LA-10892-PR
Progress Report

UC-11
Issued: January 1987

Off-site

2193

Water Quality in the Vicinity of Fenton Hill

1983 and 1984

W. D. Purtymun
R. W. Ferenbaugh
N. M. Becker
M. C. Williams
M. Maes

Los Alamos
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

4053

WATER QUALITY IN THE VICINITY OF FENTON HILL
1983 and 1984

by

W. D. Purtymun, R. W. Ferenbaugh, N. M. Becker,
M. C. Williams, and M. Maes

ABSTRACT

Water quality data have been collected since 1974 from established surface and groundwater stations at and in the vicinity of Fenton Hill (Hot Dry Rock Geothermal Demonstration Site) located in the Jemez Mountains. This is part of a continued program of environmental studies. There has been a slight variation in chemical quality of water from the surface and groundwater stations; however, these variations are within normal seasonal fluctuations. Water supply at the site is pumped from the aquifer in the Abiquiu Tuff. Cumulative production from 1976 through 1984 has been 41.5 x 10^6 gal. The water level in the supply well declined from 365 ft in 1976 to 379 ft in 1984.

I. INTRODUCTION

In 1973, a preliminary study was made by the Los Alamos National Laboratory of the Jemez River and Rio Guadalupe drainages to establish base line water quality data. The study was made prior to experimental work started on the Hot Dry Rock Geothermal Project at the Fenton Hill Site (TA-57).[1] Geologic and hydrologic investigations were made in the area and at TA-57 from 1972 through 1974.[2,3] These studies provided the basis for selecting locations for water quality monitoring stations. Water quality data from the permanently established stations have been published for 1974 through 1982.[4-11] Late in 1980, a hydrologic study was made of the aquifer that furnishes the water supply to the Fenton Hill Site.[12]

The current report interprets and evaluates the quality of water data from the monitoring station and from the supply well for 1983 and 1984.

Fenton Hill Site is located about 35 miles west of Los Alamos on the western flank of the Valles Caldera (Fig. 1). Studies at the site are based on the concept of extracting heat from dry geothermal reservoirs by developing artificial hydrothermal systems. The site contains two deep holes (each ~10,000 ft) completed

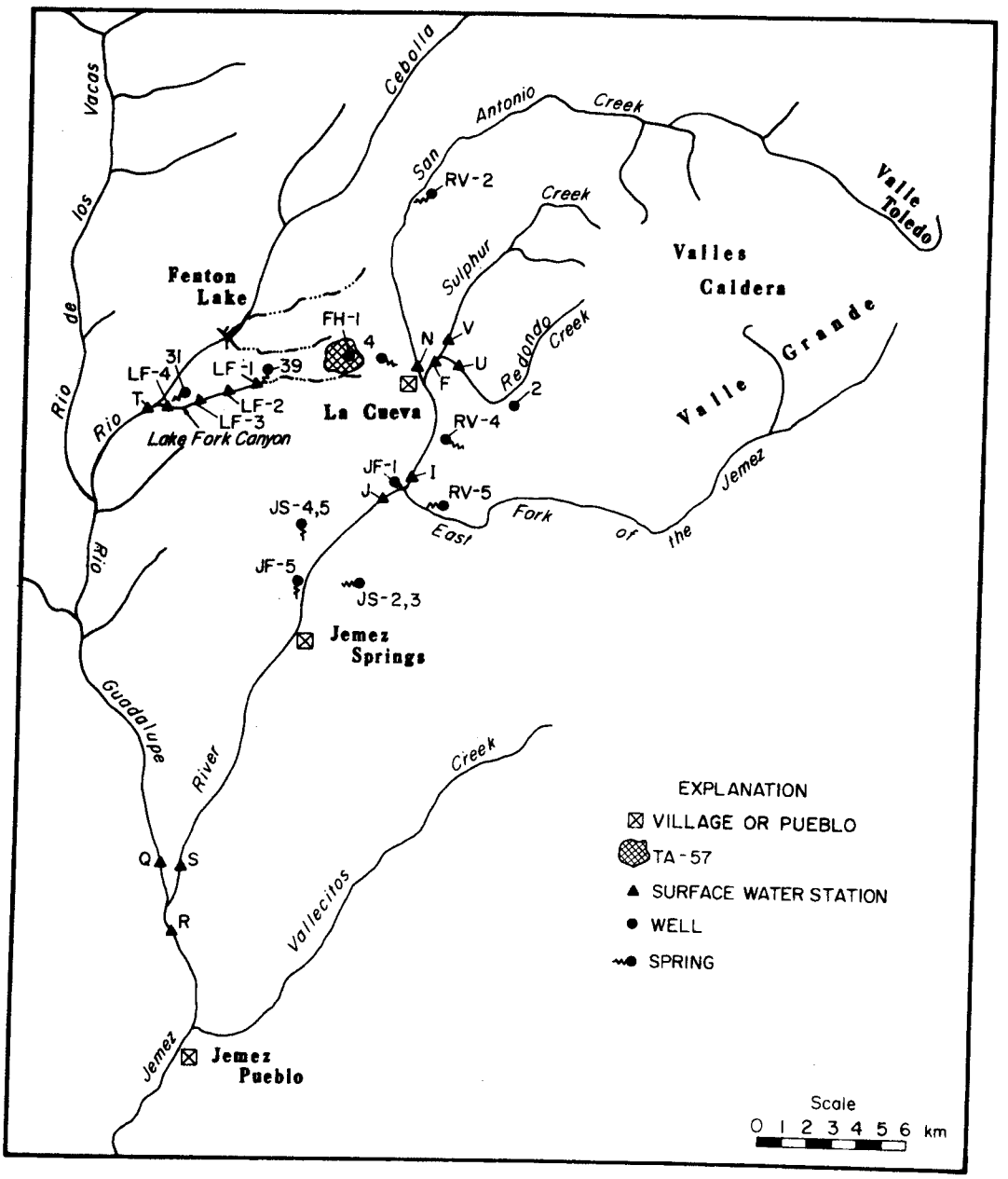

Fig. 1. Location of sampling stations.

in dry Precambrian granitic rock. The holes are connected by a large fracture, which was induced by hydraulic pressurization. Water is circulated under pressure through this system to recover heat from fracture areas. The system is complete, and initial tests have been conducted.

A second system is now being developed to a depth of about 14,000 ft to test the system at a higher temperature and develop a commercial-sized reservoir. The drilling operations to complete the second system used chemical additives (drilling mud). Water from the geothermal circulation loop contains moderate concentrations of silica, sodium, sulfates, arsenic, and lithium with moderate to high amounts of fluoride. These chemicals can be from drilling mud or dissolved from the geothermal reservoir by the circulating waters.

Two test holes were drilled through the Bandelier Tuff, Abo Formation, and completed into the Madera Limestone southeast and southwest of the Fenton Hill Site. The holes were drilled to emplace geophones for the site seismic net and to obtain geologic and hydrologic information. The geology and hydrology of these test holes are summarized in Appendix A. These test holes are not a part of the monitoring net; however, they are documented in this report to show water-bearing characteristics and chemical quality of aquifers in the Abo Formation and Madera Limestone. These units lie beneath the Abiquiu Tuff, which furnishes the water supply to the site.

The chemical quality of water from the supply well and storage ponds was documented to provide a basis for continued monitoring of chemical properties related to use as water supply and the experimental geothermal loop. The chemical quality of water from the supply well and ponds at the Fenton Hill Site are presented in Appendix B.

II. FENTON HILL SITE

The Fenton Hill Site is located on a narrow mesa on the western flank of the Valles Caldera. It is a gently sloping southwest-trending mesa, which is bounded on the east by San Antonio Creek and on the west and southwest by the Rio Cebolla (Fig. 1). Adjacent to the site, Lake Fork Canyon to the south and an unnamed canyon north of the site contain intermittent streams. Only during periods of heavy precipitation or snowmelt does water from these canyons reach the Rio Cebolla. The lower 3 miles of Lake Fork Canyon above the confluence with the Rio Cebolla contain perennial flow from springs and seeps (Fig. 1). This water is discharged from the aquifer that furnishes the water supply at the site.

III. SURFACE AND GROUNDWATER

Water samples for analyses were collected in November 1983 and 1984 (Figs. 1 and 2) from the immediate area of the site and in the major drainage of the Jemez River and Rio Guadalupe downgradient from the site. Routine analyses were made for silica, calcium, magnesium, potassium, sodium, carbonate, bicarbonate, sulfate, chloride, fluoride, nitrates, arsenic, lithium, total hardness, total dissolved solids (TDS), conductance, and pH. All analyses were performed using methods described in a United States Environmental Protection Agency (USEPA) document.[13]

This discussion is organized around stations with common chemical properties and TDS. The mean and standard deviation of the predominant ions and TDS from the period of record through 1982 are compared with those concentrations in the 1983 and 1984 analyses (Appendixes C and D). Graphs showing TDS and predominant ions were prepared for each set of analyses from Appendixes C and D (see example in Fig. 3). The mean plus or minus twice standard deviation in these appendixes is the basis for comparison of data for 1983 and 1984.

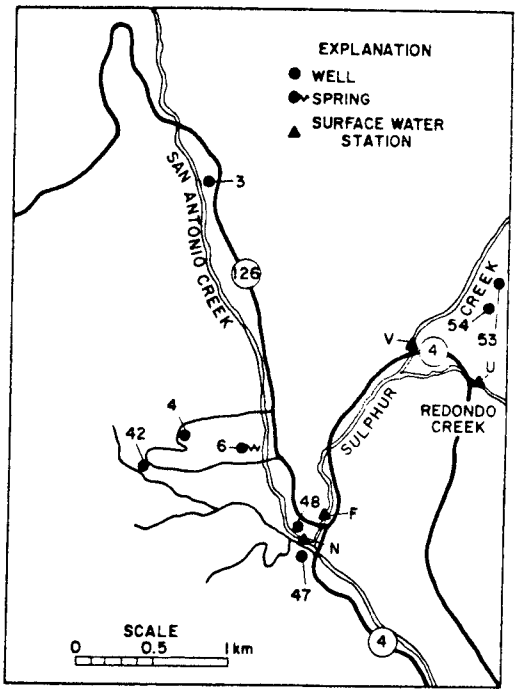

Fig. 2. Location of sampling stations at La Cueva.

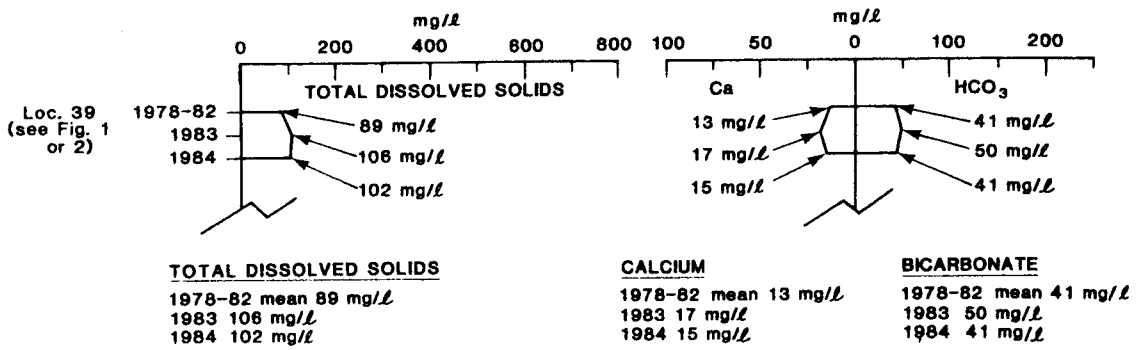

Fig. 3. Graphic explanation used on figures to compare total dissolved solids and predominant ions; mean to 1978-1982, 1983, and 1984.

A. Surface Water

Surface water stations (nine on the Jemez River, the Rio Guadalupe, and their tributaries) are identified by capital letters in Figs. 1 and 2 and are keyed to detail analyses presented in Appendix E for 1983 and 1984.

