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AMBIENT H₂S MONITORING IN THE VICINITY OF
HAWAII'S FIRST GEOTHERMAL POWER PLANT

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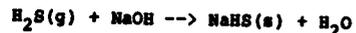
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INTRODUCTION

In December, 1975, work began on Hawaii's first successful geothermal well in the East Rift Zone of Kilauea Volcano on the Island of Hawaii (Figure 1). By July, 1976, the well, named Hawaii Geothermal Project - A (HGP-A), was complete to a depth of almost 2 km and had encountered a volcanically driven hydrothermal system having a temperature in excess of 350° C and a fluid chemistry composed of a mixture of seawater, meteoric water, and volcanic volatiles. The principal chemical constituents of the fluid are listed in Table I. Note the relatively high H₂S concentration which ranged 900 - 1,000 ppmw.

During the early testing of the well, the superheated geothermal fluid was allowed to "flash" at normal atmospheric pressure with steam and noncondensable gases being released unabated into the atmosphere. The high H₂S and noise (120 dBA) levels and the close proximity of the Lailani Estates residential subdivision (Figure 2) were cause for concern and efforts were thus made to mitigate these impacts.

Certain elements of the initial test protocol required that the well be allowed to flow freely and unabated. During these periods public notice and prewarning were the most feasible means of mitigation. At other times, the mixed fluid is separated into steam and brine phases with the steam phase being treated with NaOH and then released through a rock muffler. The brine phase is released through a separate muffling system. Chemical treatment of the steam with NaOH converts the H₂S into a soluble sulfide salt through the following reaction:



Early flow testing revealed that the well was able to produce a steady flow of approximately 50,000 kg per hour of steam and water at a pressure of 1200 kPa and thus appeared suitable for power generation. Accordingly, in 1981 a

Table I. Chemical Composition of Geothermal Fluid - HGP-A Well¹

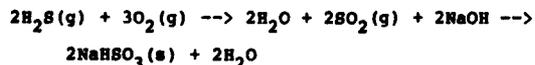
Element/Compound	Concentration (ppmw)
Chlorides	7,200
Sodium	3,700
Carbon dioxide	1,200
Hydrogen sulfide	900
Silica	800
Potassium	600
Calcium	218
Nitrogen	125
Carbonate	75
Hydrogen	56
Sulfate	50
Sulfide	17
Barium	2
Boron	2
Strontium	2
Cadmium, lead, thallium	<1.0
Helium	0.5
Niobium	<0.4
Phosphorous	0.2
Tin, uranium, magnesium	<0.2
Molybdenum, lithium, manganese, iron, nickel, silver, vanadium, cobalt, zinc	<0.1
Arsenic, platinum, titanium, copper, mercury, tantalum, gold	<0.01
Radon-222	0.75 nCi/lb steam

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wellhead generator facility was installed on the HGP-A well to continue testing the characteristics of the geothermal reservoir and to determine whether it was technically feasible to generate reliable electrical power from this system.

As part of the power generation system a wellhead separator was installed that would allow the superheated geothermal fluid to flash and separate into steam and brine phases. The steam was then piped to the turbine generator while the brine was piped to another chamber where a secondary flashing occurred due to the high temperature of the brine. The remaining brine then flowed into settling ponds where its supersaturated content of amorphous silica precipitated out. Approximately 98% of the H_2S in the resource separates into the high pressure steam phase (along with most of the other noncondensable gases) while the other 2% remains in the brine.

H_2S emission control downstream of the turbine and a surface condenser consists of an incinerator followed by a NaOH wet scrubber. The overall reaction sequence is as follows:



The overall H_2S removal efficiency of this system has been determined to exceed 99%. In the event the system is taken off line for maintenance or repair an emergency backup system is employed which treats the gas discharge with NaOH and has an approximately 98% removal efficiency. If the turbine itself is taken off line then the high pressure steam phase is directed to the previously described rock muffler where it is treated with NaOH at a removal efficiency of approximately 95%.

During initial testing of the well and during development of its electric generating capability, continuous ambient H_2S

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monitoring was conducted in the area. It is the purpose of this paper to present the results of that monitoring effort and to evaluate and discuss their significance.

