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**Preliminary Study of the Potential
Environmental Concerns Associated with
Surface Waters and Geothermal
Development of the Valles Caldera**

University of California

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Preliminary Study of the Potential Environmental Concerns Associated with Surface Waters and Geothermal Development of the Valles Caldera

G. J. Langhorst

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PRELIMINARY STUDY OF THE POTENTIAL ENVIRONMENTAL CONCERNS ASSOCIATED WITH SURFACE WATERS AND GEOTHERMAL DEVELOPMENT OF THE VALLES CALDERA

by

G. J. Langhorst

ABSTRACT

This report is a preliminary evaluation of possible and probable problems that may be associated with hydrothermal development of the Valles Caldera Known Geothermal Resource Area (KGRA), with specific reference to surface waters. Because of the history of geothermal development and its associated environmental impacts, this preliminary evaluation indicates the Valles Caldera KGRA will be subject to these concerns. Although the exact nature and size of any problem that may occur is not predictable, the baseline data accumulated so far have delineated existing conditions in the streams of the Valles Caldera KGRA. Continued monitoring will be necessary with the development of geothermal resources. Further studies are also needed to establish guidelines for geothermal effluents and emissions.

I. INTRODUCTION

Geothermal power is not a new concept. In Larderello, Italy, the first major geothermal power plant was developed in 1904, and, in the 1950s, geothermal power was being developed in New Zealand. Japan, Mexico, and the USSR have since used geothermal resources as a source of power. In 1960, the Geysers in California became the site of the first commercial geothermal power plant in the United States.

Geothermal fields are currently classified as (1) dry steam, (2) hot water, and (3) hot dry rock reservoirs. The hot water fields are further subdivided into wet steam and low temperature reservoirs.

Dry steam fields produce steam that may be used directly to run turbines. The Geysers and Larderello, Italy are examples of dry steam fields currently being exploited. These resources are easy to use; however, the occurrences of dry steam fields are rare.

A more abundant resource is the low temperature hot water fields, which produce water at points below boiling. These are typified by hot mineral and thermal springs, many of which have been used for years for various purposes. Several of those low temperature reservoirs are currently being used for small scale power generation. Few pollution problems exist with these systems.

Hot water fields, with temperatures above the boiling point, but not high enough to produce usable steam, occur in large areas of the world. Large fields are found in California and in the Valles Caldera KGRA in north central New Mexico. In these fields, approximately 20% of the fluid is converted to steam to run turbines, while the remaining 80% is liquid waste.

The most abundant geothermal resource in the world is hot dry rock. These reservoirs yield no steam or hot water because the rock is essentially

impermeable to water or because ground water circulation doesn't reach it. The Los Alamos Scientific Laboratory (LASL) has recently developed the first energy extracting system using hot dry rock.

Although there are different types of geothermal resources, their development is accomplished by operational phases that remain somewhat constant, and each phase has its concomitant environmental impacts. The production of geothermal power will entail (1) exploration, (2) test drilling, (3) production testing, (4) field development, (5) powerplant/powerline construction, and (6) full scale operations. The following discussion outlines, in general, these activities.

A. Exploration

Geothermal resource exploration may be carried out by aerial surveillance or surface exploration. Both methods are used to determine primary characteristics of a proposed geothermal area. Some of the activities and parameters looked at are (1) shallow drilling to determine thermal gradients, (2) mapping, (3) seismic surveys, and (4) environmental surveys. If this phase indicates a productive resource, the next phase is initiated.

B. Test Drilling

Test drilling gives the developer more in depth data. These data are used to locate potentially productive zones, delineate the reservoir limits, and aid in determining the properties of the reservoir and reservoir fluids. Heavy equipment and drilling rigs are used in this phase.

C. Production Testing

After test drilling operations have successfully established a well in a potentially productive geothermal zone, the well is production tested. This testing will delineate such properties as (1) flow, (2) recharge potential, (3) composition and temperature of geothermal fluids and gases, (4) pressure and other physical properties, and (5) maximum production expected from the well.