There are four general types of surface water based on common chemical properties of predominant ions. Comparison of the mean TDS for the period of record through 1982 to the concentrations of TDS in 1983 and 1984 is shown in Fig. 4. The predominant surface water types are (1) sodium and chloride, (2) calcium and bicarbonate, (3) calcium and sulfate, and (4) sodium and bicarbonate.

Each surface water station has a chemical characteristic reflecting the water source (base flow) in the drainage area. The chemical concentrations may be modified by water added through snowmelt or precipitation. Thus, as seen by Fig. 4, the chemical quality can vary widely at each individual station and from station to station over a period of time. The mean and standard deviation of the analyses for predominant ions and TDS first record to 1982 are compared with similar ions and TDS of samples in 1983 and 1984 data in Appendix C.

Sodium and chloride waters are found in base flow at Locations U, R, and S (Fig. 4). Location U is on Redondo Creek, which drains the interbasin of Valles Caldera, the site of hydrothermal (wet geothermal) development. Locations R and S are on the lower reach of the Jemez River. Location R is below the confluence of the Rio Guadalupe and Location S is above the confluence (Fig. 1). Sodium,

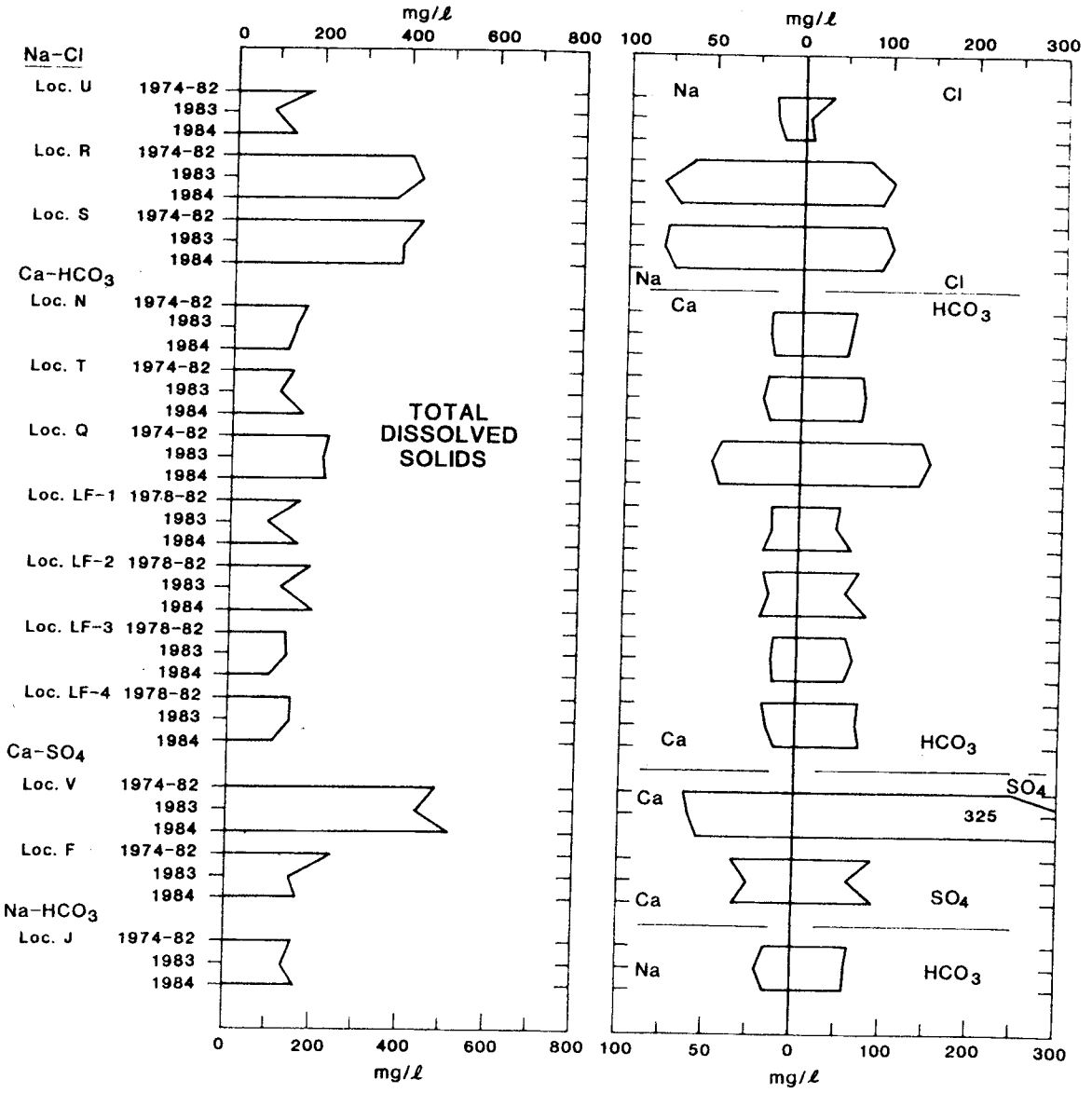

Fig. 4. Graphic comparison of TDS and predominant ions in surface water; mean to 1982, 1983, and 1984.

chloride, and TDS concentrations varied slightly in 1983 and 1984 when compared with the mean of those constituents from 1974-1982; however, the changes are within past variations.

Calcium and bicarbonate waters are found at Locations N, T, and Q (Fig. 1). Location N is in San Antonio Creek, which drains the northern part of the Valles Caldera. Location Q is on the Rio Guadalupe above the confluence with the Jemez River. Location T is located in Rio Cebolla below the Fenton Hill Site. Calcium

and bicarbonate are also the predominant ions in four surface water stations in Lake Fork Canyon (Fig. 4). The four surface water stations, LF-1, LF-2, LF-3, and LF-4, are located downgradient from the Fenton Hill Site (Fig. 1). Surface water in these stations has been sampled and analyzed annually since 1978 to determine if any changes have occurred from release of water from the ponds at the site. No significant changes in chemical quality have occurred in the period 1978 through 1984. Chemical quality of surface water at Locations N, T, and Q has varied within the range of the 1974-1982 mean concentrations showing no significant changes in chemical quality.

Calcium and sulfate waters are found in base flow at Locations V and F (Fig. 4). Location V is in Sulphur Creek. Location F is also in Sulphur Creek below the junction with Redondo Creek (Fig. 1). The discharges from the thermal and mineral springs along upper Sulphur Creek in the Valles Caldera determine the chemical quality of water at these locations. The dilution of the surface flow of water from Redondo Creek at Location F reduces the chemical concentration when compared with those concentrations at Location V (Fig. 4). The chemical quality has varied each year since 1974 but has showed no trends or significant changes in 1983 and 1984 from previous analyses.

Sodium and bicarbonate waters are found at Location J (Fig. 4). Location J is in the Jemez River below the confluence of San Antonio Creek and the East Fork of the Jemez River. These two streams drain the interior and outer portions of the Valles Caldera (Fig. 1). There was no significant change in chemical quality of water in 1983 and 1984 when compared with chemical quality from 1974-1982.

The mineral springs along the Jemez Fault discharge into the Jemez River below Location J. These springs contribute to the concentrations of sodium, chloride, fluoride, arsenic, and lithium, which are responsible for the change in surface water quality in the Jemez River below Location J (Appendix E).

In summary, a comparison of the chemical quality of surface water from 1974-1982 with the quality in 1983 and 1984 shows some variation in some chemical concentrations. No trend at individual stations was noted. As previously stated, changes in surface water discharge resulting in dilution of base flow can account for the variations in chemical quality. These variations are not considered significant.

B. Groundwater

Groundwater locations sampled annually in 1983 and 1984 included five mineral and thermal springs, five springs, and seven wells. Each station location is shown by a capital letter followed by a number or by a number alone (Figs. 1 and 2). These locations are keyed to detailed analyses presented in Appendix F. Three types of groundwater are categorized by predominant ions. These three types are (1) sodium and bicarbonate, (2) sodium and chloride, and (3) calcium and bicarbonate. The mean and standard deviation of the analyses for predominant ions and TDS from first record to 1982 are compared with similar ions and TDS in samples collected in 1983 and 1984 data (Appendix D).

Sodium and bicarbonate waters are found in spring Locations JS-2,3 and JS-4,5. Sodium and bicarbonate water are also found in springs and wells at Locations 4, 6, 31, and 47, and in water from thermal springs RV-2, RV-4, and RV-5 (Fig. 5 and Appendix C). Locations JS-2,3 and JS-4,5 are springs located on

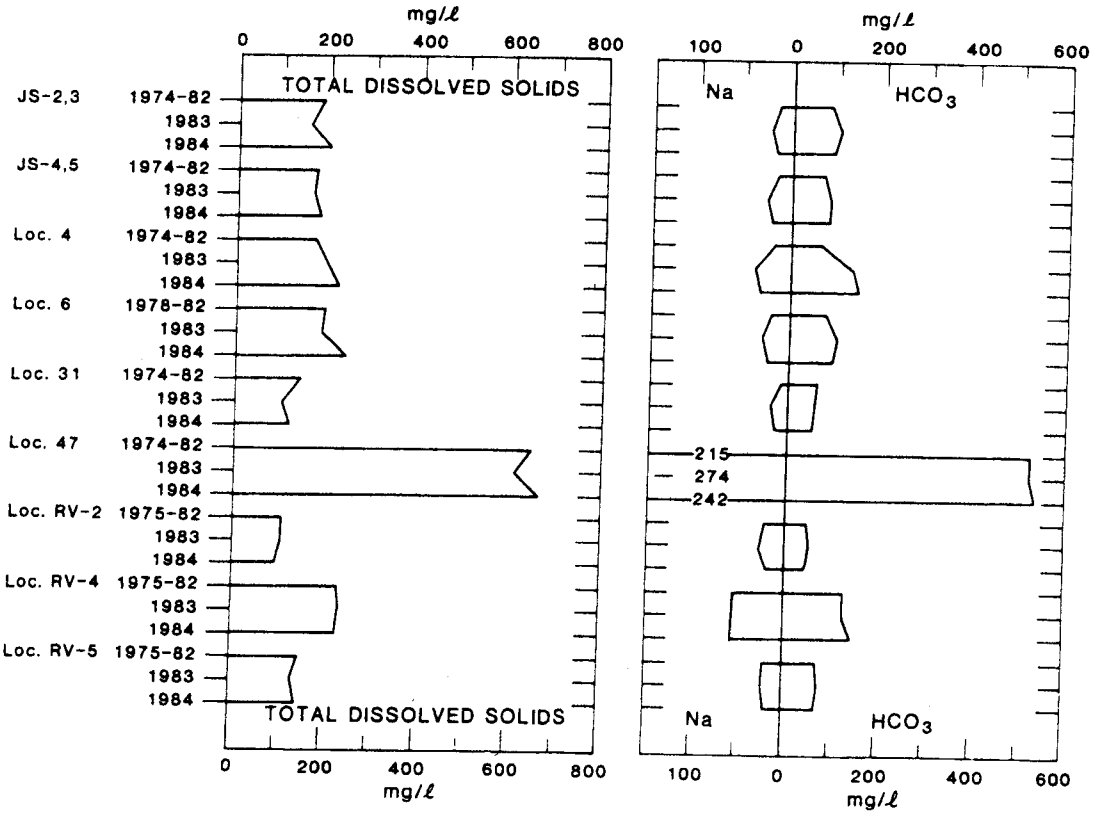

Fig. 5. Graphic comparison of TDS and predominant ions (sodium and bicarbonate) in groundwater; mean to 1982, 1983, and 1984.

the east and west walls of Jemez Canyon. Spring discharge is from the base of the Bandelier Tuff overlying the Abo Formation. These springs furnish the water supply for the village of Jemez Springs. Location 4 is a spring that is part of a water supply for several residences at La Cueva. Location 6 is a spring in the valley floor of San Antonio Creek at La Cueva and Location 31 is a spring on the north wall of Lake Fork Canyon west of the confluence with the Rio Cebolla (Fig. 1). Location 47 is a well used for water supply in La Cueva. Thermal springs RV-2 (San Antonio Hot Springs), RV-4 (Spence Springs), and RV-5 (McCauley Hot Springs) discharge from recent volcanic rock west and south of the Valles Caldera (Fig. 1). The chemical concentrations and TDS in these thermal springs are low, as in all sodium and bicarbonate groundwater with the exception of water from the well at Location 47 (Fig. 5). Water from Location 47 is from a well completed in the Abo Formation, while other sources are from recent volcanics or alluvium. Aquifers in the Abo tend to have higher mineral concentrations than those in the alluvium or recent volcanos. There has been no significant change in chemical concentrations or TDS from individual stations during the period of record.

