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PAPER

# AMBIENT AIR H<sub>2</sub>S MONITORING AT THE GEYSERS: FROM NONATTAINMENT TO ATTAINMENT

Sam L. Altshuler and Ted D. Arcado

*Pacific Gas and Electric Company, Technical and Ecological Services,  
3400 Crow Canyon Road, San Ramon, CA 94583*

## ABSTRACT

The results of three ambient air monitoring programs performed downwind of The Geysers, California, are described. These studies, conducted since 1976, have monitored the declining ambient air concentrations of hydrogen sulfide (H<sub>2</sub>S) in Lake County. During the 13 years of monitoring, geothermal power production has increased from approximately 500 to 2,000 MW, H<sub>2</sub>S emissions from power plants have declined from 1,900 to less than 200 lb/hr, and ambient H<sub>2</sub>S concentrations have significantly declined. Annual average concentrations of H<sub>2</sub>S at four long-term sites have declined by a factor of 3.0, maximum H<sub>2</sub>S concentrations have declined by a factor of 3.6, and the frequency of violation of the California Air Quality Standard (0.03 ppm) averaged over 1 hour has declined from an average frequency of 52 times per year to almost 0. The area has not had a recorded violation of the air quality standard since August 1987. As such, the area has gone 3 years without a violation was classified by the California Air Resources Board as "attainment" during their November 1990 review process.

## INTRODUCTION

Pacific Gas and Electric Company (PG&E) has been a participant in several air monitoring programs for ambient concentrations of hydrogen sulfide (H<sub>2</sub>S) in Lake County, California. This area is predominantly downwind of The Geysers, an area producing geothermal steam used to operate power plants generating over 2,000 MW of

electricity. The Geysers is located in the Mayacamas Mountains, 90 miles north of San Francisco.

Three distinct monitoring programs have been conducted since 1976. The first program was initiated in 1976 and was conducted by SRI International. The SRI program was performed for 3 years and was funded by a consortium of industries. PG&E was the contract manager. Eight sites were monitored using continuous H<sub>2</sub>S analyzers. Five of these sites were located in populated areas of Lake County (Kalm Ranch, Pine Summit, Whispering Pines, Anderson Springs, and Sawmill Flats) with two additional sites along the Lake-Sonoma County line (at the ridgeline east of The Geysers and one site west of The Geysers in Sonoma County). This network was complemented with additional meteorological measurements at each of the H<sub>2</sub>S sites and along the ridgeline (Figure 1).

The second major program, The Geysers Air Monitoring Program (GAMP), began in August 1983 and continued until July 31, 1987. This program included continuous measurements for ambient H<sub>2</sub>S at six sites and meteorological parameters at eleven sites (nine wind direction/speed and temperature/dew point sites and two acoustic sounder sites). H<sub>2</sub>S was monitored at Pine Summit, Whispering Pines, Anderson Springs, Glenbrook, Hobergs, Anderson Ridge (1983-1984), and Binckley Ranch (1985-1987). GAMP was supported by a consortium of 15 power companies, steam suppliers, local air pollution control districts, the California Air Resources

Board (ARB), and the California Energy Commission. The Northern Sonoma County Air Pollution Control District (NSCAPCD) was the project manager for GAMP. PG&E performed the noncriteria monitoring, H<sub>2</sub>S monitoring at two sites, and meteorological monitoring at three sites. The consulting firm, Environmental Systems & Services (ES&S), Kelseyville, California, performed the remainder of the monitoring and issued quarterly data reports to the GAMP consortium. The Lake County Air Quality Management District (LCAQMD) and ARB performed quality assurance activities for GAMP.

The third major program, GAMP II, began on August 1, 1987, at the conclusion of GAMP. GAMP II is basically a modified extension of GAMP. Four of the GAMP H<sub>2</sub>S monitoring sites (Whispering Pines, Anderson Springs, Glenbrook, and Pine Summit) were continued along with ridgeline meteorological monitoring at Unit 13 and Unit 17. At the beginning of 1989, the Whispering Pines site was discontinued and the Hobergs site was reactivated. This program was continued as GAMP III with 3 sites in early 1991. The monitoring performed in GAMP II is performed solely by PG&E under contract to the NSCAPCD under a similar arrangement as occurred in GAMP. The LCAQMD

and ARB continue to provide quality assurance/quality control (QA/QC) work to the GAMP II consortium. GAMP III will be a three station H<sub>2</sub>S monitoring network, plus ridgeline meteorological monitoring, lasting 3 years.

