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Environmental Geochemistry for Surface and Subsurface Waters in the Pajarito Plateau and Outlying Areas, New Mexico

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Cover photo: View looking north into White Rock Canyon, Rio Grande. Many cold springs from the main aquifer discharge from sedimentary rocks near the bottom of the canyon.

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ENVIRONMENTAL GEOCHEMISTRY FOR SURFACE AND SUBSURFACE WATERS IN THE PAJARITO PLATEAU AND OUTLYING AREAS, NEW MEXICO

by

Wayne D. Blake, Fraser Goff, Andrew I. Adams, and Dale Counce

ABSTRACT

This report contains a data base of major element, trace element, and isotope analyses of 130 water samples from 94 different springs, wells, and water bodies located in and around Los Alamos National Laboratory, New Mexico. Most waters in the study are calcium-bicarbonate waters. Well waters in the region generally have higher concentrations of conservative constituents than local surface waters because of their greater temperatures and ages at depth. Anthropogenic contamination, mixing with deep water, or significant water movement among aquifers can cause some cooler surface waters to actually become the most enriched in conservative constituents.

The sites most impacted by man are located within Pueblo, Los Alamos, and DP Canyons, where the most likely contaminant sources are the older Laboratory facilities on the town mesa. Other impacted areas include the San Ildefonso reservation, where fertilizer and stock seem the most likely contaminant sources, and the southwestern part of the Laboratory, which at places shows slightly elevated lead. Only two samples in nitrate and three samples in lead exceed the EPA drinking water limits for any of the most common contaminants. Locations with tritium concentrations above 300 T.U. caused by Laboratory activities include DP Spring at TA-21 (≤845 T.U.), the sewage outfall water at TA-21 (2800 T.U.), the drains at TA-33 (>1500 T.U.), and water residing in Test Well 2A (700 T.U. ^3H in 1992 and 1993).

The stable isotope analyses of waters in this study place the $\delta D/\delta^{18}O$ ratio of most samples on or near the World Meteoric Water Line of Craig (1961) and the parallel Jemez Mountains line of Vuataz and Goff (1986). The stable isotopes indicate that most waters discharging in White Rock Canyon and located under the Pajarito Plateau and San Ildefonso reservation have been precipitated locally, or, possibly, have migrated from the north. These waters are isotopically different from those precipitated in the Valles Caldera and higher elevations in the Jemez Mountains. Waters in the confined aquifer decribed by Purtymun and Johansen (1974) have probably migrated from the Sangre de Cristo Mountains via western dipping strata in the Española Basin.

I. INTRODUCTION

This report provides background information on waters in the Los Alamos and Santa Fe regions of northern New Mexico. Specifically, the presented data include major element, trace element, and isotope analyses of 130 water samples from 94 different springs, wells, and water bodies in the area. The region considered in this study extends from the western edge of the Valles Caldera to as far east as Santa Fe Lake, ranging from about 35° 13' N to 35° 58' N in latitude, as shown in Figure 1. Plate 1 shows the immediate Laboratory area where most of the sampling points are located. For each sample, the presented analysis includes fourteen different major elements, twenty-six trace elements, up to five stable isotopes, and tritium. In addition, this data base contains certain characteristics of the water that are calculated from the aforementioned raw data, including the water's maximum and minimum residence times, as found from tritium levels assuming no contamination, the water's recharge elevation, as found from stable isotopes, and

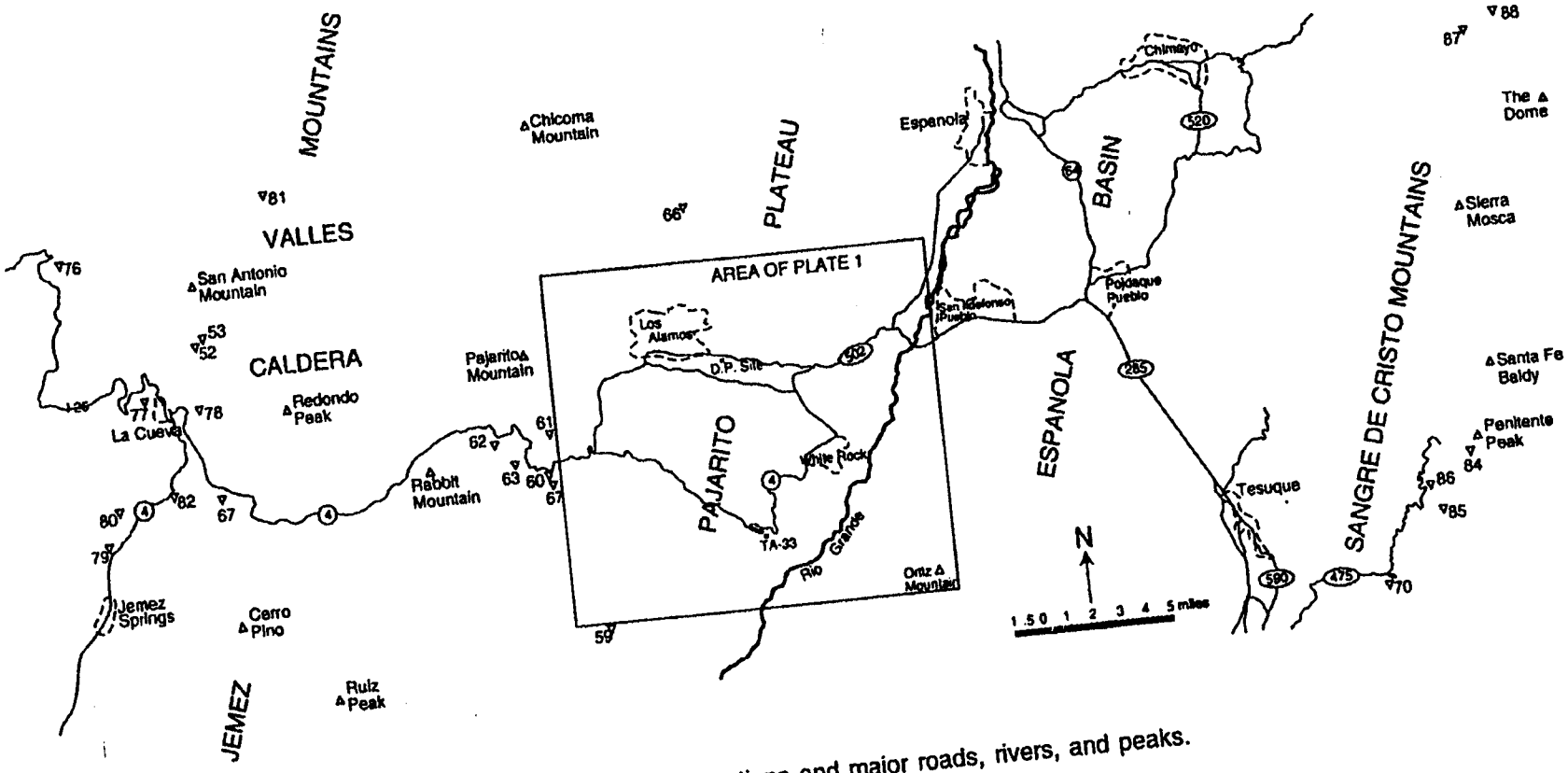

Figure 1: Location map of study area, showing sampling locations and major roads, rivers, and peaks. Samples within rectangular area are shown on detailed map of Plate 1.

the charge balance of the water.

The data in this report are meant to provide background information for investigations in groundwater hydrology and geochemistry, and for environmental projects. For the latter projects, the presented information would be useful for determining the presence of contamination at any one location by enabling one to compare potential contaminant levels to the background levels presented here. Likely locations of interest are those possibly effected by anthropogenic activities, including locations in and around Los Alamos National Laboratory, White Rock Canyon, and developed areas in the Rio Grande Valley.

II. GEOLOGY AND BACKGROUND

The study area encompasses parts of the Jemez Mountains, the Española Basin, and the Sangre De Cristo Mountains, falling mostly within the Rio Grande rift tectonic province. The Sangre de Cristo Mountains consist of Precambrian granite, gneiss, and schist overlain by Paleozoic sedimentary rocks. In the Española Basin, Tertiary-Quaternary rift-fill sediments overlie the Paleozoic to Mesozoic sedimentary sequences of the Colorado Plateau and Precambrian crystalline rocks; these sediments thicken closer to the rift axis in the studied area (Shevenell et al., 1987).

In the the Jemez Mountains, Tertiary and Quaternary lavas and tuffs overlie the same sedimentary sequence of the Colorado Plateau and similar Precambrian crystalline units (Goff et al.,1989). Volcanic activity responsible for this overlying sequence happened in the Jemez Mountains from >13 to 0.13 Ma, commencing with mostly mafic to intermediate lava flows and domes, followed by two major eruptions of Bandelier rhyolite tuff in the early Pleistocene, ending with eruptions of rhyolite domes, obsidian, and tuffs in the moat zone of the caldera (Gardner et al., 1986). The Jemez Mountains occur at the intersection of the Rio Grande rift and the northeast-trending axis of the Jemez Lineament (Goff et al., 1989). The geology of the Jemez Mountains has been further described by Ross et al. (1961), Smith et al. (1961), Griggs (1964), Doell et al. (1968), Bailey et al. (1969), Laughlin (1981), Laughlin et al. (1983), Gardner and Goff (1984), Heiken and Goff (1983), Nielson and Hulen (1984), Heiken et al. (1986), and Self et al. (1986).