EXPERIMENTAL METHODS

Houston Atlas Model 825R H_2S monitors were installed at the power plant and at several locations in the nearby community. They operate on the principal of discoloration of a lead acetate tape by H_2S due to the formation of lead sulfide according to the following reaction:



The blackening of the paper tape then produces a measurable change in light reflectance of the tape which is proportional to the amount of H_2S in the sampled air. The specifications of the instruments include reproducibility of +/- 2% of full scale (100 ppb). In practice, they are estimated to have an accuracy of +/- 10% of the ambient concentration. The monitoring site of particular interest in this study was the one located "downwind" of the HGP-A well/power plant (Schroeder Station).

The field monitoring system also included a meteorological station located "upwind" (in terms of the prevailing NE trade winds) of the plant site that continuously measured wind speed and direction, sigma theta, and solar radiation (Wood Station). During the 1981 - 1982 period, these data were recorded as 3-hourly averages at 0300, 0600, 0900, etc. Hawaiian Standard Time (HST). In subsequent years, hourly average data were recorded. See Figure 2 for the locations of the monitoring sites.

The outputs of all instruments were recorded on strip chart recorders, manually digitized and then keypunched.

Statistical analysis of the data was accomplished on a personal computer. The study covers two 12-month periods:

Year 1: 16 May 81 - 15 May 82

Year 2: 01 Jan 83 - 31 Dec 83

In the case of Wood Station during Year 1, monitoring did not begin until 01 Jun 81 and ceased on 30 Apr 82 due to instrument problems.

RESULTS

Year 1

H₂S Data. The results at the Wood and Schroeder stations are summarized in Table II. These initial results suggest a notable difference in H₂S exposure at the two sites with significant disparities between annual means (3.3 vs. 1.8 ppb) and the number of hours exceeding 20 ppb (47 vs. 0). The data also exhibited a log-normal distribution as exemplified by Figure 3. Based on this initial data summary one might conclude that the "downwind" station (Schroeder) was clearly being impacted by the HGP-A well.

Table II. Summary of H₂S monitoring at the Wood and Schroeder Stations (Year 1).

	Wood	Schroeder
Period:	6/1/81 - 4/30/82	5/16/81 - 5/15/82
No. of days:	334	365
No. of hours:	8,016	8,760
No. of good data hours:	6,452	6,862
Percentage data recovery:	80.5	78.3 %
Range of 1-hr values:	0 - 13	0 - 48 ppb
Mean concentration:	1.8	3.3 ppb
Number of values > 20 ppb:	0	47

Metereological Data. As expected, given the prevailing trade winds throughout the Hawaiian Islands, the annual windrose displayed a significant percentage of northeasterly winds. Somewhat surprisingly, however, it also indicated an even greater percentage of winds from the northwest quadrant. Wind speeds tended to be rather low with over 90% of the hours having wind speeds 10 mph or less. Approximately 45% of the time speeds were less than 7 mph (Table III).

Table III. Annual wind rose for Wood Station
16 May 81 - 15 May 82.

Direction	Speed (mph)					Total
	1 - 3	4 - 6	7 - 10	11 - 16	>16	
N	0.003	0.037	0.057	0.009	0.001	0.107
NNE	0.000	0.025	0.069	0.012	0.000	0.106
NE	0.001	0.020	0.057	0.007	0.000	0.085
ENE	0.000	0.008	0.037	0.008	0.000	0.053
E	0.001	0.008	0.015	0.007	0.000	0.031
ESE	0.001	0.005	0.019	0.008	0.002	0.035
SE	0.001	0.006	0.009	0.011	0.002	0.029
SSE	0.001	0.008	0.014	0.006	0.000	0.029
S	0.003	0.012	0.011	0.006	0.000	0.032
SSW	0.003	0.009	0.006	0.002	0.001	0.021
SW	0.001	0.007	0.007	0.001	0.000	0.016
WSW	0.005	0.047	0.003	0.000	0.000	0.055
W	0.008	0.075	0.042	0.000	0.000	0.125
WNW	0.005	0.056	0.038	0.001	0.000	0.100
NW	0.004	0.042	0.037	0.004	0.000	0.087
NNW	0.006	0.043	0.035	0.003	0.000	0.087
Total:	0.043	0.408	0.456	0.085	0.007	1.000

The wind data were further processed to produce day (0600 - 1800 HST) and night (1800 - 0600 HST) wind roses. The results are presented in Figures 4 and 5. A clear diurnal pattern is indicated with NE trade wind dominated conditions occurring during the day and northwesterly drainage winds coming off the higher elevations of the East Rift Zone during the night.