Sodium and chloride waters are found at Locations JF-1 and JF-5 (Fig. 6). Locations JF-1 and JF-5 are thermal and mineral springs that discharge along the Jemez Fault into the Jemez River. A series of thermal and mineral springs in this reach of the canyon affects the quality of water from the river, changing it from a sodium and bicarbonate water to a sodium and chloride water as found downgradient in the Jemez River at Locations R and S (Fig. 1). The spring at Location JF-5 contains TDS concentrations greater than at Location JF-1. Both springs contain high concentrations of naturally occurring arsenic and lithium (Appendix F). The quality of the hot springs has fluctuated slightly but has shown no significant change in quality for the period of record.

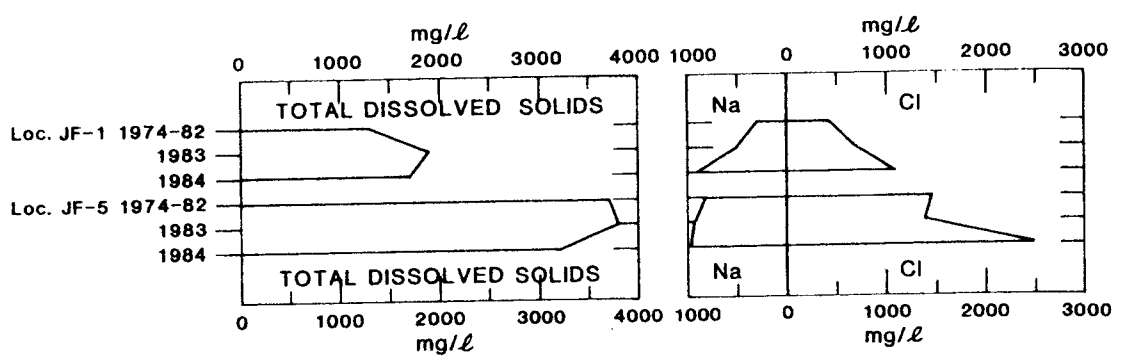

Fig. 6. Graphic comparison of TDS and predominant ions (sodium and chloride) in groundwater; mean to 1982, 1983, 1984.

Calcium and bicarbonate waters are found at Location 39, a spring fed stock tank in Lake Fork Canyon and at two wells at residual locations 42 and 48 in La Cueva (Fig. 7). Calcium and bicarbonate water locations 53, 54, and 55 are along Sulphur Creek, which furnishes a domestic supply to several houses. Water quality has remained about the same during the period of record.

The chemical quality of groundwater from springs and wells reflects the type of rock and length of time the water has been in contact with it from recharge to discharge (well or spring). Seasonal fluctuations in water quality occur as the result of recharge rate to the groundwater bodies. A comparison of the chemical data for the period of record through 1982 with 1983 and 1984 data reflects normal chemical changes (Figs. 5, 6, and 7).

IV. FENTON HILL WATER SUPPLY

The water supply (domestic and experimental use) for Fenton Hill is furnished by well FH-1 completed at a depth of about 450 ft into a perched aquifer. This aquifer is in the Abiquiu Tuff and is perched on the clays and siltstones of the Abo Formation. The aquifer is of limited extent, being terminated to the east along the canyon cut by San Antonio Creek. The water movement in the aquifer is to the southwest where a part is discharged through seeps and springs along the lower reaches of Lake Fork Canyon and Rio Cebolla. Water levels are monitored

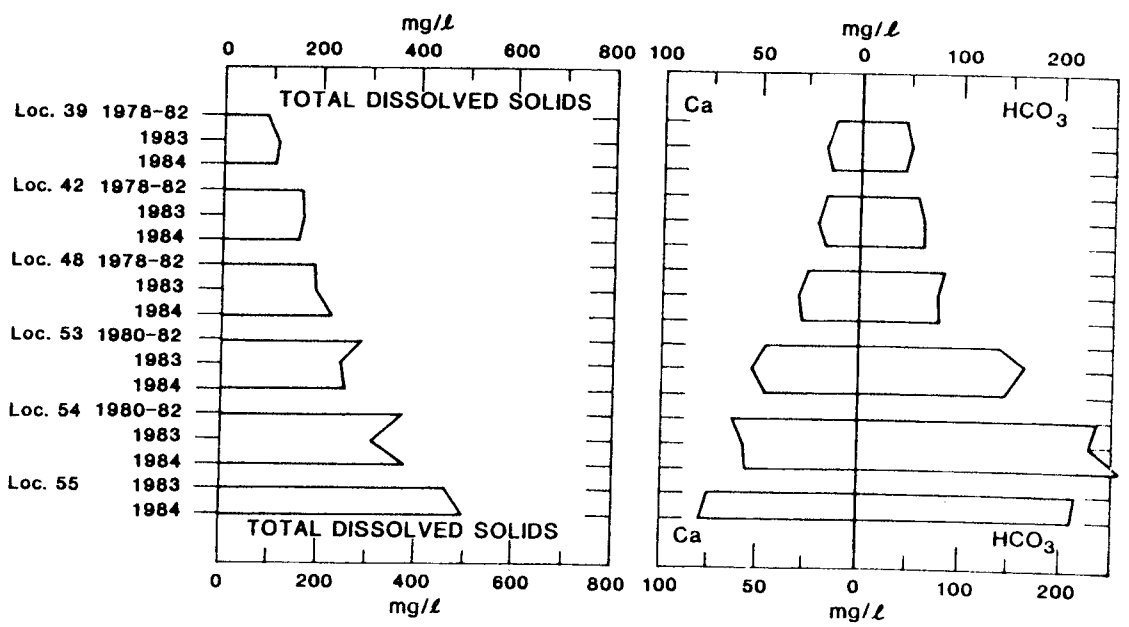

Fig. 7. Graphic comparison of TDS and predominant ions (calcium and bicarbonate) in groundwater; mean to 1982, 1983, and 1984.

in the supply well FH-1, and two observation wells, FH-2 and FH-3, which are completed through the aquifer to the top of the Abo Formation. Observation well FH-2 is located about 440 ft west-southwest of supply well FH-1, while FH-3 is located about 63 ft south of FH-1.

The supply well FH-1 was completed in November 1976. The production for the last 2 months of 1976 was 480 x 10^3 gal (Fig. 8). The annual production for 1977 to 1984 ranged from 2.5 x 10^6 gal (1977) to 7.2 x 10^6 gal (1980). The production in 1983 and 1984 was about 5.8 x 10^6 gal. The cumulative production from the well has been about 41.5 x 10^6 gal (Fig. 8).

The monthly production during 1983 and 1984 has ranged from 58 x 10^3 gal in September 1983 to 1803 x 10^3 gal in September 1984 (Fig. 9). The wide variation in monthly production is from variations in water supply for additional drilling or for use during tests using the circulation loop and hydrofracture reservoir at depth in the system. Water level trends in the supply well reflect the months of heavy pumpage (Fig. 10).

Average monthly water levels were compiled for the supply well FH-1 and observation wells FH-2 and FH-3 (Figs. 10 and 11). All wells are completed into the same aquifer, the Abiquiu Tuff. The water levels in FH-1 have declined from about 365 ft in 1976 to about 379 ft in 1984 (Fig. 10). The monthly water level fluctuation follows the monthly pumpage (Fig. 9). The cumulative effect of the pumpage has resulted in water level decline in the vicinity of the pumped well. Pumpage from the well has exceeded recharge. Water level decline in FH-1 is also reflected in FH-3. The water level decline in well FH-3 has been about 8 ft from

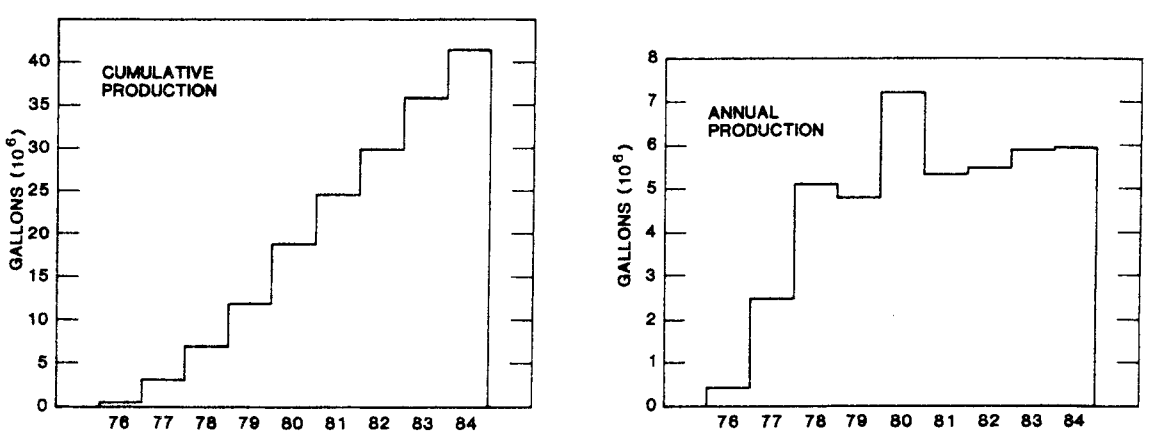

Fig. 8. Annual and cumulative production from Supply Well FH-1, Fenton Hill (TA-57), 1976-1984.

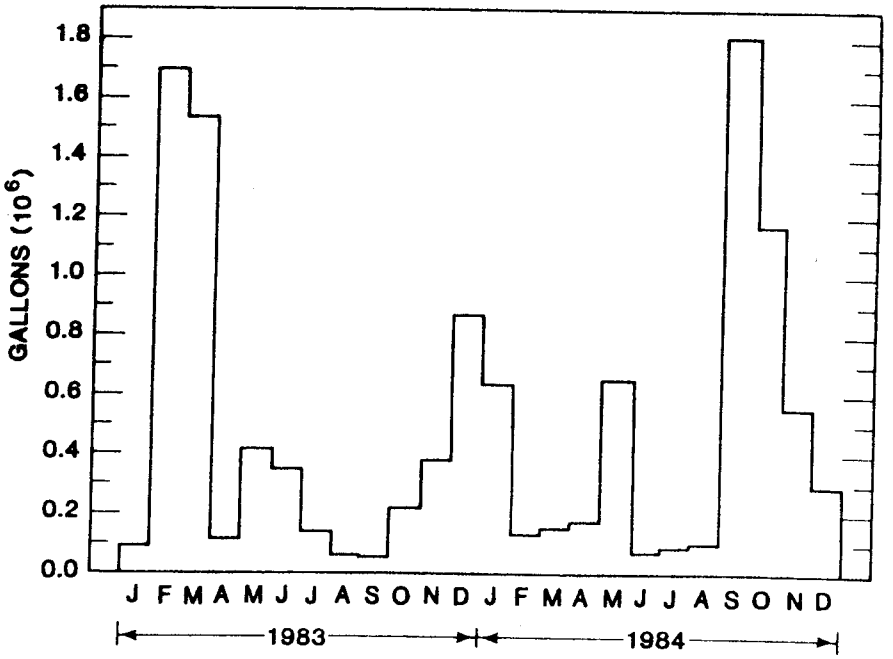

Fig. 9. Monthly production from Supply Well FH-1, Fenton Hill (TA-57), 1982-1984.