Between the conclusion of the SRI program and the beginning of GAMP, isolated monitoring occurred at Pine Summit (NSCAPCD), Anderson Springs (LCAQMD), Whispering Pines (PG&E), and Hobergs (PG&E). Each of these sites was operated and maintained independently with no uniform QA/QC procedures in use among the sites. In addition, each of these sites began operation at different times using different analyzers. As such, data collected from these sites were not as well controlled as the data collected during the larger programs. The LCAQMD also performed monitoring at Kelseyville, independently from GAMP, during the latter part of GAMP.

For this paper, we have collected all of the original H<sub>2</sub>S monitoring data and entered it into a computer. For the SRI data, we were able to obtain magnetic tapes of the data from SRI. For the GAMP data that ES&S reported, we manually keypunched the data and then entered the data into the computer. The PG&E GAMP and GAMP II data were already in a computer database as a result of our data

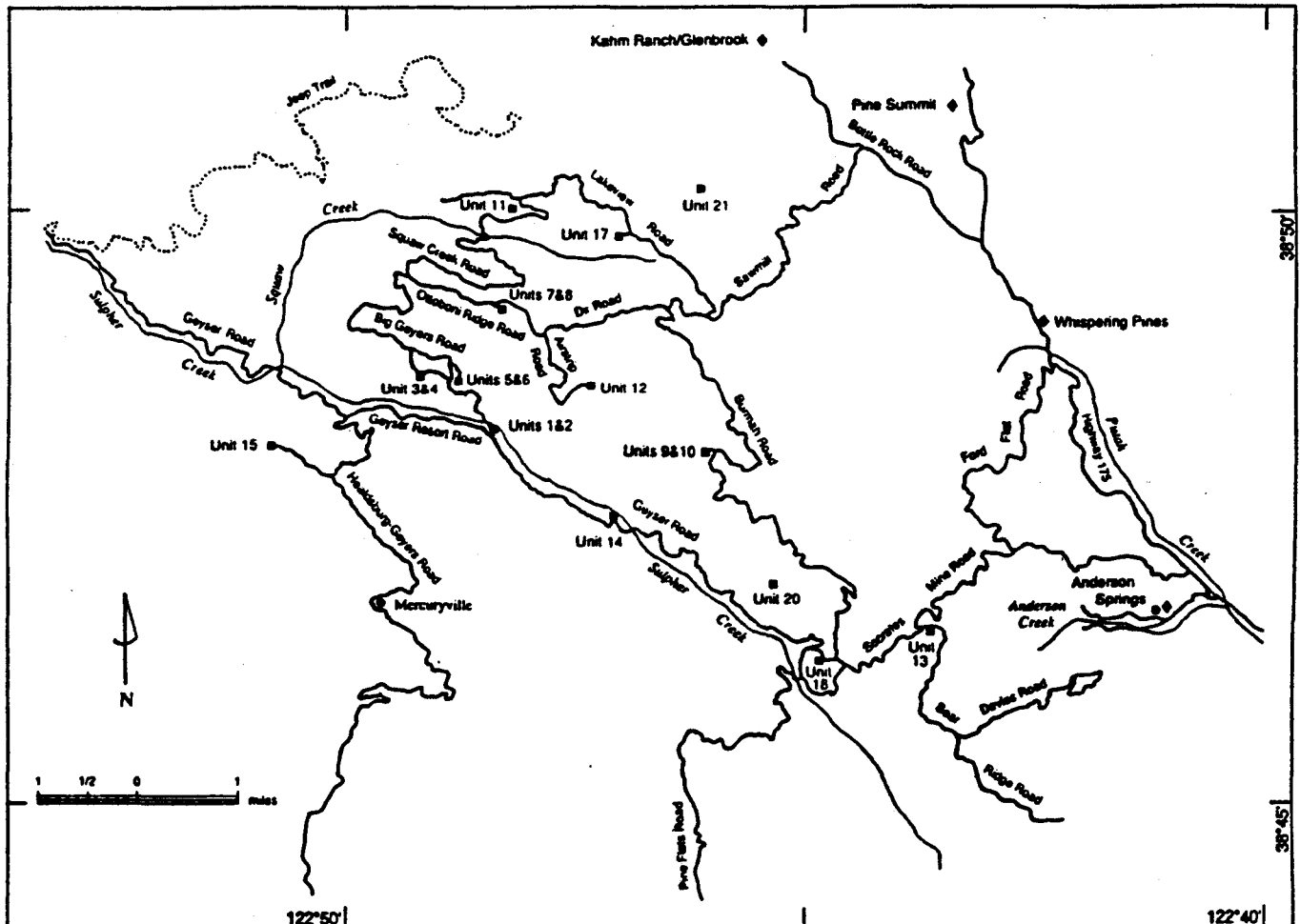


Figure 1. Air monitoring stations at The Geysers.

processing activities. Once compiled, we analyzed the data using PG&E software to generate the desired statistics and analyses.