Two major fault zones control the deeper groundwater movement in the western part of the region. The Jemez fault zone acts as a conduit for geothermal waters leaving the Valles Caldera towards the southwest, and the Pajarito fault zone acts as a barrier preventing geothermal water from moving eastward toward the Rio Grande rift (Goff and Sayer, 1980; Goff et al., 1981). Many aquifers to the east of the faults lie in Tertiary and younger units, especially in the nonindurated sandstones of the Sant Fe Group (Purtymun and Johansen 1974), while those aquifers between the two fault zones commonly lie just above the Abo or Precambrian units that act as aquitards (Trainer 1974). Some wells of the Los Alamos well field are completed in a confined aquifer whose source is probably to the east, and yield water under artesian pressure (Goff and Sayer, 1980).

Previous studies of the geohydrology of the area have provided similar chemical analyses on the waters of the region, including Shevenell et al. (1987), which focused on water sources in the southern Jemez Mountains. Meeker et al. (1990) studied many springs and creeks in the Sulphur Springs area of the Valles Caldera in an effort to monitor possible contaminants from a scientific drilling project. Also in the Jemez Mountains, in a different type of study, Vuataz and Goff (1986) evaluated over 100 stable isotope and tritium analyses to define processes and age limitations on regional groundwater systems.

III. METHODS AND PROCEDURES FOR COLLECTION AND ANALYSIS OF WATERS

The analyzed samples were taken over a four year period between 1990 and 1993. Many locations were sampled more than once at times separated by at least a year. The sampling procedure was consistent throughout the study: four separate samples (minimum) were taken at a given location and time. Two were left unfiltered for stable isotope and tritium analyses, and two were filtered for chemical analysis. Filtering was done using a hand-operated vacuum pump system. The two filtered samples to be used for chemical analysis were each poured into 125 ml polyethylene bottles, after which one was acidified with ten drops of HNO_3 to bring the pH to below 2, and then both samples were sealed with Polyseal caps. The tritium sample was poured into one 500 ml polyethylene bottle with a Polyseal cap, and the stable isotope sample was poured into a 30 ml glass bottle, also with a Polyseal cap. Care was taken to avoid air in the unacidified samples.

Data recorded in the field include pH, temperature, flow rate, and rock type (Table 1). Laboratory pH values are not considered accurate of field conditions because many waters gain or lose CO_2 gas after sampling and before laboratory analysis. This change in gas concentration alters the bicarbonate ion concentration, which in turn changes the pH (Shevenell et al. 1987). Field values of pH were determined using limited-range indicator strips (ColorpHast brand nos. 9581, 9582, and 9583). Temperatures in the field were recorded with a Fluke brand 52 K/J thermometer and probe. Flow rates of springs were visually estimated or measured approximately with a bucket and stopwatch; presented flow rates of wells came from measurements provided by the well owners or operators.

Chemical analyses were determined using the following methods: Al, Ba, Ca, Fe, K, Li, Mg, Mn, Na, Si, Sr, and Zn were analyzed by inductively coupled plasma (ICP) emission spectroscopy. SiO_2 concentrations were then calculated from Si content. Ag, Al^{+3}, As, Cd, Co, Cr, Cu, Cs, Mo, Ni, Pb, and Rb values were determined by atomic absorption (AA) spectroscopy using a graphite furnace. Br, Cl, F, NO_3, PO_4, and SO_4 contents were measured by ion chromatography. F was analyzed by selective ion electrode if there was interference using the chromatography. Low-level Na and K content were measured by flame atomic absorption. HCO_3^- and CO_3^{-2} contents were determined by titration with H_2SO_4, and S^{-2}, NH_4, and O_2 (dissolved) were analyzed with electrodes (Trujillo et al., 1987).

Oxygen-18 and deuterium analyses were performed by Mike Colucci of the Stable Isotope Laboratory, Southern Methodist University, Dallas, Texas. Tritium analyses were provided by H. Gote Ostlund of the Tritium Laboratory at the University of Miami. Carbon-13 analyses of bicarbonate were obtained from Geochron Laboratories, Cambridge, Massachusetts. Strontium isotope analyses were determined by the Geology Department, University of New Mexico.

IV. FLUID GEOCHEMISTRY

For purposes of this report, the waters analyzed in this study are sub-divided according to their sampling locations into six groups: (1) samples from DP Spring and DP Canyon, (2) samples from springs and streams in White Rock Canyon, (3) waters from wells and springs on the Pajarito Plateau, (4) samples from wells in and near the San Ildefonso Indian Reservation, (5) miscellaneous samples taken from a wide range of locations west and east of the areas already mentioned, and (6) samples from Seismic Hazards Borehole #3, located on the S site in TA-16. The reader should refer to Figures 2 through 5 and 11 through 15 for graphical representations of the chemical and isotopic data. These figures are referred to frequently in this report.

The results from three of these groups are particularly significant to local communities. DP Spring is located downstream from TA-21, a location of past nuclear research; thus, any potential contaminants released from that site could appear in the spring water there. Some wells drilled on the Pajarito Plateau supply the drinking water for LANL, Los Alamos, and White Rock; so they are of obvious interest to the local population. Similarly, waters near the San Ildefonso Reservation provide drinking water and irrigation for the inhabitants located there.

A. Major Cation/Anion Analysis

The results of the major cation/anion chemical analyses of the samples are presented in Table 2. From this data, Figure 2 is a triangular plot of weight percent bicarbonate, chloride, and sulfate, with chloride and sulfate concentrations multiplied by 10. Most waters in the study are calcium-bicarbonate waters. Exceptions include some sodium-bicarbonate waters from within the Los Alamos water-supply wells and from cold mineral springs in the Valles Caldera and sulfate-rich waters found in the west of the caldera.

The data in Table 2 provide further important information on waters in the study. Notable in the table is that the well waters tend to be warmer than surface waters because they come from deeper sources where they are more responsive to the high regional temperature gradients of 25-55°C/km (Reiter et al., 1975). This increased temperature at depth causes them to be slightly richer than surface waters in cations and anions highly influenced by solubility, such as chloride, bromide, and boron. Further, the well waters' increased depth usually means they are older, and thus have probably been exposed to soluble matter for longer periods of time, which can further increase their conservative constituent content. Figures 3 and 4 display this relationship between well water and surface waters. The figures show bromide and boron

TABLE 1. Location and Field Data for Waters in the Pajarito Plateau and Outlying Areas, New Mexico