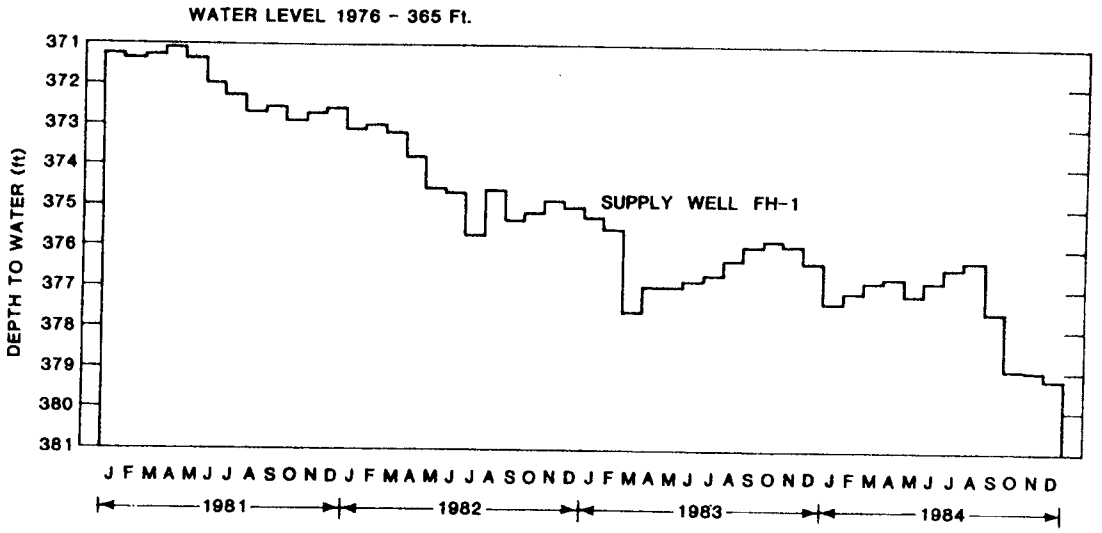

Fig. 10. Average monthly water levels in Supply Well FH-1, Fenton Hill (TA-57), 1981-1984.

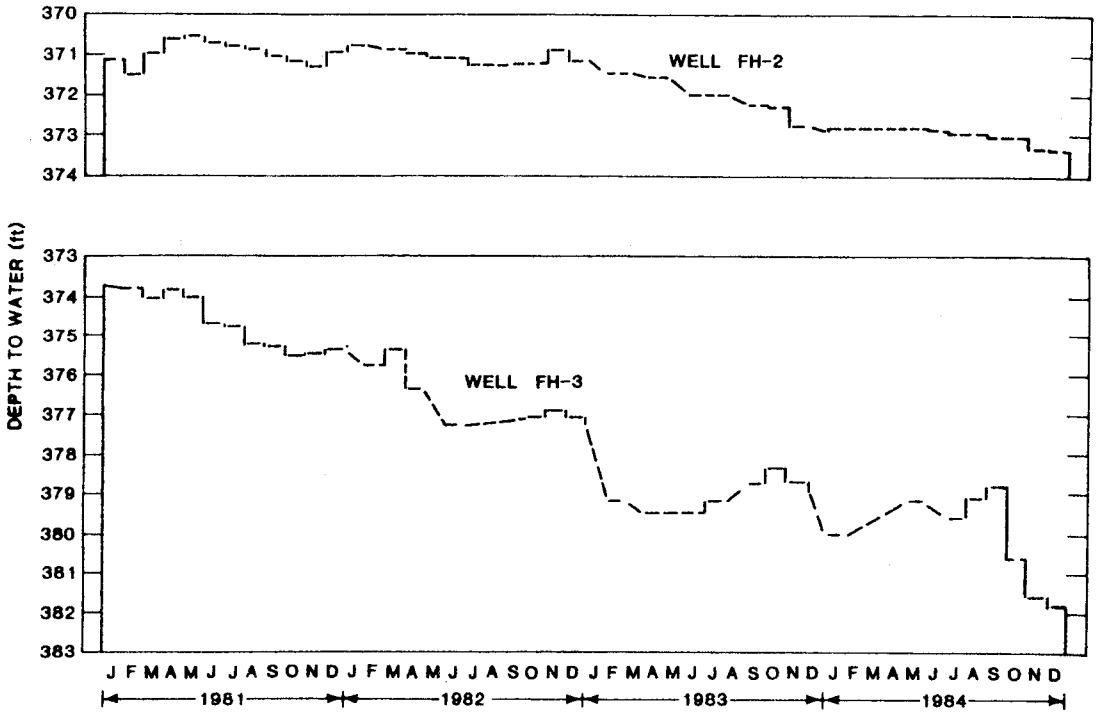

Fig. 11. Average monthly water levels in Wells FH-2 and FH-3, Fenton Hill (TA-57), 1981-1984.

January 1981 through December 1984. The decline in FH-2, at the greater distance from FH-1, has been affected the least with water levels declining about 3 ft from 1981 through 1984 (Fig. 11). The water level declines are normal under the current and past pumpage. The aquifer is not nearing depletion. The saturated thickness remaining at FH-1 and FH-3 is over 70 ft and at FH-2 is about 60 ft thick.

Calcium and bicarbonate are the predominant ions in water from supply well FH-1. There has been little change in bicarbonate concentrations from 1976-1984 (Fig. 12). The calcium concentration has increased abruptly from about 35 mg/ℓ in 1980 to 55 mg/ℓ in 1981. Since 1981 the calcium has decreased to about 40 mg/ℓ in 1984. The TDS has increased rather irregularly from 170 mg/ℓ in 1976 to over 300 mg/ℓ in 1980 and 1981. Since 1981, the TDS concentrations have decreased to about 220 mg/ℓ (Fig. 12). The increases in calcium and TDS are probably related to water level decline because water of slightly different quality was

pumped from the aquifer. This is a natural variation that can occur as different beds of the aquifer are being dewatered or as yield is being reduced with increased water level decline.

Water from well FH-1 was analyzed for chemical and radiochemical constituents for comparison with standards set by the USEPA for municipal or domestic use.[14,15] A comparison of the analytical results of the water from the well for 1983 and 1984 compared with federal and state standards shows that the constituents are below limits set for domestic use (Table I).

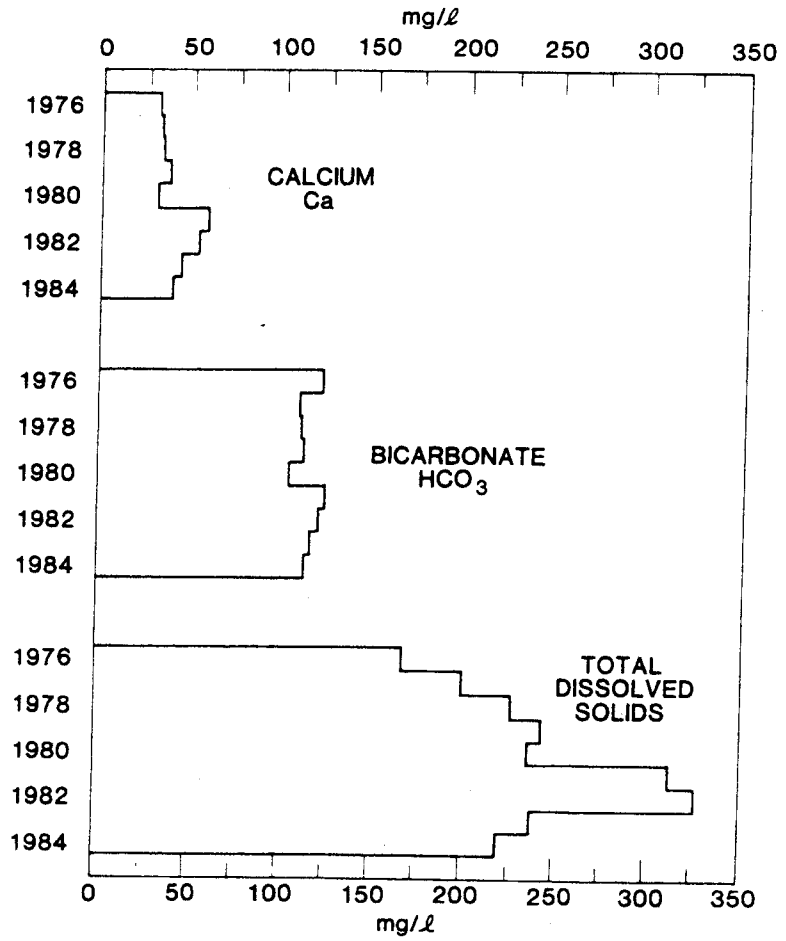

Fig. 12. Annual graphic comparison of predominant ions (calcium and bicarbonate) in groundwater from Supply Well FH-1; 1976 through 1984.

Table I. Chemical and Radiochemical Quality of Water from Supply Well FH-1, 1983 and 1984

Chemical Standards (mg/ℓ)	Supply Well FH-1 3-8-83	Supply Well FH-1 3-13-84[a]	Standard[b] or Criteria
Primary			
Ag	<0.005	<0.001	0.05
As	0.007	<0.003	0.05
Ba	0.02	0.07	1.0
Cd	<0.002	<0.002	0.01
Cr	0.012	0.001	0.05
F	1.0	0.1	2.0
Hg	<0.0002	<0.0001	0.002
NO_3	3.3	0.9	45
Pb	<0.003	<0.002	0.05
Se	<0.003	<0.003	0.01
Secondary			
Cl	5	20	250
Cu	<0.01	<0.1	1.0
Fe	0.045	0.011	0.3
Mn	<0.001	<0.001	0.05
SO_4	8	8	250
Zn	0.05	0.27	5.0
TDS	175	245	500
pH (no units)	8.4	8.2	6.5 – 8.5
Radiochemical Standards (pCi/ℓ)[b]			
^{3}H	<400	<1500	20,000
^{137}Cs	<98	<182	200
^{238}Pu	<0.014	<0.021	15
$^{239,240}Pu$	<0.068	<0.030	15
Gross Alpha	<3.9	<3.3	15

[a]Radiochemical analysis 8-16-84.
[b]Reference 14 and 15.

B. Vegetation and Soil Analyses

Drilling fluids and water from the circulation loop are stored in two ponds at the site. Periodically, these ponds are drained into the adjacent dry side canyon when additional storage is needed or drill cuttings are removed from the pond. This canyon drains to the southwest into Lake Fork Canyon. There was no discharge during 1983 and 1984. The water, when it is discharged, is under controlled conditions so that most is lost by evaporation or infiltration into the alluvium

within 400 ft of the outfall from the lower pond (see Appendix B for chemical quality of pond water). The accumulations of chemicals from the water released into the canyon vegetations and soils are monitored as part of the continued studies.

Samples of vegetation and soil from the channel bottom and the canyon bank below Pond GT-3 (Appendix B) have been collected annually, except for 1984, since 1978. The collected samples are analyzed for arsenic, boron, cadmium, fluoride, and lithium. The sampling locations are at distances of about 325, 650, 1300, and 3250 ft down canyon from the Pond GT-3 discharge point. An additional sample is collected from the canyon bottom far down the canyon at its junction with Lake Fork Canyon. Data collected to date are shown in Appendix G.

The 1983 fluoride data for roots and foliage generally represent a decrease from the 1982 data; however, fluoride in roots and foliage has been quite variable from year to year, so this is not necessarily indicative of any trend. The 1983 data for fluoride and lithium do not show the trend of decrease with progression down the canyon that has been evident in previous years. Data for 1983-84 for the other constituents has not been received and will be discussed in a subsequent report.

This may indicate that what appeared to be an accumulation of these elements immediately below the discharge point is dissipating now that discharges from the ponds have ceased. Subsequent year's data must be collected to ascertain if this is really true.

V. SUMMARY

During 1983 and 1984, the quality of surface and groundwater within the drainage of the Fenton Hill Site varied slightly; however, the variations are within normal seasonal fluctuations. The quality was within previous measured concentrations.

Production from the supply well in 1983 was 5.9×10^6 gal and in 1984 was 5.8×10^6 gal. Cumulative production since 1976 has been 41.5×10^6 gal. Pumpage from the well has exceeded recharge to the aquifer. The water level in FH-1 has declined from 365 ft in 1976 to 379 ft in 1984. Water level trends are normal as anticipated under current pumpage.