D. Field Development

When test drilling and production testing activities warrant, field development operations are

started. This involves the drilling of additional wells and further construction activities. Environmental impacts associated with field development will be similar to those from other phases, but amplified because of increased activity.

E. Powerplant and Powerline Construction

The construction of powerplant and powerline facilities is similar to that of conventional facilities. A central powerplant, fed by several geothermal wells, converts the superhot water and/or steam to electrical energy. A powerline corridor is necessary to transmit the electricity.

F. Full Scale Operation

Geothermal fields will probably not be developed unless they show commercial potential for at least 30 y.

II. PROBLEM DEFINITION AND JUSTIFICATION

The necessity of evaluating environmental concerns regarding geothermal development arises from the National Environmental Policy Act (NEPA) of 1969, implemented by Executive Order 11514, and the Council on Environmental Quality Guidelines of August 1, 1973 (38 PR 20550). Anything that will affect the quality of the human environment must have an environmental statement submitted for legislation or other appropriate federal action. Geothermal technology development is maintained under the Department of Energy (DOE) Division of Geothermal Energy (DGE). This agency was given guidelines for the preparation of an environmental statement (ERHQ-0001, Guidelines to the Preparation of Environmental Reports for Geothermal Development Projects, February 1977).² DGE guidelines require an environmental report for all phases of geothermal development.

Specific issues include land disturbances, atmospheric emissions, and aquatic emissions. This report examines these issues in relation to the surface water environment of the Valles Caldera. Major pathways to the surface waters are identified, and suggestions for mitigating impacts offered.

Union Oil Company, Public Service Company of New Mexico, and DOE have announced that they plan to construct a 50 MWe liquid-dominated

hydrothermal power plant in the Valles Caldera. Electricity generated from this plant will be transmitted to points of distribution, which are speculated to be Los Alamos, Española, Santa Fe, Cuba, or Albuquerque, New Mexico.³

This report will point out some of the potential environmental problems associated with geothermal resource development of the Valles Caldera, and serve as a vehicle for further environmental studies in the event of full field development.

III. ISSUES AFFECTING THE VALLES CALDERA

During development of geothermal resources, site alterations and their concomitant effects upon the environment will occur. The amount and extent of these effects will depend on the environmental setting, size of the planned facility, pre-planning of development, construction practices, and site restoration. In this regard the environmental issues of concern are land disturbances, atmospheric emissions, and aquatic emissions.

A. Land Disturbances

Land disturbances will not be specific to any particular activity; however, they may be more prevalent in some phases of development than in others. In test drilling, production testing, field development, and powerplant/powerline construction, considerable land alteration will occur. These activities will require road building, pipelines and other facilities, and clearing for parking lots and storage areas. Because of the steep terrain of the Valles Caldera KGRA, substantial modification of the land is likely to occur. Soil erosion may become a serious problem unless construction activities are handled effectively. Thus, extra care will have to be taken to minimize such factors as oversteepening of cut-and-fill slopes, loss of vegetative cover, and an increased concentration of runoff on natural slopes. In full scale operation, only minimal additional excavation should be necessary.

Soil erosion will cause an increase in stream siltation and the suspended sediment load. Increases in the suspended sediment load can adversely affect aquatic life by reducing the oxygen supply, reducing light penetration, and affecting water temperatures;

sediments may invade sensitive spawning areas of unique and endangered species, such as the Jemez Mountain Salamander (*Plethodon neomexicanus*), found in the Rio Cebolla.⁴ Because of leached nutrients carried into surface water, algal blooms may also occur, further depleting the dissolved oxygen supply.⁵

The most effective means of reducing damage to the surface water environment (caused by land disturbances) is through proper planning and management practices. Reseeding of disturbed land surfaces will reduce erosion and aerial photographs can be used to show the most advantageous places for roads. With proper planning and construction, one road may serve many sites. In addition, proper timing of construction activities can prevent interference with spawning habits of aquatic life near proposed site areas.