Map No.	Description	Sample No.	Date	Location		Temp. (°C)	Field pH	Flow rate (l/min)	Rock type[a]
DP SPRING (TA-21)									
1	DP Spring, DP Canyon	PP-1	05/30/90	LAT LONG.	35 52'29" 106 15'44"	8.4	6.5	2	BT
1	DP Spring, DP Canyon	PP-2	08/10/90	LAT LONG.	35 52'29" 106 15'44"	9.8	6.5	15	BT
1	DP Spring, DP Canyon	PP-4	09/06/90	LAT LONG.	35 52'29" 106 15'44"	16.0	6.5	4	BT
1	DP Spring, DP Canyon	VA-345	05/15/91	LAT LONG.	35 52'29" 106 15'44"	11.4	5.8	1	BT
1	DP Spring, DP Canyon	VA-363	06/26/91	LAT LONG.	35 52'29" 106 15'44"	8	5.8	8	BT
1	DP Spring, DP Canyon	VA-364	07/11/91	LAT LONG.	35 52'29" 106 15'44"	8.4	5.8	25	BT
1	DP Spring, DP Canyon	VA-383	05/18/92	LAT LONG.	35 52'29" 106 15'44"	9.5	6.5	1	BT
1	DP Spring, DP Canyon	VA-395a	11/92	LAT LONG.	35 52'29" 106 15'44"	—	—	2	BT
1	DP Spring, DP Canyon	PP93-28	05/26/93	LAT LONG.	35 52'29" 106 15'44"	7.3	6.6	2	BT
1	DP Spring, DP Canyon	PP93-29	06/24/93	LAT LONG.	35 52'29" 106 15'44"	5.8	—	1	BT
1	DP Spring, DP Canyon	PP93-30	07/24/93	LAT LONG.	35 52'29" 106 15'44"	6.3	—	15	BT
1	DP Spring, DP Canyon	PP93-32	10/06/93	LAT LONG.	35 52'29" 106 15'44"	9.6	—	2	BT
2	TA-21 Outfall	PP-3	08/10/90	LAT LONG.	35 52'41" 106 16'28"	18.5	—	0-20	—
2	TA-21 Outfall	PP-13	10/22/90	LAT LONG.	35 52'41" 106 16'28"	—	7.0	0-20	—
2	TA-21 Outfall	VA-346	05/15/91	LAT LONG.	35 52'41" 106 16'28"	12.3	6.0	0-15	—
WHITE ROCK CANYON SPRINGS									
3	Spring 2	Spring 2	11/91	LAT LONG.	35 52'4" 106 9'7"	<20	—	—	SF
4	Spring 3	PP-5	09/24/90	LAT LONG.	35 48'24" 106 11'40"	<20	7.9	—	SF
4	Spring 3	Spring 3	11/91	LAT LONG.	35 48'24" 106 11'40"	<20	—	—	SF
5	Spring 3b	PP-6	09/24/90	LAT LONG.	35 48'35" 106 10'41"	<20	9.1	—	SF
5	Spring 3b	Spring 3b	11/91	LAT LONG.	35 48'35" 106 10'41"	<20	—	—	SF
6	Spring 4a	Spring 4a	11/91	LAT LONG.	35 48'08" 106 11'48"	<20	—	—	SF
7	Spring 6	Spring 6	11/91	LAT LONG.	35 46'13" 106 13'11"	<20	—	—	SF
8	Spring 6a	PP-7	09/25/90	LAT LONG.	35 46'2" 106 13'33"	<20	8.8	—	SF
8	Spring 6a	Spring 6a	11/91	LAT LONG.	35 46'2" 106 13'33"	<20	—	—	SF
9	Spring 7	PP-8	09/25/90	LAT LONG.	35 45'52" 106 14'2"	<20	7.2	—	SF
9	Spring 7	Spring 7	11/91	LAT LONG.	35 45'53" 106 14'2"	<20	—	—	SF
10	Spring 8	PP-9	09/25/90	LAT LONG.	35 45'51 106 14'9"	<20	8.9	—	SF
10	Spring 8	Spring 8	11/91	LAT LONG.	35 45'51 106 14'9"	<20	—	—	SF
11	Spring 8b	PP-10	09/26/90	LAT LONG.	35 45'52" 106 14'23"	<20	7.4	—	SF
12	Spring 9a	Spring 9a	11/91	LAT LONG.	35 45'51" 106 14'31"	<20	—	—	SF
13	Doe Spring	PP-11	09/25/90	LAT LONG.	35 45'55" 106 14'38"	<20	8.1	—	CR
13	Doe Spring	ER-E	—	LAT LONG.	35 45'55" 106 14'38"	—	—	—	CR
14	Ancho Spring	PP-12	09/25/90	LAT LONG.	35 46'30" 106 13'39"	<20	7.0	—	SF
14	Ancho Spring	Ancho Spring	11/91	LAT LONG.	35 46'30" 106 13'39"	<20	—	—	SF

Map No.	Description	Sample No.	Date	Location		Temp. (°C)	Field pH	Flow rate (l/min)	Rock Type[a]
PAJARITO PLATEAU WELLS									
15	Pajarito Mesa Well #1	VA-373	10/23/91	LAT LONG.	35 51'34 106 13'29"	28.2	7.3	0-2320	SF
15	Pajarito Mesa Well #1	PM-1	08/18/92	LAT LONG.	35 51'34 106 13'29"	27.5	6.9	0-2320	SF
16	Pajarito Mesa Well #2	PM-2	08/18/92	LAT LONG.	35 50'17" 106 15'42"	3.3	7.5	0-5520	SF
16	Pajarito Mesa Well #2	PP93-15	05/19/93	LAT LONG.	35 50'17" 106 15'42"	22.4	7.2	0-5520	SF
17	Pajarito Mesa Well #3	PM-3	08/18/92	LAT LONG.	35 51'47" 106 14'31"	24.4	7.7	0-5600	SF
17	Pajarito Mesa Well #3	PP93-20	05/19/93	LAT LONG.	35 51'47" 106 14'31"	27.7	7.7	0-5600	SF
18	Pajarito Mesa Well #5	VA-372	10/23/91	LAT LONG.	35 51'31" 106 16'27"	4.7	7.2	0-5200	SF
18	Pajarito Mesa Well #5	PM-5	08/18/92	LAT LONG.	35 51'31" 106 16'27"	26.6	7.5	0-5200	SF
19	Guaje Canyon Well #1	G-1	08/18/92	LAT LONG.	35 54'07" 106 11'48"	26.9	8.2	0-1340	SF
20	Guaje Canyon Well #1a	G-1a	08/18/92	LAT LONG.	35 54'145" 106 11'58"	26.3	8.3	0-2060	SF
21	Guaje Canyon Well #2	G-2	08/18/92	LAT LONG.	35 54'22" 106 12'10"	29.6	8.3	0-1820	SF
22	Guaje Canyon Well #4	G-4	08/18/92	LAT LONG.	35 54'35" 106 13'14"	24.3	8.0	0-1260	SF
23	Guaje Canyon Well #5	VA-370	10/22/91	LAT LONG.	35 54'51" 106 13'37"	25.7	7.3	0-2100	SF
23	Guaje Canyon Well #5	G-5	08/18/92	LAT LONG.	35 54'51" 106 13'37"	30.3	7.7	0-2100	SF
24	Guaje Canyon Well #6	G-6	08/18/92	LAT LONG.	35 54'39" 106 14'04"	30.3	8.0	0-1100	SF
25	Water Canyon Gallery	W.C.G.	08/18/92	LAT LONG.	35 50'39" 106 22'19"	15.3	7.4	160	BT
25	Water Canyon Gallery	PP93-27	05/20/93	LAT LONG.	35 50'39" 106 22'19"	11.3	7.6	160	BT
26	LA-1 Well	PP93-8	05/12/93	LAT LONG.	35 53'01" 106 09'22"	—	7.0	—	SF
27	LA-1b Well	VA-371	10/22/91	LAT LONG.	35 53'01" 106 09'20"	31.8	7.6	0-2180	SF
27	LA-1b Well	PP93-9	05/12/93	LAT LONG.	35 53'01" 106 09'20"	31.5	7.0	0-2180	SF
28	LA-2 Well	PP93-7	05/12/93	LAT LONG.	35 53'04" 106 09'36"	—	8.1	—	SF
29	LA-5 Well	PP93-10	05/12/93	LAT LONG.	35 52'18" 106 11'02"	19.3	6.5	0-1880	SF
30	Test Well #1, White Rock "Y"	TW-1	10/08/92	LAT LONG.	35 52'13" 106 13'01"	14.0	7.6	—	SF
30	Test Well #1, White Rock "Y"	PP93-18	05/19/93	LAT LONG.	35 52'13" 106 13'01"	14.1	7.7	—	SF
31	Test Well #1a, White Rock "Y"	TW-1a	10/08/92	LAT LONG.	35 52'13" 106 13'01"	11.1	8.0	—	P
31	Test Well #1a, White Rock "Y"	PP93-19	05/19/93	LAT LONG.	35 52'13" 106 13'01"	15.1	7.7	—	P
32	Test Well #2, Pueblo Canyon	TW-2	10/08/92	LAT LONG.	35 53'05" 106 16'13"	15.9	7.8	0-8	SF
32	Test Well #2, Pueblo Canyon	PP93-16	05/19/93	LAT LONG.	35 53'05" 106 16'13"	17.4	7.8	—	SF
33	Test Well #2a, Pueblo Canyon	TW-2a	10/08/92	LAT LONG.	35 53'05" 106 16'14"	11.6	7.6	—	P
33	Test Well #2a, Pueblo Canyon	PP93-17	05/19/93	LAT LONG.	35 53'05" 106 16'14"	14.5	7.8	—	P
34	Test Well #3	PP93-23	05/20/93	LAT LONG.	35 52'24" 106 15'31"	21.3	7.7	0-12	P
35	Test Well #4	PP93-21	05/19/93	LAT LONG.	35 53'09" 106 18'17"	11.0	8.7	—	P
36	Deep Test Well #5a	VA-374	10/23/91	LAT LONG.	35 49'22" 106 18'01"	17.8	7.3	8	SF
36	Deep Test Well #5a	PP93-26	05/20/93	LAT LONG.	35 49'22" 106 18'01"	18.1	7.4	—	SF
37	Deep Test Well #9	PP93-25	05/20/93	LAT LONG.	35 48'50" 106 17'17"	15.4	8.2	—	SF