Monitoring of fluoride in roots and foliage shows a decrease in concentration gradient within progression down canyon, which may indicate dissipation of fluoride accumulations because there was no discharge from ponds in 1983 and 1984.

REFERENCES

1. W. D. Purtymun, F. G. West, and W. H. Adams, "Preliminary Study of the Quality of Water in the Drainage Area of the Jemez River and Rio Guadalupe," Los Alamos Scientific Laboratory report LA-5595-MS (April 1974).

2. W. D. Purtymun, "Geology of the Jemez Plateau West of the Valles Caldera," Los Alamos Scientific Laboratory report LA-5124-MS (February 1973).

3. W. D. Purtymun, F. G. West, and R. A. Pettitt, "Geology of Geothermal Test Hole GT-2 Fenton Hill Site, July 1974," Los Alamos Scientific Laboratory report LA-5780-MS (November 1974).

4. W. D. Purtymun, W. H. Adams, and J. W. Owens, "Water Quality in Vicinity of Fenton Hill Site, 1974," Los Alamos Scientific Laboratory report LA-6093 (December 1975).

5. W. D. Purtymun, W. H. Adams, A. K. Stoker, and F. G. West, "Water Quality in Vicinity of Fenton Hill Site, 1975," Los Alamos Scientific Laboratory report LA-6511-MS (September 1976).

6. W. D. Purtymun, W. H. Adams, and A. K. Stoker, "Water Quality in the Vicinity of Fenton Hill Site, 1976," Los Alamos Scientific Laboratory report LA-7307-MS (May 1978).

7. W. D. Purtymun, A. K. Stoker, W. H. Adams, and J. W. Owens, "Water Quality in Vicinity of the Fenton Hill Site, 1977," Los Alamos Scientific Laboratory report LA-7468-PR (September 1978).

8. W. D. Purtymun, R. W. Ferenbaugh, A. K. Stoker, W. H. Adams, and J. W. Owens, "Water Quality in the Vicinity of Fenton Hill Site, 1978," Los Alamos Scientific Laboratory report LA-8217-PR (January 1980).

9. W. D. Purtymun, R. W. Ferenbaugh, A. K. Stoker, and W. H. Adams, "Water Quality in the Vicinity of Fenton Hill, 1979," Los Alamos Scientific Laboratory report LA-8424-PR (June 1980).

10. W. D. Purtymun, R. W. Ferenbaugh, and W. H. Adams, "Water Quality in the Vicinity of Fenton Hill, 1980," Los Alamos National Laboratory report LA-9007-PR (September 1981).

11. W. D. Purtymun, R. W. Ferenbaugh, N. M. Becker, W. H. Adams, and M. N. Maes, "Water Quality in the Vicinity of Fenton Hill, 1981 and 1982," Los Alamos National Laboratory report LA-9854-PR (September 1983).

12. N. M. Becker, W. D. Purtymun, and W. C. Balance, "Aquifer Evaluation at Fenton Hill, October and November 1980," Los Alamos National Laboratory report LA-8964-MS (October 1981).

13. US Environmental Protection Agency, "Methods for Chemical Analysis of Water and Wastes," Office of Technology Transfer, EPA-600/4-79-020, Washington, DC (1979).

14. US Environmental Protection Agency, "National Interim Primary Drinking Water Regulations," Office of Water Supply, EPA-570/9-76-003 (1976).

15. US Environmental Protection Agency, "National Secondary Drinking Water Regulations," Federal Register **44**, No. 140 (July 19, 1979).

APPENDIX A

GEOLOGY AND HYDROLOGY OF TEST HOLES PC-1 AND PC-2

Two test holes were drilled on Forest Service Land near the Fenton Hill Site. The purpose of the test holes was for placement of geophones for the site seismic operations and to obtain as much geologic and hydrologic information as possible while drilling from the volcanic and sedimentary formations. Both holes were completed in the sediments just above the Precambrian Rock. The two test holes were drilled by cable tool by Maness Drilling Company of Farmington, New Mexico. Data for this section were furnished by D. J. Miles, ESS-1.

Test Hole PC-1

The Hole PC-1 is in the upper reach of Lake Fork Canyon in SW 1/4 Sec. 18, T19N, R3E. Elevation of the drill site is ~8,400 ft - about 300 ft lower than the Fenton Hill Site located about 3700 ft west-northwest of that hole. The hole was drilled from October through December 1983. Geologic and hydrologic notes are found in Table A-I.

The test hole penetrated in order from top to bottom - overburden, the Bandelier Tuff, Abo Formation, and Madera Limestone. It was completed in a granite wash above the Precambrian rock at a depth of 2178 ft. No geophysical logs were run of the hole, thus formation correlations are based on lithology of cuttings from the test hole. The formations log penetrated by the Test Hole PC-1 are compared with a similar log of Granite Test (GT-2) at the Fenton Hill Site. The following table presents a comparison of thickness and depths of the formations at PC-1 and GT-2.

	PC-1 (ft)		GT-2 (ft)	
	Thickness	Top of Unit Depth	Thickness	Top of Unit Depth
Overburden	12	0	--	--
Bandelier Tuff	181	12	460	0
Abo Formation	814	193	770	460
Madera Limestone	1202	1007	1174	1230
Top of Precambrian		2178	(est)	2404

Table A-I. Geologic and Hydrologic Notes on Test Hole PC-1

Interval or Depth (ft)	Formation	Estimated Yield	Remarks
225	Abo	1 gpm	Quality good (see sample No. 1, Table A-II).
386-391	Abo	35 gpm	Quality good (see sample No. 2, Table A-II).
558-578	Abo	--	Static WL 285 ft; probably penetrated aquifer in unconsolidated sand; no quality data; static WL 285 ft.
685-691	Abo	26 gpm; could not bail dry	Quality fair (see sample No. 3, Table A-II); static WL 605 ft.
1100-1105	Madera	10 gpm	Quality poor (see sample No. 4, Table A-II); water in probable fractures; static WL 1011 ft; temp. 46°C.
1247-1251	Madera	--	Water in probable cavernous limestone; no quality data.
1396-1405	Madera	1 gpm	Static WL 1050 ft; no quality data.
1425-1431	Madera	--	Coarse, loose sand; may be thief zone as static WL dropped from 1050 ft to 1310 ft.
1511	Madera	1 gpm	--
1712	Madera	--	Quality poor (see sample No. 5, Table A-II; may reflect quality of water from several above water-bearing zones.

This table presents a comparison of elevations at the top of the formations.

	Elevation	
	PC-1 (ft)	GT-2 (ft)
Overburden (land surface)	8400	---
Bandelier Tuff	8388	8702 (land surface)
Abo Formation	8207	8242
Madera Limestone	7393	7472
Top of Precambrian (est)	6191	6298 (est)

Several water-bearing beds were encountered in the Abo Formation and Madera Limestone. No aquifers were encountered in the Bandelier Tuff. Abiquiu Tuff (aquifer at Fenton Hill) was not penetrated at PC-1. To keep the hole open while drilling with the cable tool, the casing was run in conjunction with the drilling as deeper drilling progressed. Using this method, the casing above would shut off water-bearing zones and therefore would allow lower zones to be tested for yield and water samples to be collected for chemical quality. Table A-I outlines interval or depth of water-bearing beds, yield, and remarks about static water levels (WL) of the water-bearing beds penetrated. Data on selected chemical constituents from water-bearing beds in the Abo and Madera Formations are presented in Table A-II.

The tops of the formations are eroded and thus are not suitable for making structural comparisons. Based on a good marker bed, an arkosic sand, encountered in PC-1 at 1575 ft and encountered in GT-2 at 1770 ft, the formations in PC-1 are structurally about 107 ft lower than in GT-2. A north-south trending fault west of PC-1 is downfaulted to the east and probably accounts for the offset. The marker bed was used to estimate the elevation at the top of the Precambrian.

The quality of water deteriorates with increasing depth within the Abo Formation and Madera Limestone. The temperature of the water increases with depth. For example, water in the zone 1100 to 1105 ft was 46°C, while at the aquifer at Fenton Hill at a depth of 360 to 460 ft, the temperature was 22°C.

Test Hole PC-2

Test Hole PC-2 is located on the mesa west of the Fenton Hill Site in the SW 1/4 of Sec. 13, T19N, R2E about 3000 ft west-southwest of the Fenton Hill Site. Elevation of the land surface is about 8,623 ft. The hole was drilled from August

Table A-II. Chemical Quality of Water from Water-Bearing Beds in Test Holes PC-1 and PC-2

Test Hole	Sample Number	Depth (ft)	Formation	mg/ℓ										Cond (μmho)	pH
				SiO_2	Ca	Mg	Na	CO_3	HCO_3	SO_4	Cl	F	NO_3		
PC-1	1	225	Abo	52	14	4	29	7	118	7	5	0.4	<1	225	8.4
PC-1	2	396	Abo	53	9	2	30	0	110	6	5	0.3	1	200	8.1
PC-1	3	691	Abo	16	6	4	366	13	852	24	5	2.1	1	1325	8.4
PC-1	4	1100	Madera	30	78	73	740	0	2636	24	50	6.8	<1	3700	7.6
PC-1	5	1712	Madera	225	762	52	1390	0	1133	2157	1602	1.1	<1	9500	7.2
PC-2	6	600	Abo	16	5	3	257	19	715	45	3	2.0	<1	1190	8.5
PC-2	7	635	Abo	14	4	3	308	21	749	45	4	2.0	<1	1240	8.7
PC-2	8	1086	Abo	10	6	3	290	18	537	80	64	3.1	12	1260	---
PC-2	9	1356	Madera	32	80	80	403	0	1698	79	36	2.1	<1	2310	---
PC-2	10	1490	Madera	30	96	62	562	0	1729	178	45	6.5	<1	2610	---

Note: Samples PC-1 collected 10-83 to 12-83
Samples PC-2 collected 8-84 to 12-84

through December 1984 by Maness Drilling Company. Geologic and hydrologic notes are found in Table A-III.

Table A-III. Geologic and Hydrologic Notes of Test Hole PC-2

Interval or Depth	Formation	Estimated Yield	Remarks
589-600	Abo	16 gal/hour increasing to 45 gal/hour at 645 ft	Quality fair (see sample Nos. 6 and 7, Table A-II).
830-840	Abo	100 gal/hour	Quality reported fair.
1070-1090	Abo	Mudded off	Quality fair (see sample No. 8, Table A-II).
1310-1330	Madera	87 gal/hour	Quality poor, (see sample Nos. 9 and 10, Table A-II).

The test hole penetrated in order from top to bottom - the Bandelier Tuff and Abo Formation and was completed into the Madera Limestone at a depth of 1825 ft, cased to 1819 ft. While drilling at a depth of 1825 ft, the hole encountered a pocket of gas and the hole blew out. The hole was extensively damaged by the blowout. The cleanup and stemming of the gas setting casing took almost 2 months. The gas was a mixture of air, CO_2, and H_2S, with a discharge measured at about 1.6 x 10^6 ft^3/day. The H_2S concentration was about 500 ppm, a nonflammable but toxic mixture.

No geophysical logs were run of the hole, thus formation correlations are based on lithology of cuttings from the test hole. The formation logs penetrated by Test Hole PC-2 are compared with similar logs of Granite Test (GT-2) at Fenton Hill.

This table presents a comparison of thickness and depth of the formations at PC-1 and GT-2.

	PC-1 (ft)		GT-2 (ft)	
	Thickness	Top of Unit Depth	Thickness	Top of Unit Depth
Bandelier Tuff	394	0	460	0
Abo Formation	737	394	770	460
Madera Limestone	1149	1131	1174	1230
Top of Precambrian	(Est)	2280	-	2404

This table presents a comparison of elevations at the top of the formations.