### METHODS FOR MEASUREMENT AND ANALYSIS OF HYDROGEN SULFIDE

**SRI Program:** SRI deployed an H<sub>2</sub>S monitoring network of six Houston Atlas and two Tracor analyzers. The Tracor analyzers were sited at Pine Summit and Anderson Springs, with the Houston Atlas analyzers at the remaining six sites. The Houston Atlas analyzer used a lead acetate impregnated paper tape for detection of H<sub>2</sub>S. The Tracor analyzer used gas chromatography and flame photometry to measure H<sub>2</sub>S and sulfur dioxide. H<sub>2</sub>S data were reported to the nearest 5 ppb.

**GAMP:** Meloy and Monitor Labs flame photometric analyzers and Thermo Electron (TECO) Model 45 pulsed fluorescence analyzers were used by ES&S at its four monitoring sites. PG&E used TECO Model 43 sulfur dioxide analyzers retrofitted with TECO Model 340 hydrogen sulfide to sulfur dioxide converters to measure ambient H<sub>2</sub>S concentrations at The Geysers. Sulfur dioxide scrubbers were also used to prevent its interference. H<sub>2</sub>S data were reported by ES&S to the nearest 1 ppb with a lower detection limit of 4 ppb.

**GAMP II:** PG&E again used TECO Model 43 sulfur dioxide analyzers, retrofitted with TECO model 340 hydrogen sulfide to sulfur dioxide converters, to measure ambient H<sub>2</sub>S concentrations at The Geysers. Hourly concentrations of H<sub>2</sub>S were reported by PG&E to the nearest 1 ppb.

### RESULTS OF THE THREE PROGRAMS

Tables 1 through 4 list maximum concentrations, annual averages, and the number of violations of the hourly Ambient Air Quality Standard (AAQS) (0.03 ppm) for 1976-89 at the four sites with the most continuous data records. These sites are Pine Summit, Anderson Springs, Whispering Pines, and Glenbrook (originally Kalm Ranch during the SRI program). Our analysis interprets 25 ppb and greater as an exceedance of the state 0.03 ppm AAQS, which is consistent with NSCAPCD and LCAQMD policies.

Tables 1 through 4 reveal the results of aggressive reduction of H<sub>2</sub>S emissions from power plants and steam field activities at The Geysers. From 1976 to date, electric power production capacity has increased from 500 to 2,000 MW, a factor of 4. In addition, while power production was increasing at The Geysers, H<sub>2</sub>S emissions were being abated from existing geothermal facilities (power plants and steam field activities). In 1976, H<sub>2</sub>S emissions from electric power plants were estimated to be over 1,900 lb/hr; in 1988, the H<sub>2</sub>S emissions were estimated to be less than 200 lb/hr including steam field releases (Tolmasoff,

Table 1. Pine Summit Data Summary

Year	Max. Hr. Conc. (ppb)	Annual Avg. (ppb)	No. Hrs. > AAQS
1976	75	2.8	79
1977	75	1.9	116
1978	90	1.3	110
1979	55	na	na
1980	30	0.5	1
1981	45	0.5	na
1982	50	0.9	12
1983	38	0.7	10
1984	36	0.5	6
1985	50	1.0	13
1986	22	0.9	0
1987	20	0.6	0
1988	22	0.6	0
1989	17	0.6	0

Table 2. Anderson Springs Data Summary

Year	Max. Hr. Conc. (ppb)	Annual Avg. (ppb)	No. Hrs. > AAQS
1976*	35	1.0	6
1977*	60	2.3	58
1978*	30	1.9	8
1979	na	na	na
1980	35	3.8	na
1981	25	0.4	1
1982	28	na**	3
1983	23	na**	0
1984	13	1.0	0
1985	10	1.6	0
1986	8	1.2	0
1987	8	0.9	0
1988	9	0.8	0
1989	9	1.2	0

\* 1976-1978 data collected at Jackass Flats; thereafter, data collected at Recreation Center

\*\* Some of the na data are due to a lower reported limit of 10 ppb, which biased the annual averages.

personal communication, ?????). Figure 2 shows the number of violations of the AAQS versus PG&E annual power production at The Geysers. Again, significant reductions in the number of violations have occurred while electric production has increased.

Close examination of Tables 1 through 4 reveals that annual average H<sub>2</sub>S concentrations generally reached low and consistent levels in the early 1980s while peak hourly concentrations occasionally exceeded the AAQS. During the mid 1980s, increased control over steam field releases and power plant breakdown/upset conditions resulted in

elimination of the few remaining vagrant hours of violation of the AAQS.