Map No.	Description	Sample No.	Date	Location		Temp. (°C)	Field pH	Flow rate (l/min)	Rock Type[a]
38	Deep Test Well #10	PP93-24	05/20/93	LAT LONG.	35 49'19" 106 17'17"	16.8	8.3	—	SF
39	Otowi #4 Well	OT-4	03/02/93	LAT LONG.	35 52'22" 106 15'35"	28.8	7.0	—	SF
39	Otowi #4 Well	PP93-22	05/20/93	LAT LONG.	35 52'22" 106 15'35"	27.5	7.2	—	SF
40	Core Hole #2, TA-49	CH-2	05/07/93	LAT LONG.	35 49'00" 106 17'22"	—	—	—	BT
74	LADP-3 Well at 320 ft.	PP93-36	12/02/93	LAT LONG.	35 52'36" 106 17'02"	9.0	—	—	BT
75	Test Well #8	PP93-37	12/07/93	NAD 83	1632573.9 easting 1769506.6 northing		—	—	P
SAN ILDEFONSO WELLS									
41	East Side Artesian Well	VA-376	03/05/92	LAT LONG.	35 52'49" 106 08'16"	14.8	8.9	—	SF
41	East Side Artesian Well	PP93-2	05/12/93	LAT LONG.	35 52'49" 106 08'16"	14.4	9.1	—	SF
42	Westside Artesian Well	VA-380	03/05/92	LAT LONG.	35 53'40" 106 07'50"	17.7	7.5	—	SF
42	Westside Artesian Well	PP93-11	05/18/93	LAT LONG.	35 53'40" 106 07'50"	17.8	7.8	—	SF
43	Don Juan Playhouse Well	VA-377	03/05/92	LAT LONG.	35 52'38" 106 07'48"	19.1	7.8	—	SF
43	Don Juan Playhouse Well	PP93-3	05/12/93	LAT LONG.	35 52'38" 106 07'48"	19.2	8.8	—	SF
44	Halliday House Well	VA-378	03/05/92	LAT LONG.	35 52'38" 106 08'40"	15.7	8.0	—	SF
44	Halliday House Well	PP93-5	05/12/93	LAT LONG.	35 52'38" 106 08'40"	17.2	8.9	—	SF
45	Pajarito Well	VA-379	03/05/92	LAT LONG.	35 53'32" 106 08'16"	16.4	7.2	—	SF
45	Pajarito Well #2	PP93-14	05/18/93	LAT LONG.	35 53'32" 106 08'16"	16.8	7.5	—	SF
46	New Comm. Well, S.I. Pueblo	PP93-1	05/12/93	LAT LONG.	35 53'44" 106 07'12"	13.4	7.9	—	SF
47	Otowi House Well	PP93-4	05/12/93	LAT LONG.	52 30'05" 108 08'26"	15.5	7.2	—	SF
48	Martinez Well	ER-C	—	LAT LONG.	35 54'09" 106 08'00"	—	—	—	SF
48	Martinez Well	PP93-12	05/18/93	LAT LONG.	35 54'09" 106 08'00"	16.4	7.7	—	SF
49	Sanchez Well	ER-B	—	LAT LONG.	35 54'15" 106 07'57"	—	—	—	SF
49	Sanchez Well	PP93-13	05/18/93	LAT LONG.	35 54'15" 106 07'57"	16.5	7.9	—	SF
MISC. WATERS AND SPRINGS									
50	LANL TA-33 Drain, TA33-86 Outfall	TA33-1	02/08/91	LAT LONG.	35 46'57" 106 15'05"	10.6	6.5	1	—
50	LANL TA-33 Drain, TA33-86 Outfall	TA33-3	02/22/91	LAT LONG.	35 46'57" 106 15'05"	10.6	6.5	1	—
51	LANL TA-33 Drain, 30 ft. E. of TA33-1	TA33-2	02/08/91	LAT LONG.	35 47'00" 106 15'07"	0.1	6.5	1	—
51	LANL TA-33 Drain, 30 ft. E. of TA33-3	TA33-4	02/22/91	LAT LONG.	35 47'00" 106 15'07"	1.5	6.3	1	—
52	Sulfur Creek at Baca Gate	VA-327	05/07/91	LAT LONG.	35 54'15" 106 37'13"	8.1	4.8	50	CF
53	Corbin's Cistern	VA-328	05/07/91	LAT LONG.	35 54'29" 106 36'54"	8.2	6.0	—	CF
54	Pajarito Spring	VA-330	05/09/91	LAT LONG.	35 48'08" 106 11'48"	22.2	6.0	6	SF
55	Rio Grande Spring	VA-331	05/09/91	LAT LONG.	35 48'20" 106 11'32"	16.8	6.0	1	SF
56	LA Creek above Reservoir	VA-332	05/09/91	LAT LONG.	35 53'08" 106 21'37"	9.4	5.8	3000	PG

Map No.	Description	Sample No.	Date	Location		Temp. (°C)	Field pH	Flow rate (l/min)	Rock Type[a]
76	Seven Springs	VA-333	05/10/91	LAT	35 56'35"	11.5	5.8	60	BT
				LONG.	106 42'15"				
77	Horseshoe Spring	VA-335	05/10/91	LAT	35 52'41"	9.6	5.5	—	CF
				LONG.	106 39'23"				
78	Redondo Creek	VA-336	05/10/91	LAT	35 52'22"	15.8	5.8	200	CF
				LONG.	106 37'16"				
79	Panorama Spring	VA-340	05/13/91	LAT	35 48'13"	13.2	6.5	6	ML
				LONG.	106 41'10"				
80	Sino Spring	VA-341	05/13/91	LAT	35 49'17"	15.6	5.8	15	BT/A
				LONG.	106 40'42"				
80	Sino Spring	VA-393	06/08/92	LAT	35 49'17"	19.1	7.0	80	BT/A
				LONG.	106 40'42"				
80	Sino Spring	VA-396	06/16/93	LAT	35 49'17"	—	—	40	BT/A
				LONG.	106 40'42"				
81	San Antonio Creek	VA-342	05/14/91	LAT	35 58'17"	10.4	5.5	2000	CF
				LONG.	106 33'38"				
82	E. Fork Jemez River	VA-344	05/14/91	LAT	35 49'46"	14	5.5	1200	CF
				LONG.	106 38'42"				
57	Los Alamos Creek	VA-347	05/15/91	LAT	35 52'34"	10.8	5.5	7	PG
				LONG.	106 17'13"				
58	Sacred Spring	VA-348	05/16/91	LAT	35 53'35"	12.9	6.0	1	SF
				LONG.	106 8'[illegible]"				
59	Turkey Springs	VA-349	05/17/91	LAT	35 44'23"	16.5	5.5	60	KG
				LONG.	106 21'35"				
60	Apache Spring	VA-350	05/20/91	LAT	35 49'30"	8.3	5.5	15	BT/PG
				LONG.	106 23'31"				
61	Armistead Spring	VA-351	05/17/91	LAT	35 50'48"	7.1	5.5	18	BT/PG
				LONG.	106 23'08"				
62	Frijoles Spring #49	VA-352	05/22/91	LAT	35 50'36"	6.4	5.5	10	BT
				LONG.	106 25'16"				
63	Frijoles Spring #50	VA-353	05/22/91	LAT	35 50'11"	10.6	5.5	20	BT
				LONG.	106 24'39"				
64	Pajarito Creek	VA-354	05/22/91	LAT	35 52'23"	10.9	5.5	120	PG
				LONG.	106 22'29"				
65	Upper Guaje Creek	VA-355	05/23/91	LAT	35 50'58"	10	5.5	120	PG
				LONG.	106 17'02"				
66	Pine Spring	VA-356	05/24/91	LAT	35 57'25"	12.6	5.5	2	BT
				LONG.	106 17'03"				
67	Unnamed Spring near Apache Spring	VA-357	05/28/91	LAT	35 49'35"	15.7	6.0	1	BT
				LONG.	106 36'32"				
68	Basalt Spring #2	VA-358	06/11/91	LAT	35 52'03"	12.1	6.0	3	CR/P
				LONG.	106 11'44"				
69	Basalt Spring #1	VA-359	06/11/91	LAT	35 52'03"	11.8	6.0	25	CR/P
				LONG.	106 11'44"				
69	Basalt Spring #1	ER-A	—	LAT	35 52'03"	—	—	—	CR/P
				LONG.	106 11'44"				
70	Black Canyon Spring	VA-360	06/13/91	LAT	35 13'03"	8.1	5.8	10	PC
				LONG.	105 50'15"				
71	Acid Creek	VA-362	06/23/91	LAT	35 53'22"	8.2	6.0	15	BT
				LONG.	106 18'22"				
83	La Mesita Spring	ER-D	—	LAT	35 50'48"	—	—	—	SF
				LONG.	106 10'10"				
84	Santa Fe Lake	VA-365	07/17/91	LAT	35 47'23"	13.5	6.0	—	PC
				LONG.	105 46'48"				
85	Unnamed Spring, FR-150	VA-366	07/17/91	LAT	35 45'40"	3.9	6.0	30	PC
				LONG.	105 49'57"				
86	Unnamed Spring #2, FR-150	VA-367	07/17/91	LAT	35 46'44"	13.7	5.8	6	PC
				LONG.	105 50'01"				
87	Chupadero Creek	VA-368	07/18/91	LAT	35 51'23"	11.3	5.5	60	PC
				LONG.	105 46'39"				
88	Canyon de la Loba Creek	VA-369	07/18/91	LAT	36 00'45"	14.4	5.5	30	PC
				LONG.	105 45'45"				
72	Homestead Spring	VA-381	04/07/92	LAT	35 51'45"	7.8	6.5	20	BT
				LONG.	106 20'21"				
73	Indian Spring	PP93-6	05/12/93	LAT	35 53'09"	19.8	7.4	—	SF
				LONG.	106 09'37"				
89	Unnamed Spring north of Ice Rink	PP93-31	09/11/93	LAT	35 52'55"	14.0	—	—	BT
				LONG.	106 19'51"				