	Elevation	
	PC-1 (ft)	GT-2 (ft)
Bandelier Tuff (Land Surface)	8623	8702
Abo Formation	8229	8242
Madera Limestone	7492	7472
Top of Precambrian (est)	6343	6298

The estimate depth to top of the Precambrian rocks in PC-2 is based on a correlation of a siliceous limestone marker bed in PC-2 and GT-2. It occurs at a depth of 1761 ft in PC-2 and at 1880 ft in GT-2. The bed in PC-2 is about 40 ft higher than occurs in GT-2. Thus it should be about 455 ft more (present depth PC-2 1825 ft + 455 ft = 2280 ft) to the top of the Precambrian.

Several water-bearing beds were encountered in the Abo Formation and Madera Limestone. No aquifers were penetrated in the Bandelier Tuff. Abiquiu Tuff (aquifer at Fenton Hill) was not penetrated at PC-2. Casing driven as drilling progressed to deeper depth allowed selected water-bearing beds to be tested for yield and also allowed collection of water samples for chemical quality. Table A-III outlines interval or depth of water-bearing beds, yield, and remarks. Selected chemical constituents from water-bearing beds in the Abo and Madera are presented in Table A-III.

The quality of water deteriorated with increasing depth from the Abo into the Madera Limestone.

APPENDIX B

CHEMICAL QUALITY OF WATER FROM THE SUPPLY WELL AND STORAGE PONDS AT FENTON HILL

The chemical quality of water from the supply well and ponds is monitored to document the quality as well as to monitor to see if changes occur over a period of time. Chemical quality data are required for environmental studies and to determine chemical type of water used in testing of the circulation loop. Data for this section were furnished by Pat Trujillo and Dale Counce, ESS-1.

Supply Well

The supply well at the Fenton Hill Site is located near the eastern edge of the site compound. It supplies water for domestic use, drilling, and tests in the circulation loop of the geothermal system. The annual production for 1983 and 1984 was about 5.8×10^6 gal. During 1983-84, eight water samples were collected and analyzed for chemicals. Select chemical constituents are reported in Table B-I.

The water is a calcium bicarbonate type. The specific conductance, a measure of mineral content, ranged from 290 to 360 μmho with an average of 315 μmho. The quality of the water is good, mineral concentrations are low, suitable for domestic and industrial use (Table B-I). The concentration of individual constituents have varied slightly during 1983 and 1984. No trends in chemical concentrations are evident for these two years. The variations reflect the duration of pumpage before the sample was collected.

Storage Ponds

There are two ponds located in the compound west of the supply well. Pond GT-1 has a capacity of about 500,000 gal and is located north of Pond GT-3. Pond GT-3 has a capacity of about 200,000 gal. The pond designation used in this report is consistent with usage in past water quality monitoring reports. Pond GT-2 between GT-1 and GT-3 was small and therefore filled in to enlarge the area for storage and trailers (Fig. B-I). A 5,000,000 gal lined pond outside the compound is not considered, as leakage from it would be minor if it occurred.

The Pond GT-1 is used for holding water for drilling and for the experimental test circulation in the loop. During drilling operations the cuttings are discharged into the pond. The cuttings have been changed out of the pond several

Table B-I. Chemical Quality of Water from the Supply Well and Storage Ponds at Fenton Hill

		mg/ℓ														Spec Cond	
	Date	SiO_2	Ca	Na	Mg	CO_3	HCO_3	SO_4	Cl	F	NO_3	As	B	Cd	Li	(μmho)	pH
Supply Well FH-1	3-17-83	70	42	5	15	0	137	10	28	<0.1	<0.1	<0.001	0.15	<0.001	0.03	330	7.7
	3-24-83	70	43	4	16	0	143	11	30	<0.1	0.1	<0.001	0.17	<0.001	0.03	360	7.5
	5-26-83	65	39	4	15	0	140	8	16	0.1	<0.1	<0.001	0.18	<0.001	0.08	320	7.8
	6-29-83	70	41	5	16	0	139	10	22	<0.1	<0.1	<0.001	0.17	<0.001	—	320	7.5
	8-1-83	72	38	4	16	0	140	9	20	0.1	<0.1	<0.001	0.24	<0.001	<0.05	300	7.7
	9-1-83	71	35	4	15	0	142	9	19	<0.1	<0.1	<0.050	0.12	<0.001	<0.05	290	7.7
	11-7-83	71	39	4	15	0	137	11	21	0.1	0.6	<0.100	0.32	<0.001	0.10	290	7.5
	2-2-84	71	41	4	15	0	139	8	22	0.1	0.8	<0.100	0.19	<0.001	0.11	320	7.8
	$\bar{X}$	70	40	4	14	0	140	10	22	<0.1	<0.3	<0.032	0.19	<0.0001	<0.06	315	7.6
	SD	2	3	0.5	4	—	2	1	5	~	0.3	0.045	0.06	—	0.03	25	0.1
Pond GT-1	4-14-83	110	35	2	1480	0	1623	180	1858	6.9	<0.1	2.5	50	0.003	19.5	8400	7.7
	5-27-83	128	33	3	1580	0	1621	128	1639	6.1	<0.1	1.1	50	0.003	23.0	8200	8.2
	6-28-83	114	31	4	1610	0	1620	145	1720	6.5	<0.1	1.9	47	<0.001	19.5	7800	8.1
	8-1-83	113	31	4	1560	85	1464	134	906	7.1	<0.1	1.6	46	<0.001	18.5	7400	8.6
	9-1-83	106	29	3	1370	78	1290	125	1402	5.5	<0.1	44	1.0	<0.001	16.6	6700	8.6
	11-7-83	113	36	4	1084	0	1039	110	1560	4.2	<0.1	0.8	37	<0.001	17.2	5900	7.8
	12-14-83	194	77	3	1270	0	693	215	1656	9.1	<0.1	5.1	45	<0.001	23.1	6300	7.6
	2-23-84	86	51	3	700	0	711	129	930	6.4	<0.1	2.2	19	<0.001	11.5	3300	7.7
	3-26-84	94	49	3	700	0	503	103	880	5.4	<0.1	1.1	14	<0.001	11.7	3700	7.4
	5-14-84	99	57	4	300	0	508	118	860	5.5	<0.1	1.4	22	<0.001	10.8	3300	8.2
	$\bar{X}$	116	43	3	1165	<16	1107	139	1341	6.3	<0.1	1.9	37	<0.001	17	6100	8.0
	SD	30	15	1	455	34	473	34	401	1.3	—	1.3	14	0.001	4	2004	0.4
Pond GT-3	4-19-83	30	26	3	122	0	200	33	115	0.8	0.2	<0.2	3.5	0.001	1.0	810	8.0
	5-25-83	40	26	3	95	0	192	21	81	0.6	<0.1	0.1	2.1	0.003	0.7	660	7.6
	6-28-83	46	31	4	96	13	167	25	91	0.6	0.2	<0.2	2.1	<0.001	0.8	675	8.6
	8-1-83	46	30	4	96	0	198	24	89	0.7	<0.1	<0.2	2.1	<0.001	0.7	660	8.0
	9-1-83	31	25	3	71	0	152	22	72	0.6	<0.1	<0.2	1.6	<0.001	0.6	530	8.3
	$\bar{X}$	39	28	3	96	<2.6	182	25	90	0.7	<0.3	<0.2	2.3	<0.001	0.8	670	8.1
	S	8	3	0.5	18	5.8	21	5	16	0.09	0.4	0.4	0.7	0.001	0.2	100	0.4
Pond GT-3	7-2-84	11	27	3	266	0	73	108	340	0.7	<0.1	<0.2	1.8	<0.001	0.2	380	7.6

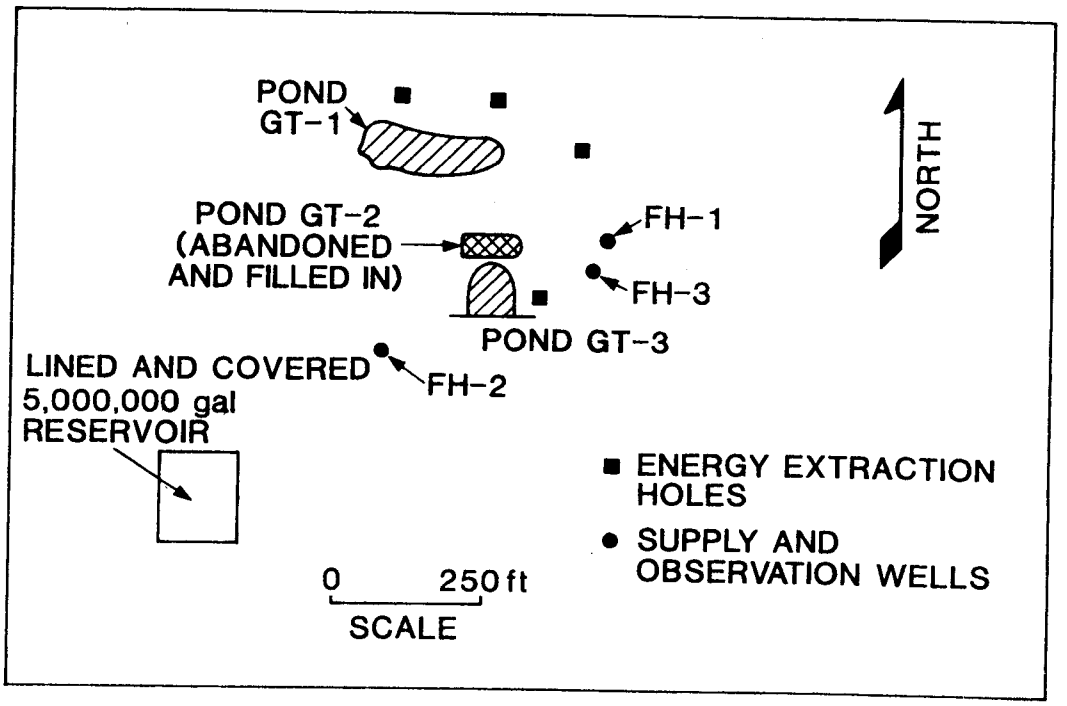

Fig. B-1. Map showing locations of ponds, energy extraction holes, and observation and supply wells.

charged into the pond. The cuttings have been changed out of the pond several times in the past few years. The pond was lined with plastic during 1983 and 1984; however, the liner deteriorated with time.

Water quality changes in relation to the operations that are being carried out in the two systems. Each system consists of two deep holes to each system. Drilling muds and chemical and other compounds used during periods of drilling operation are released into the pond along with the drill cuttings. Circulating water in the loop during tests of the system is recycled through the pond. The water circulating through the hot rock reservoir picks up minerals from the rock reservoir.

As a result, the water in Pond GT-1 is highly mineralized. It is a sodium chloride type water. The specific conductance ranges from 3300 to 8400 μmho with an average of 6100 μmho for 1983 and 1984 (Table B-I). The 6100 μmho is equivalent to TDS of about 4000 mg/ℓ. Most of the constituents reported in Table B-I (with the exception of calcium, magnesium, nitrate, and cadmium) were in concentrations greater than in surface and spring water in Lake Fork Canyon. The general trend of the two years, 1983 and 1984, was a general decline in concentrations of most constituents. This may be because of the addition of fresh "make-up"

water to the pond or because of some precipitation of some minerals in the ponds or circulation loop.

Pond GT-3 was filled with water until August 1984. The pond was constructed in a small canyon cut into the mesa. The pond was drained in August 1984. The dam breached; the cuttings in the bottom of pond were allowed to dry out. The cuttings were removed to form a part of the dam that was repaired in 1984.

The water in the pond during 1983 was a sodium bicarbonate type. The specific conductance ranged from 530 to 810 μmho with an average of 670 μmho. The 670 μmho is equivalent to a TDS of 435 mg/ℓ. This pond does collect some runoff from the area to the west, north, and east. The relative fresh water entering the pond probably caused some dilution as illustrated by a general decline of most chemical concentrations during the year. For example, the specific conductance (the measure of minerals in water) declined from 810 to 530 μmho during 1983. Water quality in pond GT-3 is quite good when compared with Pond GT-1. The one sample in 1984 (July) indicated a continued decline of specific conductance to 380 μmho (Table B-I).

