and research modules would be destroyed, unless located on hills where inundation is nearly impossible.[19] The need to locate the station in close proximity to the wellhead negates that option; therefore, a lava-diversion barrier appears to be the only alternative mitigating measure for both the wellhead and the installations that surround it. Unfortunately, lava-diversion barriers are not always as effective as containment devices. Strong earthquakes always precede and accompany a volcanic eruption, so that structural damage is likely to occur even if inundation by lava does not.

REFERENCES FOR SECTION 3

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4. COORDINATION WITH FEDERAL, STATE, AND LOCAL PLANS

Because of Federal, State, and local involvement in planning and funding of the HGP, no conflicts with plans appear to exist. The State of Hawaii has prepared an Environmental Impact Statement for the power plant project. Comments from a number of Federal and State agencies have been received and published in the Final Environmental Impact Statement issued by the State. No major conflicts with agency plans have surfaced. The following Federal and State agencies were also contacted during preparation of this Environmental Impact Assessment: (1) the U.S. Soil Conservation Service and (2) the County of Hawaii.

5. ALTERNATIVES

This section addresses other nonconventional alternatives to fossil fuel energy resources, as well as different site and design geothermal alternatives.

5.1 PROJECT ALTERNATIVES

The overall objective of Hawaii's State Energy Program is to reduce petroleum imports per capita as rapidly as possible.[1] The County, State, Federal, and private funds appropriated for the Hawaii State Alternative Energy Program from 1972 to 1977 are listed in Table 5.1. Solar demonstrations and biomass have the most support from the private sector. A biomass pilot project (molasses to alcohol) on Maui is in the planning stage. Numerous other biomass projects involving sugarcane, corn, algae, and agricultural waste products are under way. Future private development of solar and biomass energy seems to be assured. By the year 2000, it is projected that biomass will account for 30% of the State's energy requirements. Ocean Thermal Energy Conversion (OTEC) technology has not developed sufficiently to warrant funding of pilot-scale projects. Most research to date involves bench-scale heat exchangers, biofouling, and salt-scale inhibitor experiments.[1]

The technology exists for the conversion of geothermal energy to electrical power. The principal impediment to the private development of geothermal energy is the high financial risk involved in successfully completing a production well. The time appears to be right for the pilot-scale development of the successful HGP-A production well. Other nonconventional energy alternatives either are successfully competing for support from the private sector or are not being developed because the technologies are not sufficiently advanced to warrant the construction of pilot or demonstration facilities.

It is the considered judgment of program developers that all alternative energy resources will have to be developed in order to meet the objective of the State Energy Program. Abandonment of support for the HGRS would be a serious impediment to achieving that objective.

Table 5.1. Hawaii State Alternative Energy Program funding – 1972 to 1977

Subprogram	Cumulative funds (millions of dollars)	
	Total	Private sector
Geothermal	6.7	0.144
Solar demonstration	2.7	1.022
Solar-wind	1.3	
OTEC technology	1.3	0.005
Biomass	1.1	0.336
Energy systems	0.3	0.035
Operations and facilities	0.7	
	14.1	1.542

Source: Energy Resources Coordinator, *1977 Annual Report*, Department of Planning and Economic Development, State of Hawaii, Honolulu, February 1978.

The Department of Planning and Economic Development forecasts that 7% of the State's energy requirements will be supplied by geothermal resources by the year 2000.[1]

5.2 SITE AND DESIGN ALTERNATIVES

5.2.1 Site alternatives

Site alternatives were limited by a number of factors. Site selection for the HGP-A well was based on two years of geophysical exploration, geothermal test holes, and negotiations for land acquisition.[2] The exploration effort was limited by time and funding constraints and by inaccessibility to remote areas. The original proposal to drill production test holes on the southwest rifts of Mauna Loa and Kilauea as well as on the present site was abandoned for lack of funds. Low-risk geothermal resources are available only in the younger rift zones of Hawaii (Sect. 2.1.3).[3] Substantial lengths of these zones lie within Hawaii Volcanoes National Park, where land development is prohibited by law.[2,3] Hence, most of the exploration effort was concentrated east of the park along the more readily accessible east rift zone of Kilauea (Fig. 1.1). Negotiations for the most promising site (based on geophysical evidence) were unsuccessful. Land was finally acquired for the HGP-A well at a prime alternative site.

There is no reasonable alternative location for the HGRS.[2] The successful completion of the HGP-A well dictates the location of the research station because it would be costly, inefficient, and environmentally disruptive to transmit the steam and hot water over any distance.[2] Developing a new production well at another site might be a less costly alternative, but a risk of failure exists that could force a return to the original site. Even if a new production well were successful, funds used in the development of the HGP-A well would never be recovered, except through its sale to commercial interests. Private development would inevitably lead to greater environmental impact.

5.2.2 Design alternatives

The major HGRS design alternatives are concerned with power plant operations. These alternatives include the selection of an acceptable commercial hydrogen sulfide (H_2S) abatement technology, turbine selection, and the design of an inexpensive electrical load-dissipation bank.

Although project planners would prefer to scrub H_2S from the geothermal steam before it enters the power plant, the commercial technology to accomplish this does not yet exist.

Downstream removal of H_2S using an iron catalyst system or a Stretford process is likely for the HGRS power plant. A comparison of the two processes was made in the HGRS proposal to DOE on April 6, 1977. Overall, a power plant using an iron catalyst system would be less expensive but not as effective or reliable as a power plant using a Stretford process for H_2S abatement.

Turbine selection is another possible HGRS power plant design alternative. Three turbines are being considered: (1) an advanced wellhead turbine, (2) a modified Westinghouse turbine, and (3) a surplus U.S. Navy turbine. The advanced wellhead turbine would be capable of generating a variable net power output of 2 to 3 MWe and would allow the most efficient and flexible use of the geothermal fluids by the HGRS. The modified Westinghouse turbine would be capable of generating a fixed net power output of 2 MWe and a variable amount of geothermal fluids, depending on the production characteristics of the HGP-A well. Unlike the other turbines, the surplus navy turbine would operate in a noncondensing mode for short periods. The nuisance value of the H_2S released in the exhaust of the navy turbine will militate against its selection for the HGRS. Power generated by the navy turbine would be dissipated at the site.

A less significant HGRS power plant design alternative involves the onsite dissipation of excess electrical power. Excess electrical power will be sent to load-dissipation banks that consume the power in resistors or by boiling excess geothermal liquids.

Trade-off studies are currently under way for all the power plant design alternatives mentioned, and a complete conceptual design of the HGRS power plant is due later this year (1978). A description of power plant operation is presented in Sect. 1.3.

REFERENCES FOR SECTION 5

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APPENDIX

UNITED STATES DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

P. O. Box 50004, Honolulu, HI 96850

October 11, 1978

Mr. Bill Staub
Oak Ridge National Laboratory
P. O. Box X
Oak Ridge, TN 37830

Dear Mr. Staub:

Subject: Agricultural Lands of Importance to the State of Hawaii

The attached map shows prime and other important agricultural lands of statewide or local importance around a 3-mile radius of the geothermal well in Puna, Hawaii. There are no unique lands in this area. Most of the area is in ohia forest. Some sugarcane is grown between Pahoa and Kaniahiku Village. The University Experiment Station conducts tests on orchard crops such as macadamia nuts, guava, and papaya.

Also attached is a bulletin by the State Department of Agriculture that defines prime and other agricultural lands in Hawaii.

Sincerely,

Jack P. Kanalz
State Conservationist

Attachments