Map No.	Description	Sample No.	Date	Location		Temp. (°C)	Field pH	Flow rate (l/min)	Rock Type[a]
90	Chaquehui Creek below TA-33	PP93-33	10/23/93	LAT LONG.	35 46'42" 106 15'27"	13.3	6.6	seep	CR
91	2 mile Creek dwnstrm of Van de Graff	PP93-34	10/19/93	LAT LONG.	35 52'07" 106 19'20"	6.0	6.0	2	BT
92	2 mile Creek upstm 50m frm PP93-34	PP93-35	10/19/93	LAT LONG.	35 52'07" 106 19'20"	7.4	6.0	2	BT
SWAB SAMPLES, SHB-3 COREHOLE, TA-16									
93	Fawcet at SM 205, Drilling Water	SHB92-1	07/08/93	LAT LONG.	35 50'11" 106 21'00"	16.9	—	—	—
94	In-situ sample SHB-3 Well 258m.	SHB93-2	07/20/93	LAT LONG.	35 50'11" 106 21'00"	16.9	—	—	BT/P
94	Run 1, Swab SHB-3 Well	SHB93-3	08/29/93	LAT LONG.	35 50'11" 106 21'00"	16.4	—	—	BT/P
94	Run 2, Swab SHB-3 Well	SHB93-4	08/29/93	LAT LONG.	35 50'11" 106 21'00"	16.6	—	—	BT/P
94	Run 3, Swab SHB-3 Well	SHB93-5	08/29/93	LAT LONG.	35 50'11" 106 21'00"	16.9	—	—	BT/P
94	Run 4, Swab SHB-3 Well	SHB93-6	08/29/93	LAT LONG.	35 50'11" 106 21'00"	16.9	—	—	BT/P
94	Run 5, Swab SHB-3 Well	SHB93-7	08/30/93	LAT LONG.	35 50'11" 106 21'00"	16.9	—	—	BT/P

[a] BT = Bandelier Tuff, CR = Cerros del Rio basalt, P = Puye Formation, SF = Santa Fe Group, CF = caldera fill rocks in Valles Caldera, PG = Polvadera Group, ML = Madera Limestone, A = Abo Formation, KG = Keres Group, PC = Precambrian

concentration plotted against chloride concentration for all samples in this study, and in both figures the typical concentration of chloride, bromide, and boron in the Pajarito Plateau and San Ildefonso well samples is greater than in the White Rock Canyon and miscellaneous samples taken from surface sources.

Within the Pajarito Plateau area itself, however, the correlation between chloride, bromide, and boron concentration and temperature is poor. The highest chloride concentration in the plateau is found in sample TW-1a, which has a temperature of only 8.0°C, and the warmest Pajarito Plateau sample's chloride concentration is only the ninth highest in the group. Further, many of the wells with temperatures in the high 20s only contain concentrations of chloride between one and three mg/kg. In bromide, the warmest samples beneath the plateau, the LA-1b well samples, indeed have relatively high concentrations, but the highest bromide concentration is found in sample PP93-19 from Test Well 1a, White Rock "Y", whose temperature,15.1°C, is lower than many in the Pajarito Plateau group. In addition, many of the wells with temperatures in the high 20s contain only trace amounts of bromide. In boron, similarly, some of the coldest samples like TW-1 and 1a from Test Wells #1 and 1a, near the White Rock "Y" have some of the highest concentrations, while some of the warmest samples like VA-373 and PM-5 from Pajarito Mesa Wells #1 and 5 and G-2, 5, and 6 from Guaje Canyon Wells #2, 5, and 6 contain boron values below threshold detection limits.

This poor correlation between conservative cation/anion concentration and temperature on the Pajarito Plateau region could result from a combination of some or all of the following factors: (1) some lower temperature near-surface wells with anamolous amounts of chloride, bromide, and boron could be effected by contamination; these are further marked by elevated quantities of certain trace species including nitrate, phosphate, chlorate, and lead, and one major anion, sulfate; (2) some waters beneath the plateau could be mixing with deep mineralized water rising along faults in the Rio Grande rift (Goff and Sayer, 1980); (3) there may be significant water mobility between aquifers within the Pajarito Plateau. Such movement could mobilize waters from warm locations where they were mineralized to cooler locations, thus causing some of the cooler water samples to actually be the most concentrated in various constituents.

A different situation from that of the waters in the Pajarito Plateau exists for waters in the San Ildefonso area. There, the warmest samples are commonly among the highest in chloride, bromide, and boron concentration. One reason for this observation could be that the wells on the reservation are farther away from LANL, where they are less likely to be effected by Laboratory activities than the Pajarito Plateau wells. Such impacts tend to warp natural temperature/soluble element relationships by increasing conservative constituent concentrations in impacted, near-surface, cold waters. Low concentrations of phosphate and lead in most San Ildefonso samples lend support to this explanation.

TABLE 2. Major Cation/Anion Analysis For Waters In the Pajarito Plateau and Outlying Areas, New Mexico (Values in mg/kg)[a]