Weather is also an important consideration. Heavy excavation activities should be avoided during times of increased precipitation. The Jemez Plateau usually receives 35 to 36 cm of precipitation per year.³ During 1976 and 1977, more than 50% of the rainfall occurred during July, August, and September (Fig. 1).

B. Atmospheric Emissions

Most of the atmospheric emissions of a geothermal power plant occur as part of the natural composition of the atmosphere and at levels that are not normally toxic. However, there are some constituents of concern from both a toxic and environmental point of view. Table I shows ranges of gases in geothermal vapors in concentration per volume per cent. In This table, H₂S appears to pose the greatest potential pollution problem.

After treatment by current abatement procedures, H₂S released to the atmosphere should be diluted, during periods of normal atmospheric mixing, to such an extent that it would be of no particular concern. However, during an inversion or stagnant air conditions, H₂S could then have an effect on the surface water environment via rainfall transport to the ground and surface waters. Both H₂S and sulfur dioxide could be converted to elemental sulfur or sulfate acids, which would then be reflected by changes in the pH and odor of the waters.⁶

Fig. 1.
Precipitation at Fenton Hill, 1976 and 1977.

TABLE I
GAS COMPOSITION OF
GOETHERMAL VAPORS

Constituent	Concentration (vol%)
Ammonia	0 - 5.36
Argon	0 - 6.3
Arsenic	0.002 - 0.05
Boric Acid	0 - 0.45
Carbon Dioxide	0 - 99
Carbon Monoxide	0 - 3
Helium	0 - 0.3
Hydrocarbon (C ₂ and greater)	0 - 18.3
Hydrogen	0 - 39
Hydrogen Fluoride	0.00002
Hydrogen Sulfide (H ₂ + H ₂ S)	0 - 42 0.2 - 6
Mercury	0.007 - 40.7(ppb)
Methane	0 - 99.8
Nitrogen (N ₂ + Ar)	0 - 97.1 0.6 - 96.2
Oxygen	0 - 64
Sulfide Oxides	0 - 31

Mercury has been reported at varying concentrations from different geothermal fields. Reported concentrations range from 200 to 50 000 parts per billion. Gaseous mercury can be transformed by rainfall into particulate form through reduction or adhesion on inorganic surfaces, or by combining with organics.⁷ In the particulate form, mercury can then be introduced into the watershed and, subsequently, accumulate in the food chain.

Radium is usually found in geothermal systems, and, if present in sufficient quantities, tends to precipitate out in well piping and machinery.⁷ Radon, a gaseous product of radium decay, has a half life of 3.82 days and is an alpha emitter. If inversion conditions occurred for an extended period of time, radon and its decay products (²¹⁰Pb, etc) could become an environmental problem by wet or dry deposition to ground and surface waters.

A major mechanism for a large release of geothermal pollutants is a blowout. A blowout is a sudden escaping of steam and perhaps hot water from a geothermal well. This may be caused by either ruptures of casing and wellhead equipment or improper drilling procedures. Adverse impacts can result from direct discharges of geothermal fluids to surface waters, or indirect effects when the atmospheric emissions are returned to the ground by rainfall or settling. In California, a blowout occurred at the

Geysers in 1957. Because it could not be capped, this blowout emitted, by 1972, more than 8 164 800 metric tons of steam, 4536 metric tons of ammonia, 5443 metric tons of methane, and 3629 metric tons of hydrogen sulfide.⁷

Blowout prevention is accomplished by (1) proper site selection, (2) use of appropriate casing material, and (3) correct drilling procedures. Planning for equipment and training of personnel in the event of a blowout, coupled with a thorough cleanup operation afterwards, can lessen the impact to the surface water environment.⁵

There are several contemporary processes available for the control of air pollution from geothermal operations. Hydrogen sulfide is the atmospheric pollutant of greatest concern. At the Geysers geothermal power plant in California, Pacific Gas and Electric Company has used a new treatment system, the Stretford process, for removal of H_2S . Basically this process removed H_2S by scrubbing the gas stream after it leaves the condenser ejector and before it reaches the cooling tower. Elemental sulfur is produced after a series of reactions in the scrubbing process. Applied to the geothermal systems at the Geysers, an 80 to 90% removal of H_2S has been achieved. The remaining 10 to 20% is apparently released to the atmosphere.