Correlation of H₂S and Wind Data. In an effort to determine the possible relationship between the maximum H₂S concentrations and the operations of the geothermal well, the H₂S and meteorological data files were co-processed to select all hours in which the H₂S concentration at the Schroeder Station exceeded 20 ppb and match them with the corresponding wind data. These were then further sorted into diurnal and wind directional distributions as shown in Table IV.

Table IV. Correlation of maximum H₂S values at the Schroeder Station with time of day and wind direction.

Diurnal distribution of 1-hr H ₂ S values > 20 ppb.	Day:	36%
	Night:	64%
Distribution of 1-hr H ₂ S values > 20 ppb by wind quadrant.	NE:	17.0%
	SE:	8.5%
	SW:	22.3%
	NW:	50.0%
	Missing:	2.2%

Since the HGP-A well is located northeast of the Schroeder Station, the data suggest that there are other significant sources of H₂S which affect that particular site.

Also of interest was an "upwind - downwind" comparison of H₂S concentrations; thus, Table V was produced for the six hours in which NE winds occurred and H₂S exceeded 20 ppb. Although only a few hours representing the times of maximum H₂S concentration under NE trade wind conditions, they are nonetheless representative of the "upwind - downwind" relationship. Analysis of 61 hours with NE winds and H₂S values exceeding 10 ppb produced similar results (mean upwind contribution = 3.9 ppb based on Wood Station data).

Table V. Upwind - downwind comparison of maximum H₂S concentrations.

Date	Hour	Schroeder Station (downwind)	Wood Station (upwind)	Difference
6/08/81	1400	21 ppb	4 ppb	17 ppb
6/21/81	1600	24	4	20
6/21/81	2000	26	4	22
9/16/81	1100	21	7	14
1/16/82	1000	23	1	22
2/28/82	1700	33	1	32

Year 2

H₂S Data. The H₂S monitoring data for calendar year 1983 showed a marked difference from the May 81 - May 82 period as is evident from the summary in Table VI.

Table VI. Summary of H₂S monitoring at the Wood and Schroeder Stations (Year 2).

	Wood	Schroeder
Period:	1/1/83 - 12/31/83	1/1/83 - 12/31/83
No. of days:	365	365
No. of hours:	8,760	8,760
No. of good data hours:	8,050	7,837
Percentage data recovery:	91.9	89.5 %
Range of 1-hr values:	0 - 13	0 - 8 ppb
Mean concentration:	1.2	1.4 ppb
Number of values > 10 ppb:	5	0

Overall data capture was improved during this period with recovery averaging about 90% as compared to approximately 80% during the 1981 - 82 period. Annual mean H₂S concentrations were lower, especially at the Schroeder Station, and the maximum 1-hr concentration for both stations was 13 ppb.

Meteorological Data. These data were carefully scrutinized to see if there had been any change in normal wind patterns during this period which might account for the change in H₂S levels. The wind data failed to show any significant difference from the Year 1 data and, in fact, were quite similar.

CONCLUSIONS

Correlation of the H₂S and wind data clearly suggests that the HGP-A well is a contributor, although not the only significant contributor, to ambient H₂S levels in the Leilani Estates subdivision. Annual mean concentrations in the area are near the odor threshold of H₂S while maximum hourly

values recorded during the 1981 - 82 sampling were at a level that would be considered a clearly recognizable and perhaps objectionable odor by most people. The most intriguing aspect of this study was the discovery that most of the H₂S maxima occurred at night under wind conditions suggesting that drainage flows coming down the sides of Kilauea Volcano were carrying the gas from natural sources in the East Rift Zone. This is not too surprising a revelation given that there are a few known fumaroles which emit H₂S and perhaps many other unknown ones in this active volcanic area.