APPENDIX C

PREDOMINANT IONS AND TOTAL DISSOLVED SOLIDS IN SURFACE WATER

Station	Year	Number of Samples	mg/ℓ		
			Na	Cl	TDS
Loc. U (Redondo Creek)	1974-1982	18	16 ± 9	32 ± 23	165 ± 68
	1983	1	13	8	77
	1984	1	10	20	117
Loc. R (Jemez River)	1974-1982	28	63 ± 29	78 ± 41	396 ± 108
	1983	1	78	102	428
	1984	1	68	92	364
Loc. S (Jemez River)	1974-1982	22	76 ± 30	95 ± 47	427 ± 115
	1983	1	78	102	380
	1984	1	74	91	376
			Ca	HCO_3	TDS
Loc. N (San Antonio Creek)	1974-1982	21	16 ± 4	62 ± 17	163 ± 34
	1983	1	16	60	139
	1984	1	13	55	126
Loc. T (Rio Cebolla)	1974-1982	20	18 ± 3	72 ± 16	132 ± 21
	1983	1	20	75	102
	1984	1	19	74	156
Loc. Q (Rio Guadalupe)	1974-1982	21	44 ± 12	143 ± 48	222 ± 78
	1983	1	49	150	207
	1984	1	45	139	212
Loc. LF-1 (Lake Fork Canyon)	1978-1982	6	15 ± 3	49 ± 19	151 ± 38
	1983	1	14	45	89
	1984	1	19	60	152
Loc. LF-2 (Lake Fork Canyon)	1978-1982	7	19 ± 2	72 ± 23	192 ± 53
	1983	1	16	55	116
	1984	1	20	80	183
Loc. LF-3 (Lake Fork Canyon)	1978-1982	8	13 ± 2	59 ± 5	129 ± 25
	1983	1	14	65	133
	1984	1	13	55	97
Loc. LF-4 (Lake Fork Canyon)	1978-1982	8	17 ± 2	73 ± 6	145 ± 19
	1983	1	16	70	142
	1984	1	13	71	110
			Ca	SO_4	TDS
Loc. V Sulphur Creek)	1974-1982	18	62 ± 24	248 ± 110	482 ± 169
	1983	1	60	325	442
	1984	1	54	295	518
Loc. F (Sulphur Creek)	1974-1982	21	34 ± 13	91 ± 52	242 ± 91
	1983	1	25	62	150
	1984	1	29	94	169
			Na	HCO_3	TDS
Loc. J (Jemez River)	1974-1982	22	16 ± 7	63 ± 16	152 ± 27
	1983	1	20	60	131
	1984	1	16	57	168

APPENDIX D

PREDOMINANT IONS AND TOTAL DISSOLVED SOLIDS IN GROUNDWATER

Station	Year	Number of Samples	mg/ℓ		
			Na	HCO_3	TDS
JS-2,3 (springs)	1974-1982	21	15 ± 2	77 ± 11	180 ± 32
	1983	1	23	97	151
	1984	1	17	90	200
JS-4,5 (springs)	1974-1982	21	15 ± 2	77 ± 12	170 ± 19
	1983	1	20	85	164
	1984	1	17	84	174
Loc. 4 (well)	1974-1982	21	17 ± 4	67 ± 7	169 ± 23
	1983	1	38	130	190
	1984	1	32	140	220
Loc. 6 (spring)	1978-1982	8	19 ± 4	85 ± 6	189 ± 27
	1983	1	27	100	188
	1984	1	22	98	235
Loc. 31 (spring)	1974-1982	21	13 ± 3	63 ± 5	146 ± 43
	1983	1	17	60	97
	1984	1	13	59	111
Loc. 47 (well)	1974-1982	9	215 ± 32	526 ± 20	649 ± 21
	1983	1	274	520	610
	1984	1	242	538	662
Loc. RV-2 (Hot Spring)	1975-1982	8	23 ± 2	49 ± 3	155 ± 22
	1983	1	26	50	154
	1984	1	23	48	145
Loc. RV-4 (Hot Spring)	1975-1982	9	51 ± 5	115 ± 6	231 ± 35
	1983	1	53	115	231
	1984	1	54	119	230
Loc. RV-5 (Hot Spring)	1975-1982	9	20 ± 2	73 ± 4	150 ± 24
	1983	1	23	75	137
	1984	1	20	70	148
			Na	Cl	TDS
Loc. JF-1 (Hot Spring)	1974-1982	21	275 ± 77	410 ± 116	1301 ± 247
	1983	1	500	690	1902
	1984	1	925	1100	1754
Loc. JF-5 (Hot Spring)	1974-1982	22	820 ± 145	1457 ± 68	3746 ± 259
	1983	1	925	1400	3876
	1984	1	965	2500	3268
			Ca	HCO_3	TDS
Loc. 39 (Spring-Tank)	1978-1982	9	13 ± 2	41 ± 12	89 ± 16
	1983	1	17	50	106
	1984	1	15	41	102
Loc. 42 (well)	1978-1982	9	12 ± 1	74 ± 2	165 ± 15
	1983	1	14	75	166
	1984	1	13	75	158
Loc. 48 (well)	1978-1982	7	22 ± 1	92 ± 3	190 ± 21
	1983	1	25	90	191
	1984	1	25	86	228
Loc. 53 (well)	1980-1982	5	44 ± 4	145 ± 9	286 ± 53
	1983	1	50	170	247
	1984	1	43	152	254
Loc. 54 (well)	1980-1982	4	59 ± 3	247 ± 17	370 ± 40
	1983	1	55	235	310
	1984	1	53	259	376
Loc. 55 (well)	1983	1	73	220	460
	1984	1	78	213	500

APPENDIX E

SURFACE WATER QUALITY 1983 AND 1984

Station	Location	Date	SiO_2	Ca	Mg	K	Na	CO_3	HCO_3	SO_4	Cl	F	NO_3	TDS	Total Hard	As	Li	Spec Cond (µmho)	pH
			(mg/ℓ)																
F	Sulphur Creek	11/83	29	25	1	5.0	13	0	25	62	8	0.2	0.4	150	68	0.001	0.03	190	6.3
F	Sulphur Creek	11/84	36	29	5	7.2	13	0	4	44	28	0.2	2.0	169	92	<0.001	0.04	290	6.4
J	Jemez River	11/83	49	15	1	1.0	20	0	60	9	2	0.7	0.3	131	43	0.004	0.07	130	7.3
J	Jemez River	11/84	53	13	2	1.5	16	0	57	10	3	1.6	1.6	168	40	0.004	0.07	160	7.7
N	San Antonio Creek	11/83	57	16	2	1.0	20	0	60	35	1	1.0	0.3	139	50	0.005	0.07	145	7.6
N	San Antonio Creek	11/84	53	13	3	2.7	15	0	55	10	4	1.3	1.4	126	42	0.002	0.03	145	7.3
Q	Rio Guadalupe	11/83	25	49	3	2.0	20	0	150	8	2	0.5	0.4	207	135	0.002	0.03	290	7.7
Q	Rio Guadalupe	11/84	28	45	1	2.7	12	0	139	7	5	0.4	1.4	212	128	<0.001	0.03	300	8.1
R	Jemez River	11/83	48	43	4	11	78	0	160	16	102	1.1	0.3	428	125	0.105	0.97	590	8.1
R	Jemez River	11/84	49	38	4	2.2	68	0	142	13	92	1.1	1.4	364	104	1.51	0.07	580	8.2
S	Jemez River	11/83	51	45	3	12	78	0	165	15	102	1.1	0.3	380	125	0.105	0.96	640	8.1
S	Jemez River	11/84	56	31	4	12	74	0	142	38	91	1.4	1.0	376	96	0.084	0.78	580	8.1
T	Rio Cebolla	11/83	37	20	2	3.0	15	0	75	5	1	0.4	0.3	102	58	<0.001	0.02	150	7.3
T	Rio Cebolla	11/84	40	19	2	2.6	12	0	74	5	4	0.4	1.3	156	59	0.003	0.01	170	7.8
U	Redondo Creek	11/83	28	15	1	1.0	13	0	40	8	8	0.1	0.4	77	43	0.001	0.07	110	7.0
U	Redondo Creek	11/84	39	15	2	2.9	10	0	39	12	20	0.1	2.2	117	44	<0.001	0.05	160	7.4
V	Sulphur Creek	11/83	55	60	12	9.0	25	0	0	325	3	0.4	0.5	442	200	0.008	0.04	590	3.2
V	Sulphur Creek	11/84	60	54	8	11	19	0	0	295	3	0.4	1.5	518	166	<0.001	0.03	640	3.6
LF-1	Lake Fork (6085)[a]	11/83	29	14	3	2.0	9	0	45	14	2	0.3	0.3	89	48	<0.001	0.03	120	5.8
LF-1	Lake Fork (6085)[a]	11/84	42	19	3	4.7	7	0	60	13	5	0.3	1.6	152	59	0.001	0.01	160	7.1
LF-2	Lake Fork (7285)[a]	11/83	29	16	1	2.0	13	0	55	7	2	0.5	0.3	116	45	<0.001	0.03	130	6.0
LF-2	Lake Fork (7285)[a]	11/84	54	20	3	5.4	13	0	80	10	7	0.6	1.5	183	56	0.005	0.02	200	7.6
LF-3	Lake Fork (8500)[a]	11/83	57	14	1	3.0	17	0	65	5	1	1.1	1.5	133	40	0.001	0.04	130	6.3
LF-3	Lake Fork (8500)[a]	11/84	64	13	2	2.4	13	0	55	5	5	1.1	2.7	97	36	0.002	0.02	145	7.6
LF-4	Lake Fork (9420)[a]	11/83	53	16	2	3.0	19	0	70	5	3	1.1	0.7	142	50	<0.001	0.05	160	6.8
LF-4	Lake Fork (9420)[a]	11/84	53	13	3	2.9	16	0	71	5	6	1.1	2.1	110	43	0.012	0.01	170	7.6

[a]Number represents meters below Lower Pond (GTP-3) in Lake Fork Canyon.

Note: Cadmium in all samples (1983-1984) was less than 0.001 mg/ℓ.