A more recent H_2S abatement technique, developed by the EIC Corporation (EIC process), removes the H_2S from the incoming steam before it reaches the turbines. This method is valuable because it can help to reduce the corrosive properties of the steam. In field tests at the Geysers, a 97% H_2S removal efficiency has been achieved, along with about 80% removal of ammonia and boric acid.⁶ However, some factors, such as operating costs, make the EIC process less desirable at this point than the Stretford process.

C. Aquatic Emissions

During geothermal power production, pollution of surface water by liquid or condensate emissions is likely. In the producing geothermal field several points exist where accidental or planned emissions may occur. Some of these emission points are at the

1. well head during initial or periodic full flow venting,
2. separator during liquid phase wasting,

3. condenser during condensate discharge,
4. cooling tower during heat reduction,
5. fluid treatment system during waste water treatment or sludge removal, and
6. at the reinjection well during fluid reinjection.

The number and types of occurrences will depend on the type of system employed, character of the fluid, and whether reinjection is possible. The Redondo Creek area of the Valles Caldera KGRA is the site for Union Oil's proposed power plant. Disposal of the brine will probably be by reinjection, with limited or no surface disposal.

Two types of geothermal power generation systems are shown in Figs. 2 and 3. Figure 2 shows a liquid dominated flash steam turbine system in which the spent fluids and gases are discharged directly to the surface or atmosphere. From an environmental point of view this is the most undesirable of the two systems. Figure 3 shows the same type of power conversion cycle, but with all remaining wastes being reinjected into the ground or lost to the atmosphere from the cooling tower as drift or evaporation. The actual system to be used in the Valles Caldera will probably be much like the system in Fig. 3.⁸

Aquatic emissions from geothermal sources pollute surface water environments in two ways—thermal and/or chemical. Because of the low efficiency of heat to power conversion (current conversion efficiencies are on the order of about 20%),⁶ waste heat can be a substantial problem. The use of external cooling water in the Valles Caldera is not possible because of the limited surface water resource. With the use of cooling towers and with recycling of cooling water, most of the heat will be dissipated to the atmosphere. However, if cooling water is discharged into the streams, or if the geothermal fluid itself is released directly into the streams, intense thermal pollution would occur. The extent of this effect would depend on the amount and duration of the fluid released.

Short term temperature increases would cause temperature sensitive species to move out of the thermally affected areas. After the thermal effects have subsided, these species could be expected to return. In the Valles Calders, trout would probably be the aquatic organism most affected.⁹

Fig. 2.
Schematic of a geothermal power plant with direct discharges to the environment.

Fig. 3.
Schematic of a geothermal power plant with reinjection of wastes.

A long term thermal input would cause a decrease in both biomass and numbers of the nontolerant species, with a corresponding increase in biomass and numbers of thermally tolerant species. However, changes in the aquatic insect population, caused by thermal fluctuation, may be genetic rather than physiological.¹⁰

Even though the exact chemical composition of the brine in the Valles Caldera KGRA has not been reported, other studies (Cushman, R.M., et al, 1977) have shown, by comparing other geothermal fields, that there are some general constituents that should be of concern. That study¹¹ found Fe, Pb, and Zn had high potentials for toxic effects on aquatic organisms and that Fe, Mn, Pb, and Zn had high hazard potentials to aquatic organisms by bioaccumulation. In Big Sulfur Creek in the Geysers geothermal area in California, boron, as boric acid, was identified as the toxin possibly responsible for a steelhead trout kill.¹¹ All geothermal fluids have Na, Cl, Ca, K, Mg, HCO₃, SO₄, and SiO₄ in varying concentrations. Many hot water fields average between 2000 and 20 000 ppm TDS. Dissolved gases may include O₂, CO₂, H₂S, CH₄, H₂, NH₃, and N₂. Actual concentrations of any of these constituents will be site specific and may even vary from well to well, and, from time to time, within a well.