Map No.	Description	Sample No.	Date	Temp. (°C)	SiO2	Ca	Mg	Sr	Na	K	Li	HCO3	SO4	Cl	F	Br	B	CO3	TDS	Cation Sum	Anion Sum	Balance
DP SPRING (TA-21)																						
1	DP Spring, DP Canyon	PP-1	05/30/90	8.4	24	13.2	1.54	0.12	72.0	11.1	0.02	145	14.5	39.5	1.88	<0.05	<0.05	0.0	330.2	4.221	4.014	0.0502
1	DP Spring, DP Canyon	PP-2	08/10/90	9.8	31	12.1	1.52	0.09	50.6	10.4	0.02	134	10.1	24.7	1.73	<0.05	0.53	0.0	282.7	3.330	3.304	0.0080
1	DPSpring, DP Canyon	PP-4	09/06/90	16.0	29	13.4	1.37	0.08	49.1	11.1	<0.01	95.1	9.23	21.1	1.69	<0.05	0.10	22.8	258.9	3.345	3.264	0.0246
1	DPSpring, DP Canyon	VA-345	05/15/91	11.4	20	28.3	3.37	0.19	75.2	17.2	0.02	111	11.8	115	1.26	0.03	<0.01	0.0	390.0	5.454	5.436	0.0032
1	DP Spring, DP Canyon	VA-363	06/26/91	8.0	21	20.1	2.23	0.14	62.8	13.2	<0.01	106	9.88	76.0	1.37	0.02	<0.01	0.0	317.6	4.272	4.222	0.0119
1	DPSpring, DP Canyon	VA-364	07/11/91	8.4	20	13.9	1.69	0.11	53.8	12.6	0.01	109	8.93	52.8	1.53	<0.02	0.01	0.0	280.9	3.586	3.622	-0.0101
1	DP Spring, DP Canyon	VA-383	05/18/92	9.5	19	27.2	2.78	0.22	72.6	16.1	0.06	122	10.1	105	1.23	<0.02	<0.05	0.0	379.4	5.178	5.260	-0.0157
1	DP Spring, DP Canyon	PP93-28	05/26/93	7.3	16.1	20.0	2.01	0.17	71.5	10.6	0.03	100.4	11.7	82.2	1.14	<0.01	<0.01	0.0	331.0	4.586	4.499	0.0147
1	DPSpring, DP Canyon	PP93-29	06/23/93	5.8	18.4	18.7	2.17	0.16	67.6	10.7	0.02	115	11.8	68.8	1.31	0.02	0.07	0.0	331.7	4.374	4.406	-0.0073
1	DP Spring, DP Canyon	PP93-30	07/23/93	6.3	28.9	15.1	1.90	0.12	60.2	10.4	0.02	105	11.1	55.6	1.26	0.02	<0.05	0.0	305.9	4.283	3.761	0.1297
1	DP Spring, DP Canyon	PP93-32	10/06/93	9.6	24.2	14.5	1.59	0.14	49.7	10.3	<0.01	115	8.56	38.4	1.41	0.05	0.15	0.0	269.1	3.401	3.284	0.0349
2	TA-21 Outfall	PP-3	08/10/90	18.5	44	19.7	1.86	0.13	104	14.3	0.05	106	31.2	38.1	1.25	<0.05	<0.05	0.0	525.7	6.043	6.354	-0.0501
2	TA-21 Outfall	PP-13	10/22/90	-	41	38.4	3.72	0.26	69.0	15.4	0.03	48.8	25.1	36.2	0.58	<0.05	0.06	0.0	479.7	5.638	5.852	-0.0374
2	TA-21 Outfall	VA-346	05/15/91	12.3	43	17.0	2.51	0.12	112	22.4	0.05	239	34.3	51.7	1.60	0.09	0.10	0.0	563.0	6.569	7.023	-0.0669
WHITE ROCK CANYON SPRINGS																						
3	Spring 2	Spring 2	11/91	<20	40	22.4	1.17	0.28	62.4	1.73	0.04	205	11.4	5.50	1.21	0.05	<0.05	0.0	351.3	3.989	3.821	0.0430
4	Spring 3	PP-5	9/24/90	<20	54	20.8	1.73	0.25	15.3	0.30	0.02	56.1	3.90	2.98	0.38	0.04	<0.02	24.0	183.7	1.866	1.955	-0.0469
4	Spring 3	Spring 3	11/91	<20	49	21.0	1.74	0.24	15.2	2.98	<0.01	96.2	4.43	3.00	0.39	0.03	<0.05	0.0	197.8	1.939	1.837	0.0539
5	Spring 3b	PP-6	9/24/90	<20	45	19.2	1.65	0.26	119	4.70	0.09	301	15.6	4.09	0.51	0.06	0.34	26.4	547.9	6.414	6.433	-0.0029
5	Spring 3b	Spring 3b	11/91	<20	43	16.9	1.34	0.22	116	4.13	0.06	322	15.7	3.17	0.58	0.04	<0.05	0.0	534.2	6.119	5.900	0.0364
6	Spring 4a	Spring 4a	11/91	<20	67	19.6	4.48	0.13	12.0	2.17	0.01	89.2	5.35	4.13	0.39	0.05	<0.05	0.0	208.6	1.939	1.767	0.0927
7	Spring 6	Spring 6	11/91	<20	71	12.1	3.70	0.07	10.5	2.00	<0.01	73.4	2.34	1.99	0.28	0.03	<0.05	0.0	178.2	1.421	1.341	0.0581
8	Spring 6a	PP-7	9/25/90	<20	78	9.60	2.82	0.06	10.0	1.70	0.02	73.2	1.64	1.59	0.25	0.02	0.02	0.0	160.6	1.196	1.314	-0.0936
8	Spring 6a	Spring 6a	11/91	<20	74	9.90	2.73	0.06	10.2	2.12	<0.01	62.8	1.82	1.71	0.24	0.02	<0.05	0.0	167.1	1.222	1.152	0.0588
9	Spring 7	PP-8	9/25/90	<20	82	12.6	3.29	0.09	14.6	2.20	0.02	87.8	4.22	2.78	0.28	<0.05	<0.02	0.0	213.1	1.601	1.664	-0.0383
9	Spring 7	Spring 7	11/91	<20	76	12.2	3.14	0.07	13.5	2.33	0.01	77.2	3.70	1.91	0.27	0.02	<0.05	0.0	191.0	1.518	1.428	0.0605
10	Spring 8	PP-9	9/25/90	<20	77	21.3	4.96	0.16	24.7	3.00	0.02	137	10.8	3.74	0.28	0.04	<0.02	0.0	287.2	2.631	2.652	-0.0079
10	Spring 8	Spring 8	11/91	<20	72	21.0	4.73	0.17	24.5	3.49	<0.01	130	10.5	3.34	0.32	0.04	<0.05	0.0	273.8	2.596	2.519	0.0303
11	Spring 8b	PP-10	9/26/90	<20	83	13.4	3.19	0.09	15.5	2.20	0.01	85.4	5.84	2.43	0.35	<0.05	<0.02	0.0	214.3	1.667	1.642	0.0151
12	Spring 9a	Spring 9a	11/91	<20	70	10.4	2.99	0.07	11.4	1.60	<0.01	68.8	1.85	1.80	0.39	0.02	<0.05	0.0	170.1	1.307	1.251	0.0442
13	Doe Spring	PP-11	9/25/90	<20	83	12.7	3.37	0.09	13.9	1.80	0.02	85.4	3.72	2.19	0.40	<0.05	0.04	0.0	207.8	1.570	1.576	-0.0041
14	Ancho Spring	PP-12	9/25/90	<20	79	12.6	3.01	0.08	10.7	1.60	0.02	86.6	2.01	1.74	0.30	0.03	<0.02	0.0	198.9	1.390	1.547	-0.1071
14	Ancho Spring	Ancho Spring	11/91	<20	72	13.7	3.37	0.08	10.4	2.04	0.02	76.7	2.27	2.02	0.30	0.03	<0.05	0.0	184.1	1.481	1.391	0.0629
PAJARITO PLATEAU WELLS																						
15	Pajarito Mesa Well #1	VA-373	10/23/91	28.2	72	22.3	6.01	0.18	20.0	2.82	<0.01	120	4.71	5.67	0.21	0.05	<0.02	8.7	264.6	2.556	2.557	-0.0004
15	Pajarito Mesa Well #1	PM-1	08/18/92	27.5	72.8	24.3	6.18	0.19	20.0	3.65	0.03	146	5.00	5.50	0.22	<0.02	0.07	0.0	285.8	2.698	2.696	0.0005
16	Pajarito Mesa Well #2	PM-2	08/18/92	23.3	75.5	8.80	2.80	2.80	10.5	1.93	0.02	63.5	1.49	1.42	0.18	<0.02	<0.05	0.0	170.7	1.304	1.130	0.1424
16	Pajarito Mesa Well #2	PP93-15	05/19/93	22.4	86.0	8.94	2.73	0.06	10.4	1.81	0.02	65.0	1.69	1.61	0.25	0.02	0.11	0.0	180.2	1.174	1.190	-0.0137
17	Pajarito Mesa Well #3	PM-3	08/18/92	24.4	84.3	23.9	8.04	0.14	18.7	3.77	0.04	142	5.08	6.16	0.26	<0.02	<0.05	0.0	293.9	2.777	2.642	0.0497
17	Pajarito Mesa Well #3	PP93-20	05/19/93	27.7	92.4	25.3	7.54	0.19	18.5	3.54	0.04	144	5.37	6.91	0.29	0.06	0.07	0.0	306.6	2.790	2.724	0.0239
18	Pajarito Mesa Well #5	VA-372	10/23/91	24.7	85.0	8.8	3.63	0.02	13.0	2.23	<0.01	73.5	2.05	1.83	0.23	0.02	<0.02	0.0	192.2	1.369	1.333	0.0261
18	Pajarito Mesa Well #5	PM-5	08/18/92	26.6	87.1	11.8	4.47	0.07	12.9	2.41	0.02	86.3	2.46	2.24	0.23	<0.02	<0.05	0.0	210.8	1.596	1.550	0.0289
19	Guaje Canyon Well #1	G-1	08/18/92	26.9	81.1	12.2	0.49	0.17	27.4	3.24	0.02	104	4.29	2.35	0.59	<0.02	<0.05	8.6	244.0	1.935	2.133	-0.0973
20	Guaje Canyon Well #1a	G-1a	08/18/92	26.3	71.7	10.2	0.45	0.12	33.8	2.80	0.02	90.6	4.13	2.86	0.53	<0.02	0.22	7.7	227.3	2.104	1.973	0.0641
21	Guaje Canyon Well #2	G-2	08/18/92	29.6	71.3	9.6	0.50	0.10	39.0	2.87	0.02	102	3.80	2.28	0.68	<0.02	<0.05	0.0	233.9	2.296	1.879	0.1995
22	Guaje Canyon Well #4	G-4	08/18/92	24.3	58.6	17.4	3.60	0.19	12.5	2.10	0.01	96.5	3.21	2.34	0.28	<0.02	<0.05	0.0	199.3	1.772	1.769	0.0014
23	Guaje Canyon Well #5	VA-370	10/22/91	25.7	58.0	17.0	4.04	0.06	12.0	2.15	<0.01	90.1	3.51	2.86	0.27	0.03	<0.02	0.0	193.3	1.765	1.690	0.0430
23	Guaje Canyon Well #5	G-5	08/18/92	30.3	58.9	17.2	3.77	0.14	12.3	2.14	0.01	91.9	3.39	2.39	0.26	<0.02	<0.05	0.0	195.0	1.763	1.702	0.0352
24	Guaje Canyon Well #6	G-6	08/18/92	30.3	51.6	13.4	1.93	0.08	18.6	2.46	0.01	92.0	2.93	1.93	0.26	<0.02	<0.05	0.0	186.9	1.703	1.666	0.0219
25	Water Canyon Gallery	WCG	08/18/92	15.3	43.7	7.20	3.05	0.07	6.30	1.72	<0.01	52.8	1.05	0.64	0.05	<0.02	<0.05	0.0	117.1	0.931	0.916	0.0158
25	Water Canyon Gallery	PP93-27	05/20/93	11.3	39.8	6.94	2.79	0.07	4.90	1.79	0.01	44.6	2.85	0.69	0.06	0.01	<0.01	0.0	105.9	0.865	0.832	0.0389
26	LA-1 Well	PP93-8	05/12/93	—	6.4	3.71	0.03	0.29	37.2	1.63	0.02	67.7	8.95	7.74	0.29	0.06	0.13	7.0	141.7	1.861	1.768	0.0616
27	LA-1b Well	VA-371	10/22/91	31.8	37.0	6.60	0.33	0.16	161	2.73	<0.01	327	37.1	16.1	2.97	0.10	0.15	14.6	609.3	7.433	7.290	0.0195
27	LA-1b Well	PP93-9	05/12/93	31.5	38.9	7.10	0.31	0.40	166	2.51	0.11	346	35.5	18.6	2.87	0.12	0.38	11.1	632.4	7.689	7.509	0.0238
28	LA-2 Well	PP93-7	05/12/93	—	30.8	10.7	0.14	0.62	33.1	1.54	0.04	88.0	7.50	2.58	0.61	0.03	0.08	6.9	184.9	2.049	1.970	0.0395
29	LA-5 Well	PP93-10	05/12/93	19.3	38.7	19.5	0.76	0.51	15.8	2.49	0.03	93.5	5.63	3.22	0.44	0.03	0.04	0.0	183.0	1.817	1.797	0.0110
30	Test Well #1, White Rock "Y"	TW-1	10/08/92	14.0	49.6	47.6	9.34	0.29	15.5	3.70	0.03	130	24.8	32.8	0.34	0.15	0.23	0.0	340.8	3.954	4.008	-0.0135