APPENDIX F

GROUNDWATER QUALITY 1983 AND 1984

Station	Location	Date	SiO_2	Ca	Mg	K	Na	CO_3	HCO_3	SO_4	Cl	F	NO_3	TDS	Total Hard	As	Li	Spec Cond (µmho)	pH
			(mg/l)																
JS-2,3	Jemez Village (Spr)	11/83	72	20	3	<0.5	23	0	97	4	2	0.5	1.1	151	63	0.002	0.01	170	7.3
JS-2,3	Jemez Village (Spr)	11/84	68	20	3	5.5	17	0	90	8	5	0.5	3.2	200	63	<0.001	0.03	195	8.2
JS-4,5	Jemez Village (Spr)	11/83	70	19	2	1.0	20	0	85	4	2	0.5	0.3	164	58	0.001	0.04	170	7.3
JS-4,5	Jemez Village (Spr)	11/84	72	17	3	1.1	17	0	84	4	4	0.5	0.6	174	56	0.002	0.03	180	8.1
FH-1	Fenton Hill (Well)	11/83	70	41	2	4.0	17	0	115	7	18	<0.1	1.1	236	113	0.003	0.04	270	6.8
FH-1	Fenton Hill (Well)	11/84	71	38	4	4.6	13	0	112	8	22	<0.1	2.4	219	107	0.009	0.03	280	7.7
JF-1	Jemez Canyon (Hot Spr)	11/83	48	182	16	59	500	0	660	30	690	2.5	1.4	1902	520	0.007	5.1	2930	6.8
JF-1	Jemez Canyon (Hot Spr)	11/84	64	100	27	68	925	0	730	28	1100	2.5	3.4	1754	364	0.004	7.0	3120	7.6
JF-5	Jemez Canyon (Hot Spr)	11/83	47	148	21	196	925	0	730	36	1400	3.5	0.4	3876	455	1.65	13	5960	6.5
JF-5	Jemez Canyon (Hot Spr)	11/84	42	116	24	182	965	0	1236	20	2500	3.2	1.7	3268	390	1.49	13	5230	8.0
RV-2	San Antonio (Hot Spr)	11/83	77	5	2	2.0	26	0	50	7	1	0.7	1.3	154	23	0.003	0.04	110	6.7
RV-2	San Antonio (Hot Spr)	11/84	88	5	<1	1.1	23	0	48	6	3	0.7	3.3	145	12	0.007	0.04	115	7.9
RV-4	Spence (Hot Spr)	11/83	65	8	1	2.0	53	0	115	15	5	0.8	0.4	231	23	0.060	0.95	260	7.5
RV-4	Spence (Hot Spr)	11/84	72	7	2	1.4	54	0	119	—	—	0.7	1.5	230	25	0.056	0.66	260	8.0
RV-5	McCauley (Hot Spr)	11/83	55	10	5	<0.5	23	0	75	6	2	1.0	1.9	137	45	0.023	0.41	160	7.8
RV-5	McCauley (Hot Spr)	11/84	63	9	4	0.9	20	0	70	5	4	0.9	3.1	148	40	0.021	0.29	140	9.2
Loc. 4	La Cueva (Well)	11/83	65	22	4	5.0	38	0	130	5	2	0.5	1.6	190	73	0.002	<0.01	250	6.7
Loc. 4	La Cueva (Well)	11/84	63	20	4	6.9	32	0	140	5	6	0.5	3.3	220	69	0.004	0.03	260	8.5
Loc. 6	La Cueva (Spr)	11/83	70	23	5	1.0	27	0	100	18	2	0.5	1.3	188	80	0.026	0.02	230	6.5
Loc. 6	La Cueva (Spr)	11/84	62	26	1	4.4	22	0	98	4	4	0.5	2.1	235	70	0.011	0.03	255	8.3
Loc. 31	Lake Fork (Spr)	11/83	52	15	3	3.0	17	0	60	6	1	0.9	1.1	97	50	<0.001	0.04	135	6.6
Loc. 31	Lake Fork (Spr)	11/84	53	15	2	7.4	13	0	59	5	6	1.1	2.7	111	43	0.004	0.02	155	7.9
Loc. 39	Lake Fork (Tank)	11/83	26	17	3	2.0	8	0	50	13	1	0.1	0.8	106	55	<0.001	0.03	130	5.7
Loc. 39	Lake Fork (Tank)	11/84	34	15	4	2.3	4	0	41	15	7	0.1	2.2	102	52	<0.001	<0.01	130	7.8
Loc. 42	La Cueva (Well)	11/83	73	14	5	2.0	16	0	75	3	1	0.3	0.3	166	58	0.003	<0.01	150	6.2
Loc. 42	La Cueva (Well)	11/83	69	13	5	4.5	11	0	75	4	2	0.3	1.7	158	54	0.014	0.01	160	7.9
Loc. 47	La Cueva (Well)	11/83	22	7	4	5.0	274	0	520	22	1	3.2	0.8	610	33	0.005	0.10	950	8.0
Loc. 47	La Cueva (Well)	11/84	22	7	3	14.0	242	0	538	21	3	2.9	1.6	662	30	<0.001	0.15	960	8.3
Loc. 48	La Cueva (Well)	11/83	62	25	3	3.0	25	0	90	18	5	0.8	0.8	191	75	0.001	0.03	220	6.5
Loc. 48	La Cueva (Well)	11/84	62	25	4	5.1	21	0	86	22	8	0.7	2.3	228	79	<0.001	<0.01	250	7.1
Loc. 53	Sulphur Creek (Well)	11/83	66	50	7	4.0	23	0	170	19	1	0.4	0.8	247	153	0.007	0.03	345	6.5
Loc. 53	Sulphur Creek (Well)	11/84	55	43	6	2.1	13	0	152	11	4	0.4	1.6	254	120	0.012	0.02	320	7.1
Loc. 54	Sulphur Creek (Well)	11/83	61	55	9	4.0	46	0	235	14	2	0.4	1.0	310	173	0.006	0.05	455	6.6
Loc. 54	Sulphur Creek (Well)	11/84	62	53	10	—	42	0	259	16	5	0.4	1.6	376	111	<0.001	0.06	470	7.3
Loc. 55	Sulphur Creek (Well)	11/83	84	73	10	16	48	0	220	90	15	0.5	0.4	460	223	0.022	0.14	625	6.5
Loc. 55	Sulphur Creek (Well)	11/84	90	78	6	18	50	0	213	109	5	0.4	1.5	500	221	0.009	0.12	640	7.1

APPENDIX G

CHEMICAL ANALYSIS OF VEGETATION AND SOILS IN EFFLUENT RELEASE AREA, FENTON HILL

	Arsenic (ppm)				
Sample Location	**1978**	**1979**	**1980**	**1981**	**1982**
Foliage (bank)					
325 ft	0.13	<0.04	<0.08	0.11	0.02
650 ft	0.14	<0.04	<0.04	0.08	0.03
1300 ft	0.06	<0.02	<0.05	0.35	0.08
3300 ft	<0.05	<0.03	<0.03	<0.06	0.10
Foliage (channel)					
325 ft	0.22	0.44	<0.06	<0.11	0.23
650 ft	<0.05	0.21	<0.06	0.09	0.16
1300 ft	0.12	<0.04	<0.05	0.45	0.04
3300 ft	0.34	<0.05	<0.04	0.24	0.08
lower canyon	0.08	<0.04	<0.04	0.30	0.14
Roots (bank)					
325 ft		2.24	0.41	3.75	1.82
650 ft		0.67	0.12	2.18	1.57
1300 ft		0.45	0.76	2.87	1.62
3300 ft		0.78	0.35	5.72	0.88
Roots (channel)					
325 ft		0.97	8.37	13.3	8.47
650 ft		5.39	5.86	5.69	6.99
1300 ft		1.86	2.13	6.47	9.31
3300 ft		1.60	0.31	1.93	1.53
lower canyon		0.41	0.27	1.06	0.62
Soil (bank)					
325 ft			3.10	2.80	3.10
650 ft			4.20	3.30	3.10
1300 ft			3.30	4.20	3.90
3300 ft			4.80	3.60	5.40
Soil (channel)					
325 ft			8.40	4.90	11.7
650 ft			3.40	3.70	17.1
1300 ft			5.70	3.80	12.1
3300 ft			2.40	2.50	2.90
lower canyon			3.20	3.40	2.80

APPENDIX G (cont)

Sample Location	Boron (ppm) 1978	1979	1980	1981	1982
Foliage (bank)					
325 ft		<25	32	15	11
650 ft		<25	30	14	13
1300 ft		<25	9	20	32
3300 ft		<25	9	12	9
Foliage (channel)					
325 ft		150	173	210	188
650 ft		286	182	110	434
1300 ft		350	113	130	110
3300 ft		26	18	13	12
lower canyon		<25	10	15	13
Roots (bank)					
325 ft		14	9	42	29
650 ft		<5	<5	29	37
1300 ft		9	13	28	30
3300 ft		8	<5	35	34
Roots (channel)					
325 ft		13	56	73	114
650 ft		21	64	140	139
1300 ft		28	34	61	130
3300 ft		20	9	36	30
lower canyon		<5	<5	21	32
Soil (bank)					
325 ft			10	16	14
650 ft			13	16	23
1300 ft			19	15	17
3300 ft			23	15	31
Soil (channel)					
325 ft			31	38	49
650 ft			42	51	104
1300 ft			36	17	54
3300 ft			18	15	18
lower canyon			20	19	15

APPENDIX G (cont)

Sample Location	Cadmium (ppm) 1978	1979	1980	1981	1982
Foliage (bank)					
325 ft	<500	270	100	<20	
650 ft	<500	190	290	28	
1300 ft	<500	140	30	47	
3300 ft	<500	270	110	55	
Foliage (channel)					
325 ft	<500	170	340	120	
650 ft	<500	150	370	53	
1300 ft	<500	150	140	83	
3300 ft	<500	190	170		
lower canyon	<500	150	210	49	
Roots (bank)					
325 ft		180	680	180	
650 ft		310	550	100	
1300 ft		180	660	170	
3300 ft		320	390		
Roots (channel)					
325 ft		40	400	200	
650 ft		290	460	530	
1300 ft		350	190	260	
3300 ft		390	340	330	
lower canyon		380	720	320	
Soil (bank)					
325 ft			170	130	80
650 ft			170	170	160
1300 ft			110	110	80
3300 ft			290	160	510
Soil (channel)					
325 ft			250	160	210
650 ft			220	170	440
1300 ft			290	150	220
3300 ft			80	130	210
lower canyon			200	140	140

APPENDIX G (cont)

Sample Location	Fluoride (ppm) 1978	1979	1980	1981	1982	1983
Foliage (bank)						
325 ft		2.40		6.70	12.0	0.50
650 ft		13.0		1.80	170	1.90
1300 ft		0.50		6.00	10.0	1.00
3300 ft		1.20		3.80	1.80	3.00
Foliage (channel)						
325 ft		3.30		19.0	70.0	1.20
650 ft		1.20		2.70	84.0	3.30
1300 ft		8.80		11.0	8.40	2.90
3300 ft		0.80		6.00	19.0	1.90
lower canyon		0.30		5.20	28.0	3.40
Roots (bank)						
325 ft		66.0		45.0	45.0	8.10
650 ft		28.0		28.0	52.0	31.0
1300 ft		25.0		59.0	40.0	20.0
3300 ft		23.0		46.0	43.0	16.0
Roots (channel)						
325 ft		50.0		92.0	78.0	16.0
650 ft		34.0		96.0	170	25.0
1300 ft		78.0		70.0	61.0	22.0
3300 ft		47.0		52.0	37.0	10.0
lower canyon		14.0		34.0	77.0	40.0
Soil (bank)						
325 ft				90.0	121	98.0
650 ft			80.0	150	151	71.0
1300 ft			95.0	130	106	100
3300 ft			160	140	130	120
Soil (channel)						
325 ft			420	350	279	135
650 ft			140	250	459	115
1300 ft			180	170	249	81.0
3300 ft			105	160	129	100
lower canyon			210	180	202	120

APPENDIX G (cont)

Sample Location	Lithium (ppm) 1978	1979	1980	1981	1982	1983
Foliage (bank)						
325 ft	1.93	0.80	44.0	1.22	0.80	0.29
650 ft	1.93	0.80	3.40	0.85	0.70	0.55
1300 ft	0.69	3.30	0.38	2.10	1.30	1.30
3300 ft	1.00	0.80	0.86	0.75	0.60	0.28
Foliage (channel)						
325 ft	3.50	46.0	29.9	51.7	0.60	17.0
650 ft	9.10	109	15.9	32.0	10.0	66.0
1300 ft	12.9	239	53.0	19.2	4.80	28.0
3300 ft	1.93	2.60	2.50	0.61	1.50	5.10
lower canyon	1.00	2.60	0.35	4.30	0.60	8.90
Roots (bank)						
325 ft		6.80	2.00	23.4	0.70	4.40
650 ft		3.00	1.30	19.1	0.70	13.0
1300 ft		4.60	1.90	19.9	0.90	5.70
3300 ft		2.20	1.80	3.70	1.10	6.70
Roots (channel)						
325 ft		2.10	15.0	43.0	2.90	5.00
650 ft		4.90	8.70	15.8	2.70	4.00
1300 ft		12.0	12.0	6.00	2.20	10.0
3300 ft		5.20	2.20	4.50	0.90	2.10
lower canyon		3.90	4.0	3.60	1.50	15.0
Soil (bank)						
325 ft			35.1	29.7	10.0	15.0
650 ft			32.1	30.3	28.0	30.0
1300 ft			29.2	29.3	22.0	18.0
3300 ft			33.1	25.9	27.0	26.0
Soil (channel)						
325 ft			57.7	44.5	37.0	28.0
650 ft			35.9	35.3	39.0	38.0
1300 ft			38.9	31.6	39.0	43.0
3300 ft			29.2	30.6	21.0	30.0
lower canyon			39.9	39.7	33.0	51.0