The greatest problem in liquid dominated geothermal systems may be disposal of the massive amounts of waste water. In the Valles Caldera, a proposed system of 50 MWe would normally consume 34 to 68 kg/kwhr. This translates to 16 to 32 × 10⁶ m³/y (13 000 to 26 000 acre feet) of water. Because 88% of this fluid must be disposed of, it is logical to assume that disposal will be by reinjection. Proper casing of reinjection wells is necessary to prevent indirect contamination of surface waters by ground waters.

If there are to be any discharges to streams, special procedures are called for. Holding ponds will be necessary to cool waste waters, and chemical treatment will be necessary to mitigate harmful chemical constituents.

IV. BASELINE DATA

Nine major drainage systems are found within the Valles Caldera KGRA. These perennial streams are Rio de Las Vacas, Rio Cebolla, Rio Guadalupe, Jemez River, East fork of the Jemez River, Redondo

Creek, Sulfur Creek, San Antonio Creek, and Vallecitos Creek. Vallecitos Creek will not be considered in this report because it does not drain areas currently considered for geothermal development. The other eight streams drain areas of potential contamination in the immediate and near future. Figure 4 shows the area being considered in this report, along with the eight streams.

Four years of data from the sampling stations located on these streams have been accumulated by LASL's Environmental Surveillance Group (H-8).¹²⁻¹⁵ A baseline information table has been compiled from these data (Table II). Table II shows mean values and confidence intervals ($\alpha = 0.05$) for the measured parameters. Because of conditions resulting from seasonal variations, some sample values are expected to fall outside the indicated range. However, when two or three consecutive samples fall outside the expected distribution, investigative procedures should be initiated to determine the cause of the variance and whether it can be attributed to geothermal activities.

The New Mexico Water Quality Standards (October 1976)¹⁶ list designated uses of surface water in the Valles Caldera KGRA and set standards for those waters. The recognized uses of surface waters in the area include domestic water supplies, fish cultures, high quality cold water fisheries, irrigation, livestock and wildlife watering, and secondary contact recreation.

A comparison of Table II with the New Mexico Water Quality Standards for Interstate and Intrastate Streams shows that the only parameters with mean values in excess of the standards are pH at sampling station V and specific conductance at sampling stations R, V, and S (Fig. 4). Sampling station V is located on Sulfur Creek above its confluence with Redondo Creek. Sulfur Creek drains a small basin that contains thermal springs (the most important is Sulfur Hot Springs), which contributes to the base flow of the creek. The high specific conductivity and low pH of Sulfur Creek is attributed to these springs.¹⁷

Sampling station S is located above the confluence of the Rio Guadalupe with the Jemez River, and sampling station R is located below that confluence. The high specific conductivity at these locations is caused by highly mineralized water from thermal springs, which flow into the Jemez River

Fig. 4.
Major drainage systems within the Valles Caldera KGRA.

above these stations. The thermal springs at Soda Dam are the main contributors.¹⁷

Given these naturally-occurring sources of variance from the water quality standards, it seems reasonable that those standards for the parameters of pH and specific conductance for the given reaches of the Jemez River and Sulfur Creek should be revised accordingly.

V. MONITORING

Monitoring surface water quality is necessary, even if there are to be no planned surface water discharges. The reasons for this are accidental discharge of fluids by broken or leaking pipes, escape of fluids from reinjection wells into aquifers and springs, leakage or seepage of holding ponds or sumps, and/or possible contamination of surface water by air emissions as "fallout." Water quality monitoring

is recommended for the same constituents and properties for which the geothermal effluent itself is monitored.