Map No.	Description	Sample No.	Date	Temp. (°C)	SiO2	Ca	Mg	Sr	Na	K	Li	HCO3	SO4	Cl	F	Br	B	CO3	TDS	Cation Sum	Anion Sum	Balance
30	TestWell #1, White Rock "Y"	PP93-18	05/19/93	14.1	49.0	48.7	9.20	0.35	15.6	3.60	0.04	125	23.0	31.5	0.38	0.16	0.06	0.0	333.2	3.995	3.853	0.0363
31	Test Well #1a, White Rock "Y"	TW-1a	10/08/92	8.0	21.6	29.9	8.47	0.17	57.1	6.89	0.01	152	34.0	52.4	0.57	0.17	0.28	0.0	379.1	4.923	4.941	-0.0036
31	Test Well #1a, White Rock "Y"	PP93-19	05/19/93	15.1	55.4	29.4	8.35	0.22	61.6	7.40	0.02	158	24.3	44.3	0.57	0.22	0.18	0.0	424.5	5.077	5.009	0.0134
32	Test Well #2, Pueblo Canyon*	TW-2	10/08/92	15.9	50.5	11.5	2.90	0.07	12.2	1.37	0.03	74.5	2.20	1.90	0.45	<0.02	0.09	0.0	159.0	1.399	1.363	0.0258
32	Test Well #2, Pueblo Canyon*	PP93-16	05/19/93	17.4	43.0	11.2	2.91	0.09	13.8	1.43	0.03	78.3	2.21	2.06	0.55	0.04	0.05	0.0	156.9	1.454	1.435	0.0134
33	Test Well #2a, Pueblo Canyon*	TW-2a	10/08/92	11.6	33.2	41.4	7.98	0.26	22.6	3.58	0.01	111	30.5	42.9	0.21	0.08	0.17	0.0	313.6	4.029	3.868	0.0409
33	Test Well #2a, Pueblo Canyon*	PP93-17	05/19/93	14.5	64.8	37.3	6.81	0.36	23.7	3.48	0.03	89.8	27.1	40.0	0.23	0.13	0.11	0.0	310.5	3.583	3.435	0.0422
34	Test Well #3	PP93-23	05/20/93	21.3	79.6	17.6	5.15	0.11	12.2	2.33	0.01	99.2	3.00	3.06	0.41	0.05	0.03	0.0	225.6	1.902	1.842	0.0321
35	Test Well #4	PP93-21	05/19/93	11.0	6.0	11.6	3.82	0.10	12.8	3.42	0.02	73.4	2.56	3.24	0.26	0.03	0.06	3.2	121.3	1.567	1.471	0.0631
36	Deep Test Well #5a	VA-374	10/23/91	17.8	63.0	7.80	2.46	0.08	11.2	2.13	<0.01	60.6	1.34	1.47	0.15	0.02	<0.02	0.0	152.2	1.149	1.088	0.0546
36	Deep Test Well #5a	PP93-26	05/20/93	18.1	68.7	8.49	2.22	0.06	11.1	1.70	0.02	62.9	1.37	1.51	0.23	0.03	<0.01	0.0	161.6	1.264	1.139	0.1037
37	Deep Test Well #9	PP93-25	05/20/93	15.4	68.9	10.2	2.64	0.08	11.2	1.03	0.02	58.4	1.48	1.53	0.27	0.02	<0.01	4.4	161.9	1.251	1.216	0.0283
38	Deep Test Well #10	PP93-24	05/20/93	16.8	59.5	12.1	3.35	0.08	11.4	1.42	0.03	80.7	1.36	1.42	0.23	0.02	<0.01	0.0	173.3	1.468	1.416	0.0363
39	Otowi #4 Well	OT-4	03/02/93	28.8	105.0	21.0	8.06	0.15	21.0	3.56	0.05	137	5.05	7.03	0.28	0.05	<0.05	0.0	308.2	2.735	2.564	0.0646
39	Otowi #4 Well	PP93-22	05/20/93	27.5	95.9	20.7	7.23	0.24	20.4	3.49	0.05	136	5.18	7.49	0.30	0.05	0.11	0.0	298.9	2.630	2.596	0.0130
40	Core Hole #2, TA-49	CH-2	05/07/93	—	2.0	2.38	0.27	0.04	32.1	7.46	0.03	49.9	14.3	1.27	0.52	0.12	3.44	14.9	130.1	1.765	1.838	-0.0295
74	LADP-3 Well at 320 ft.	PP93-36	12/01/93	9.0	42.8	11.7	4.08	0.13	33.8	6.70	0.02	65.0	12.8	46.8	0.38	0.07	0.04	0.0	229.3	2.688	2.702	-0.0052
75	Test Well #8	PP93-37	12/06/93	—	58.2	11.3	3.54	0.08	10.5	1.59	0.02	78.3	2.36	2.31	0.11	0.04	<0.02	0.0	169.6	1.388	1.408	-0.0144
SAN ILDEFANSO WELLS																						
41	EastSide Artesian Well	VA-376	03/05/92	14.8	0.2	2.20	0.11	0.09	91.2	0.59	0.09	179	12.4	3.13	0.74	0.04	<0.02	20.3	310.5	4.131	3.992	0.0340
41	EastSide Artesian Well	PP93-2	05/12/93	14.4	1.3	2.82	0.17	0.09	94.1	0.85	0.08	189	13.9	3.41	0.76	0.06	0.17	22.5	329.5	4.296	4.277	0.0045
42	Westside Artesian Well	VA-380	03/05/92	17.7	21.0	12.6	0.44	0.34	416	1.44	0.24	317	79.2	357	5.18	1.84	1.56	33.1	1247.2	18.821	18.296	0.0283
42	Westside Artesian Well	PP93-11	05/18/93	17.8	23.3	14.3	0.78	0.75	422	1.73	0.17	390	75.1	354	4.81	1.83	1.71	14.6	1305.7	19.206	18.699	0.0267
43	Don Juan Playhouse Well	VA-377	03/05/92	19.1	22.0	5.90	0.39	0.11	66.9	0.73	0.08	144	15.6	3.03	0.57	0.05	<0.02	11.1	278.7	3.271	3.295	-0.0073
43	Don Juan Playhouse Well	PP93-3	05/12/93	19.2	24.6	6.33	0.45	0.21	69.3	1.02	0.06	151	15.7	3.40	0.58	0.06	0.12	9.9	291.8	3.417	3.407	0.0028
44	Halliday House Well	VA-378	03/05/92	15.7	24.0	3.40	<0.01	0.16	41.4	0.60	0.08	90.1	13.0	3.60	0.58	0.04	<0.02	7.7	187.8	2.001	2.173	-0.0826
44	Halliday House Well	PP93-5	05/12/93	17.2	26.8	4.19	0.04	0.29	45.7	0.77	0.04	89.8	13.9	4.09	0.49	0.05	0.09	7.5	196.2	2.241	2.193	0.0218
45	Pajarito Well	VA-379	03/05/92	16.4	31.0	47.5	4.54	1.27	313	2.96	0.28	501	48.1	173	0.78	1.01	1.22	0.0	1126.7	16.491	14.178	0.1508
45	Pajarito Well #2	PP93-14	05/18/93	16.8	36.6	28.2	1.54	0.54	104	2.64	0.08	259	23.8	46.7	0.83	0.27	0.36	0.0	511.8	6.150	6.230	-0.0129
46	New Comm. Well, S.I. Pueblo	PP93-1	05/12/93	13.4	24.2	33.2	2.01	0.56	67.3	1.33	0.08	209	32.7	10.1	0.28	0.07	0.16	8.9	394.7	4.810	4.787	0.0049
47	Otowi House Well	PP93-4	05/12/93	15.5	55.4	66.8	4.92	0.95	43.3	3.61	0.06	256	20.5	35.4	0.33	0.15	0.08	0.0	489.2	5.756	5.660	0.0168
48	Martinez Well	PP93-12	05/18/93	16.4	40.7	45.9	2.50	0.71	56.8	3.24	0.03	192	35.2	18.7	0.56	0.16	0.20	0.0	435.9	5.073	5.081	-0.0015
49	Sanchez Well	PP93-13	05/18/93	16.5	40.4	37.9	2.50	0.53	116	2.26	0.06	245	52.9	48.6	1.48	0.28	0.34	10.1	562.9	7.222	6.986	0.0332
MISC. WATERS AND SPRINGS																						
50	LANL TA-33 Drain, TA33-86 Outfall	TA33-1	02/08/91	10.6	80	11.8	3.18	0.05	12.1	2.1	0.03	92.7	1.91	2.71	0.22	0.01	<0.02	0.0	208.0	1.444	1.664	-0.1415
50	LANL TA-33 Drain, TA33-86 Outfall	TA33-3	02/22/91	10.6	71	9.9	2.49	0.05	12.8	2.2	0.03	79.3	2.35	3.14	0.25	<0.01	<0.02	0.0	184.1	1.332	1.451	-0.0858
51	LANL TA-33 Drain, 30 ft. E. of TA33-1	TA33-2	02/08/91	0.1	76	11.1	2.77	0.05	12.3	2.6	0.03	85.4	2.31	2.77	0.23	<0.01	<0.02	0.0	196.0	1.399	1.539	-0.0952
51	LANL TA-33 Drain, 30 ft. E. of TA33-3	TA33-4	02/22/91	0.1	84	13.0	3.30	0.05	12.0	2.1	0.02	87.8	1.78	2.31	0.21	0.02	<0.02	0.0	207.3	1.504	1.564	-0.0390
52	Sulfur Creek at Baca Gate	VA-327	05/07/91	8.1	41	9.6	1.91	0.07	5.00	4.3	<0.01	?	84.4	1.00	0.01	0.02	<0.02	0.0	161.4	1.952	1.801	0.0802
53	Corbin's Cistern	VA-328	05/07/91	8.2	27	61.6	11.4	0.31	16.3	8.3	0.06	191	82.5	12.6	0.25	0.05	<0.02	0.0	411.2	4.953	5.231	-0.0545
54	Pajarito Spring	VA-330	05/09/91	22.2	70	19.6	4.85	0.11	13.7	3.1	0.03	107	4.74	4.69	0.33	0.05	0.04	0.0	231.3	2.062	2.053	0.0046
55	Rio Grande Spring	VA-331	05/09/91	16.8	53	25.0	5.38	0.14	13.5	3.0	0.02	117	8.63	7.00	0.40	0.07	<0.02	0.0	235.7	2.356	2.355	0.0044
56	LA Creek above Reservoir	VA-332	05/09/91	9.4	33	6.3	2.27	0.04	5.6	2.5	<0.01	47.3	3.92	5.72	0.05	<0.02	<0.02	0.0	108.0	0.913	1.021	-0.1116
76	Seven Springs	VA-333	05/10/91	11.5	31	12.9	1.71	0.06	6.3	2.4	<0.01	61.0	3.85	1.22	0.16	0.02	<0.02	0.0	121.7	1.152	1.132	0.0179
77	Horseshoe Spring	VA-335	05/10/91	9.6	49	21.6	4.57	0.14	33.1	3.3	0.02	184	5.02	5.57	0.17	0.06	<0.02	0.0	309.4	3.039	3.300	-0.0823
78	Redondo Creek	VA-336	05/10/91	15.8	28	8.2	1.04	0.05	6.3	2.7	0.01	45.1	7.64	4.17	0.08	0.02	<0.02	0.0	104.9	0.919	1.021	-0.1050
79	Panorama Spring	VA-340	05/13/91	13.2	56	55.5	23.0	0.46	94.8	5.3	0.09	454	18.8	11.6	0.68	0.12	0.11	0.0	721.1	8.958	8.210	0.0871
80	Sino Spring	VA-341	05/13/91	15.6	82	11.3	3.76	0.05	16.2	1.8	0.02	91.5	3.63	2.27	0.39	0.04	<0.01	0.0	213.7	1.632	1.661	-0.0178
80	Sino Spring	VA-393	06/08/92	19.1	73	12.8	3.22	0.09	18.5	1.44	0.08	84.3	3.79	3.13	0.44	0.03	0.22	0.0	202.1	1.760	1.604	0.0929
81	San Antonio Creek	VA-342	05/14/91	10.4	45	9.1	1.74	0.05	8.2	2.4	0.01	61.0	6.17	0.98	0.83	<0.02	<0.01	0.0	137.2	1.121	1.201	-0.0693