The second most interesting aspect of the work was the sharp reduction in the number of hours and magnitude of maximum H₂S concentrations during the 1983 sampling as compared to the 1981 - 82 period. The various improvements in control technology at the HGP-A plant since 1982 could have accounted for some reduction in the number and magnitude of maxima, but not all since most of the earlier maxima appeared to be attributable to natural sources. One significant event that began in January, 1983 and has continued to the present is the eruption of Kilauea Volcano which can involve emission of hundreds of tons of sulfur dioxide (SO₂) per day and result in ambient concentrations as high as 982 ug/m³. One wonders if the reduced sulfur source is perhaps now exposed to highly oxidizing conditions resulting in emission of oxidized rather than reduced forms of sulfur.

REFERENCES

1. D. M. Thomas, Chemistry, Scale, and Performance of the Hawaii Geothermal Project - A Plant, EPRI No. 4342, 1985.
2. D. Layton et al., Health and Environmental Effects Document on Geothermal Energy - 1981, Lawrence Livermore Laboratory, 1981, pp. 23-24.
3. State of Hawaii, Department of Health, Complete Sulfur Dioxide and TSP Results for Volcano Monitoring, Memorandum dated February 14, 1983.

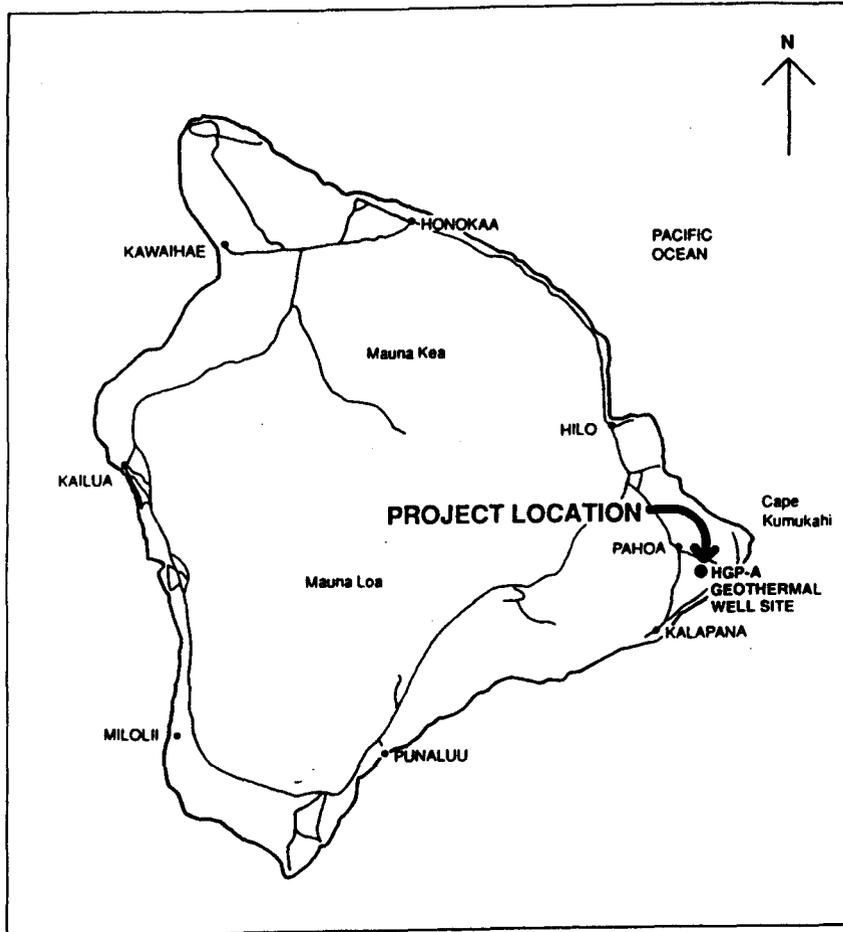


FIGURE 1. PROJECT LOCATION

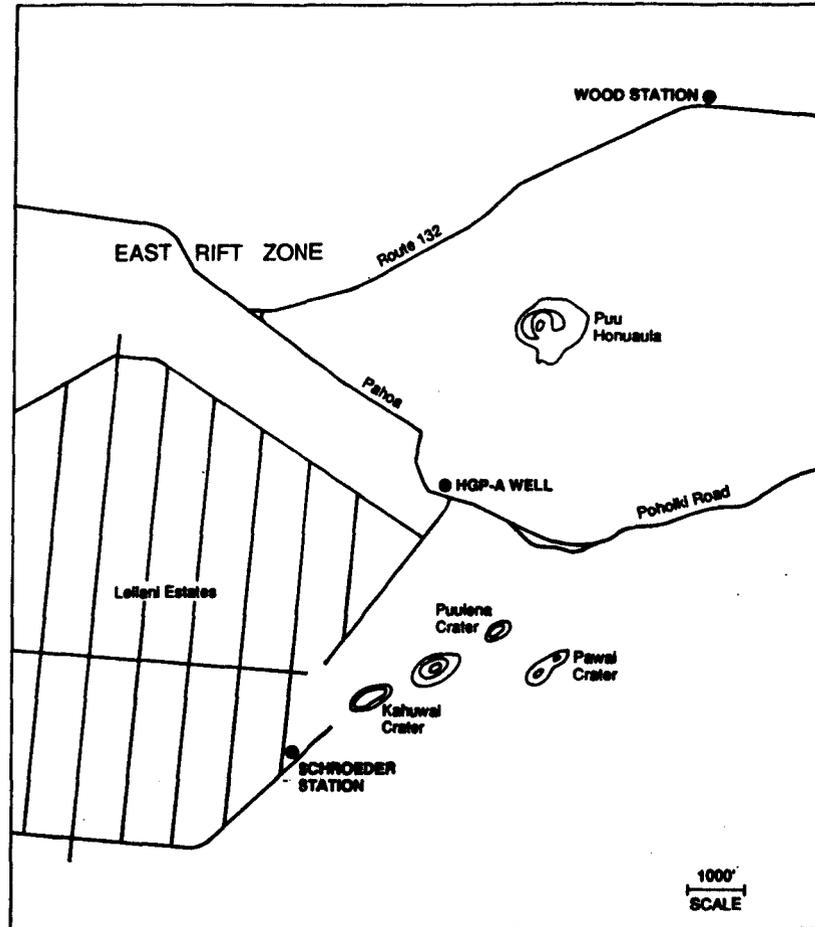


FIGURE 2. LOCATIONS OF GEOTHERMAL WELL AND H₂S MONITORING STATIONS

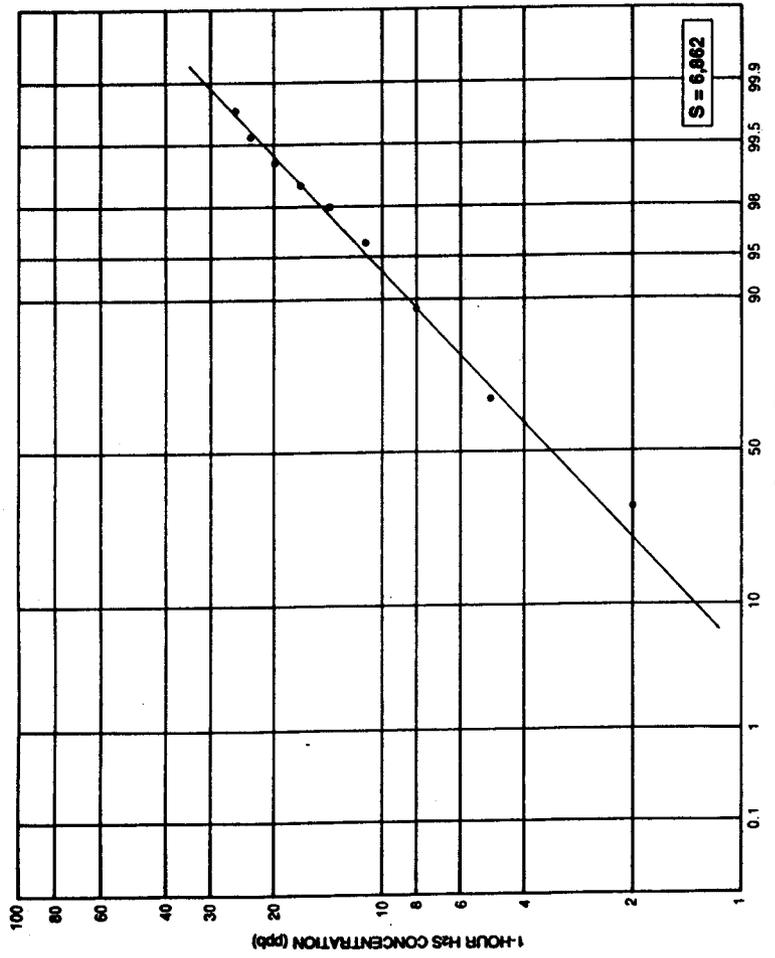


FIGURE 3. CUMULATIVE FREQUENCY DISTRIBUTION
1 - HOUR H₂S CONCENTRATIONS
SCHROEDER STATION
15 MAY 81 - 16 MAY 82

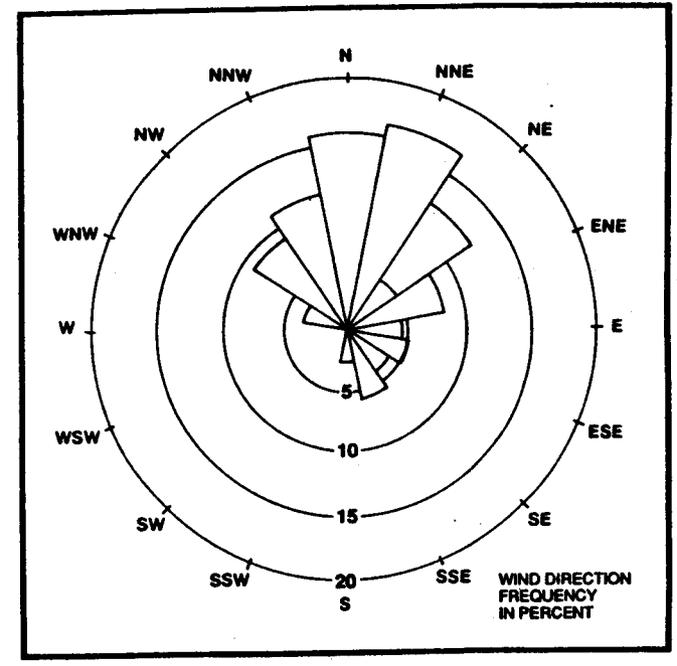


FIGURE 4. DAY-TIME WIND ROSE
WOOD STATION
MAY, 1981 - MAY, 1982

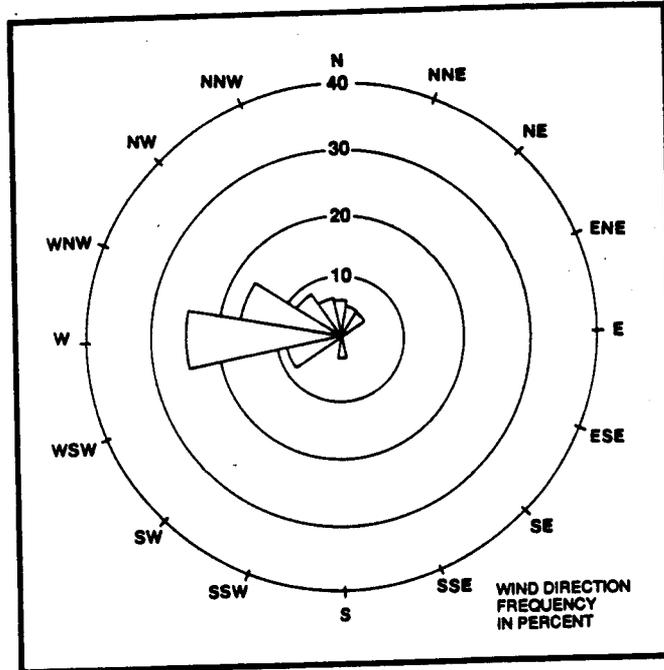


FIGURE 5. NIGHT-TIME WIND ROSE
WOOD STATION
MAY, 1981 - MAY, 1982