The monitoring scheme should be simple but thorough. Samples should be taken at three points—one upstream from the effluent or point of discharge, one at the effluent or point of discharge, and one far enough downstream from the effluent or point of discharge to allow for mixing. Sampling frequency should reflect the variability of effluent characteristics and of stream flow.

The Environmental Protection Agency's Office of Water and Hazardous Materials has developed criteria for various constituents in geothermal fluids in relation to aquatic life and agricultural uses. These criteria are shown in Tables III and IV. Many of the known chemical constituents of geothermal fluids have not been considered. Boron, arsenic, and

TABLE II
SURFACE WATER QUALITY

Chemical Analyses	Station R	Station T	Station U	Station V	Station F
Silica (mg/l)	42.13 ± 28.42 ^a	35.82 ± 8.04	29.67 ± 8.78	42.22 ± 8.82	33.58 ± 5.94
Calcium	43.65 ± 19.10	19.00 ± 4.82	30.22 ± 8.64	72.89 ± 47.34	41.58 ± 17.66
Magnesium	5.18 ± 3.82	2.45 ± 2.08	3.44 ± 3.18	11.22 ± 6.70	6.42 ± 5.22
Sodium	93.84 ± 283.28	11.27 ± 3.70	17.44 ± 18.96	23.11 ± 15.02	20.83 ± 15.10
Carbonate	1.89 ± 9.38	0.91 ± 6.04	0 ± 0	0 ± 0	0 ± 0
Bicarbonate	164.76 ± 92.66	77.64 ± 22.62	37.33 ± 14.56	0 ± 0	12.42 ± 15.58
Sulfate	14.41 ± 8.24	3.14 ± 5.10	9.71 ± 13.76	267 ± 210.18	113.17 ± 86.56
Chloride	92.65 ± 90.10	3.18 ± 4.36	42.11 ± 49.42	7.89 ± 10.92	34.58 ± 30.28
Fluoride	0.89 ± 0.70	0.46 ± 0.32	0.28 ± 0.64	0.42 ± 0.38	0.32 ± 0.30
Nitrate	0.19 ± 0.26	0.15 ± 0.24	0.19 ± 0.26	0.23 ± 0.26	0.14 ± 0.10
TDS	426.94 ± 239.96	137.27 ± 47.68	196.33 ± 123.42	537.67 ± 343.16	279.83 ± 152.60
Total Hardness (as CaCO ₃)	129.29 ± 57.32	58.64 ± 14.76	69.11 ± 31.46	133.75 ± 194.88	130.50 ± 56.22
Specific Cond (μmho/cm)	625.00 ± 475.08	167.27 ± 46.76	245.56 ± 180.94	722.78 ± 525.96	327.62 ± 36.20
pH	8.06 ± 0.60	7.79 ± 0.80	7.52 ± 0.58	3.82 ± 0.90	7.00 ± 2.14
Temperature (°C)	10.69 ± 13.48	10.09 ± 11.18	4.22 ± 10.58	4.89 ± 7.52	5.30 ± 10.34
Discharge	584.00 ± 641.40	78.50 ± 112.56	15.75 ± 19.30	18.38 ± 34.36	30.70 ± 58.06
Estimate (l/s)					