Table 5 summarizes the results of Tables 1 through 4. Except for the column of maximum hourly concentrations, all annual statistics are averages of data contained in the tables. Furthermore, 1976-1978 and 1987-1989 have been grouped and averaged to show the 10-year trend. Annual maximum hourly concentrations and average annual concentrations dropped by a factor of 3.6 and 3.0, respectively over the 10-year period. This reduction is consistent with the reduction in H<sub>2</sub>S emissions occurring from geothermal facilities at The Geysers, which experienced a factor of 10 reduction. The average number of violations of the AAQS fell much more dramatically: the 1987-1989 period averaged almost 0 violations among the four monitoring sites. Since August 1987, no violations of the AAQS have been recorded at any monitoring site. As such, the area has gone

Table 3. Whispering Pines Data Summary

Year	Max. Hr. Conc. (ppb)	Annual Avg. (ppb)	No. Hrs. > AAQS
1976	40	3.5	79
1977	80	3.1	37
1978	50	2.2	55
1979	na	na	na
1980*	20	na	0
1981	30	0.7	3
1982	18	0.4	0
1983	24	0.8	0
1984	20	0.9	0
1985	25	0.9	3
1986	10	0.7	0
1987	19	0.6	0
1988	8	0.5	0
1989	discontinued		

\* 1980 represents half a year of data.

Table 4. Glenbrook Data Summary

Year	Max. Hr. Conc. (ppb)	Annual Avg. (ppb)	No. Hrs. > AAQS
1976*	65	2.1	63
1977*	50	2.0	12
1978*	75	2.0	10
1979	na	na	na
1980	na	na	na
1981	na	na	na
1982	na	na	na
1983**	42	na	7
1984	40	1.0	4
1985	38	1.2	5
1986	27	1.4	0
1987	27	0.5	2
1988	24	0.8	0
1989	16	0.8	0

\* 1976-1978 data collected at SRI site Kahm Ranch, which is near the current Glenbrook site.

\*\* 1983 represents about a half year.

Table 5. Summary Table, Average of Tables 1-4

Year	Max. Hr. Conc. (ppb)	Annual Avg. (ppb)	No. Hrs. > AAQS
1976	75 \	2.4 \	57 \
1977	80 = 82	2.3 = 2.2	56 = 53
1978	90 /	1.8 /	46 /
1983	42	0.8	4
1984	40	0.8	2
1985	50	1.2	5
1986	27	1.0	<1
1987	27 \	0.6 \	<1 \
1988	24 = 23	0.7 = 0.7	0 = <<1
1989	17 /	0.9 /	0 /

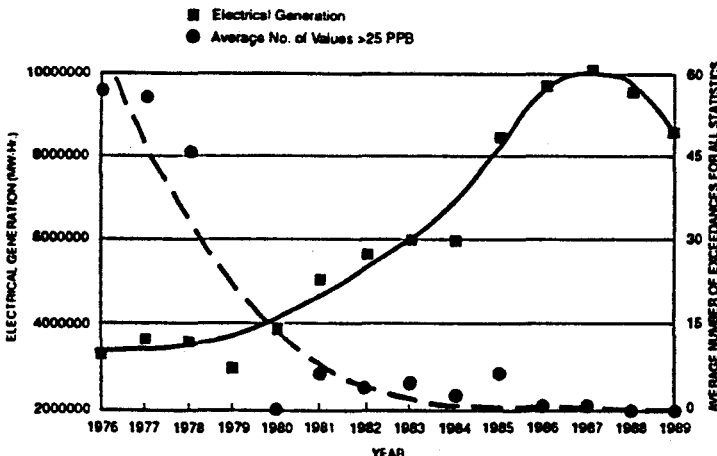


Figure 2. PG&E electrical generation and exceedances of the AAQS.

over 3 years without a violation of the AAQS and was designated as "attainment" by the ARB in their November 1990 review process.

### CONCLUSIONS

The three programs described herein were progressive programs designed to assess the impact of geothermal steam utilization at The Geysers. The first program was initiated at the time of rapid development at The Geysers. From 1976 to 1989, electric power production increased four-fold, from 500 to 2,000 MW. During this same period, overall emissions of H<sub>2</sub>S from power plants, including emissions from new sources, declined by about an order

of magnitude from about 1,900 lb/hr to less than 200 lb/hr. Ambient concentrations of H<sub>2</sub>S in the populated areas of Lake County, as evidenced by measurements at four sites with the longest and most continuous data set, showed a decline in the annual average by a factor of 3.0 and a decline in the peak hourly concentrations by a factor of 3.6. In comparing the 1976-1978 period with the 1987-1989 period, violations of the state AAQS declined from an average of 52 per year to almost 0. No violations have been recorded at any air monitoring site since August of 1987. As such, the area has gone 3 years since a violation of the AAQS was recorded. ARB designated the area as "attainment" in their November 1990 review process.

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