Chemical Analyses	Station J	Station H	Station Q	Station S
Silica (mg/l)	43.69 ± 21.60	50.46 ± 19.36	25.62 ± 19.42	49.92 ± 21.40
Calcium	14.85 ± 5.46	15.92 ± 5.50	45.08 ± 23.80	43.50 ± 23.34
Magnesium	3.23 ± 2.18	3.23 ± 4.62	6.31 ± 4.58	5.67 ± 3.82
Sodium	16.00 ± 11.10	13.85 ± 10.36	14.38 ± 9.88	67.33 ± 56.22
Carbonate	0 ± 0	0 ± 0	1.00 ± 3.82	2.40 ± 8.58
Bicarbonate	65.86 ± 34.70	66.92 ± 29.42	152.54 ± 90.48	169.73 ± 83.36
Sulfate	9.14 ± 6.70	8.21 ± 5.88	6.68 ± 6.28	18.83 ± 35.86
Chloride	7.69 ± 6.44	3.85 ± 3.98	7.00 ± 9.42	84.67 ± 86.64
Fluoride	0.68 ± 0.52	1.11 ± 1.00	0.57 ± 0.58	0.93 ± 0.54
Nitrate	0.15 ± 0.20	0.17 ± 0.12	0.17 ± 0.26	0.29 ± 1.28
TDS	160.08 ± 62.00	167.31 ± 64.40	219.92 ± 158.16	412.0 ± 195.5
Total Hardness (as CaCO ₃)	50.92 ± 14.94	52.85 ± 24.64	138.77 ± 70.54	137.53 ± 54.32
Specific Cond (μmho/cm)	167.32 ± 58.40	159.00 ± 42.26	308.08 ± 176.42	640.00 ± 374.80
pH	7.75 ± 0.62	7.74 ± 0.66	7.98 ± 0.52	8.13 ± 0.50
Temperature (°C)	7.64 ± 10.64	6.73 ± 11.04	11.09 ± 11.88	11.36 ± 10.92
Discharge	328.50 ± 321.18	107.40 ± 184.22	119.50 ± 336.54	383.50 ± 328.02
Estimate (l/s)				

^aConfidence value expressed as $\bar{x} \pm t_{0.05} s_x$

TABLE III
AGRICULTURAL USE CRITERIA FOR CONSTITUENTS IN
GEOTHERMAL FLUIDS FROM "QUALITY CRITERIA FOR WATER"^a

Livestock Watering	Crop Irrigation	Remarks
Ammonia		No criteria suggested
Arsenic	0.1 mg/l	Toxicity to some crops at 0.5 mg/l
Barium		No criteria suggested
Beryllium	0.001 to 0.500 mg/l	Crop toxicity acidity dependent; no livestock criteria suggested
Boron	0.75 mg/l	Toxic to sensitive plants, e.g., citrus at <1 mg/l; no livestock criteria suggested
Cadmium		Reduced crop yields at 1 mg/l; crop accumulation related to zinc concentrations; no livestock criteria suggested
Chromium		No criteria suggested
Copper		Toxicity for plants begins at 0.1 mg/l; no livestock criteria suggested
Iron		No criteria suggested
Lead		Toxic to plants at <30 mg/l; no criteria suggested
Manganese	0.2 mg/l suggested for acidiphilic crops	Toxicity to plants increases with decreasing pH; no livestock criteria suggested
Mercury		Bioaccumulated but no criteria suggested
Nitrates		No criteria suggested; nutrient for crops
Phosphorus		No criteria suggested; nutrient for crops
Selenium		No criteria suggested
Silver		No criteria suggested
Hydrogen sulfide		No criteria suggested
Zinc		Toxic to some crops at 0.4 to 25 mg/l; may cause iron deficiency in plants; no livestock criteria suggested
TDS	500 to 15 000 mg/l suggested	Osmotic effects in plants; variable harm to both plants and animals
Sodium		Toxic to certain plants; ratio to other cations important; no criteria given

^aEnvironmental Protection Agency; *Quality Criteria for Water*;
Office of Water and Hazardous Materials; EPA-440/9-76-023;
July 1976.

TABLE IV
AQUATIC LIFE CRITERIA FOR CONSTITUENTS IN
GEOTHERMAL FLUIDS FROM "QUALITY CRITERIA FOR WATER"^a

Criteria for Constituent	Criteria for Fresh Water	Marine Water	Remarks
Ammonia (un-ionized)	0.02 mg/l		Toxicity pH dependent
Arsenic			Daphnia impaired by 4.3 mg/l
Barium		Toxicity level > 50 mg/l	
Beryllium	0.11 mg/l (soft water) 1.1 mg/l (hard water)	Toxicity hardness-dependent	
Boron			Toxic to minnows at 19 000 mg/l
Cadmium	0.004 to 0.0004 mg/l (soft water) 0.12 to 0.0012 mg/l (hard water)	0.005 mg/l	Toxic at < 0.5 mg/l all tests
Chromium	0.1 mg/l		Toxicity varies with pH and oxidation state
Copper	0.1 96 h LC ₅₀	0.1 96 h LC ₅₀	Toxicity alkalinity-dependent
Iron	1.0 mg/l		Toxicity variable
Lead	0.01 96 h LC ₅₀ (soluble lead)		Salmonids most sensitive fish
Manganese		0.1 mg/l	Not a problem in fresh water
Mercury	0.0005 mg/l	0.001 mg/l	High bioaccumulation; thus affects human food
Nitrates			Toxicity to fish > 900 mg/l
Phosphorus		0.001 mg/l P	Eutrophication factor
Selenium	0.01 96 h LC ₅₀	0.01 96 h LC ₅₀	Toxic at > 2.5 mg/l
Silver	0.01 96 h LC ₅₀	0.01 96 h LC ₅₀	Toxicity dependent on compound
Hydrogen sulfide	0.0002 mg/l	0.0002 mg/l	Toxic at very low levels
Zinc	0.01 96 h LC ₅₀		Toxicity dependent on temperature, Dissolved oxygen, hardness
TDS			Osmotic effects variable

^aEnvironmental Protection Agency, *Quality Criteria for Water*, Office of Water and Hazardous Materials, EPA-440/9-76-023, July 1976.

barium have been found in geothermal fluids in concentrations that are higher than those found in other waters.⁶ Ultimately, the toxic effect of the various constituents, whether from acute or chronic exposures, will be the guideline for establishing effluent or emission standards.

VI. SUMMARY AND CONCLUSIONS

In Lake County, Sonoma County, and Imperial County, California, water pollution has resulted from the geothermal plants currently in operation.¹⁸ Water pollution is also likely to occur in the Valles Caldera KGRA (because of geothermal resource development). Pollution of the streams originates from three sources—land disturbances, atmospheric

emissions, and liquid effluent emissions. The exact amounts and consequences of these pollutants are site specific.

Land disturbances can be mitigated by proper construction practices and adequate planning. Erosion from construction activities is typically the main cause of concern.

Atmospheric emissions from geothermal power plants contain several constituents of environmental concern. Of these concerns, hydrogen sulfide is the greatest because of relatively high concentrations in geothermal fluids, obnoxious odor, and toxicity at higher concentrations. Various other constituents, such as sulfur dioxide, boron, mercury, radium, and radon, may also be considered as potential environmental problems.

Blowouts, a potential problem in any hydrothermal system, can be lessened by adequate construction of wells and proper training of personnel. In the event of a blowout, immediate and thorough clean up procedures can lessen the impact to the aquatic surface supply.

Liquid effluents can have a double impact—thermal and/or chemical. The extent of the impacts will be partially dependent on the type of power generation system used, character of the geothermal fluid, and the type of waste water disposal used. Because of the limited land area and massive quantities of spent fluids, reinjection is typically the major method of disposal. Holding ponds and waste water treatment are necessary before any surface disposal can occur.

Baseline data, accumulated from four years of sampling by LASL's Environmental Surveillance Group, has delineated the existing conditions of the streams in the Valles Caldera KGRA. Constant variations in any of the measured parameters should be looked at in relation to geothermal activities in the area.

Monitoring is necessary on streams at or near any geothermal development activity. Monitoring programs should reflect the variability of the geothermal effluent and the stream flow.

Further studies are required to establish guidelines for geothermal effluents and emissions. Some constituents such as boron, arsenic, and barium have no effluent or emission standards, even though they are sometimes found in relatively high concentrations in geothermal emissions.

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