Map No.	Description	Sample No.	Date	Temp. (°C)	SiO2	Ca	Mg	Sr	Na	K	Li	HCO3	SO4	Cl	F	Br	B	CO3	TDS	Cation Sum	Anion Sum	Balance
82	E. Fork Jemez River	VA-344	05/14/91	14.0	31	5.8	1.13	0.03	5.4	1.7	<0.01	34.2	2.94	1.39	0.22	<0.02	<0.01	0.0	85.1	0.768	0.674	0.1282
57	Los Alamos Creek	VA-347	05/15/91	10.8	37	16.9	4.70	0.11	41.6	4.4	0.01	56.1	8.10	77.5	0.20	0.08	<0.01	0.0	246.9	3.168	3.275	-0.0331
58	Sacred Spring	VA-348	05/16/91	12.9	14	21.8	0.29	0.46	23.4	3.0	0.02	126	5.50	1.85	0.44	0.03	<0.01	0.0	197.5	2.231	2.258	-0.0120
59	Turkey Springs	VA-349	05/17/91	16.5	31	20.2	5.53	0.09	10.1	1.9	<0.01	109	3.25	3.27	0.13	0.06	<0.01	0.0	186.7	1.981	1.990	-0.0143
60	Apache Spring	VA-350	05/20/91	8.3	28	11.0	4.70	0.09	9.2	4.4	<0.01	69.5	5.47	6.02	0.07	0.03	<0.01	0.0	140.9	1.488	1.455	0.0224
61	Armistead Spring	VA-351	05/17/91	7.1	21	8.6	3.34	0.09	4.3	2.5	<0.01	51.2	5.67	0.97	0.04	<0.02	<0.01	0.0	104.4	1.355	0.999	0.3020
62	Frijoles Spring #49	VA-352	05/22/91	6.4	17	8.0	2.98	0.09	6.8	2.9	<0.01	39.0	3.85	14.0	0.03	<0.02	<0.01	0.0	97.9	1.247	1.119	0.1087
63	Frijoles Spring #50	VA-353	05/22/91	10.6	25	7.9	3.71	0.07	7.2	2.5	<0.01	53.6	2.66	6.11	0.04	<0.02	<0.01	0.0	111.6	1.197	1.123	0.0644
64	Pajarito Creek	VA-354	05/22/91	10.9	18	6.1	2.55	0.05	3.8	2.3	<0.01	40.3	3.26	0.72	0.04	<0.02	<0.01	0.0	79.0	0.859	0.754	0.1302
65	Upper Guaje Creek	VA-355	05/23/91	10.0	20	4.1	1.08	0.02	5.4	2.6	<0.01	32.9	3.24	1.11	0.15	<0.02	<0.01	0.0	71.7	0.659	0.649	0.0154
66	Pine Spring	VA-356	05/24/91	12.6	25	10.7	3.55	0.08	6.4	3.6	<0.01	61.0	7.70	1.47	0.08	<0.02	<0.01	0.0	126.0	1.594	1.208	0.2757
67	Unnamed Spring near Apache Spring	VA-357	05/28/91	15.7	21	9.1	2.44	0.05	7.0	4.6	<0.01	56.1	5.73	1.34	0.14	<0.02	<0.01	0.0	125.5	2.244	1.087	0.6952
68	BasaltSpring #2	VA-358	06/11/91	12.1	35	32.1	8.09	0.17	17.9	4.0	<0.01	105	36.0	20.6	0.84	0.30	<0.01	0.0	275.3	3.157	3.352	-0.0598
69	Basalt Spring #1	VA-359	06/11/91	11.8	42	27.0	7.32	0.15	27.2	4.1	<0.01	128	21.1	17.8	0.43	0.14	<0.01	0.0	297.0	3.245	3.454	-0.0624
70	Black Canyon Spring	VA-360	06/13/91	8.1	18	9.7	4.47	0.05	6.8	1.4	<0.01	52.5	7.23	5.32	0.30	<0.02	<0.01	0.0	106.8	1.251	1.178	0.0602
71	Acid Creek	VA-362	06/23/91	8.2	16	17.0	2.13	0.09	83.6	5.3	<0.01	53.7	10.9	132	0.20	<0.02	<0.01	0.0	326.4	4.798	4.911	-0.0232
84	Santa Fe Lake	VA-365	07/17/91	13.5	2.0	1.7	0.44	<0.01	1.53	0.64	<0.01	13.4	2.07	0.43	0.04	<0.02	<0.01	0.0	22.5	0.209	0.278	-0.2824
85	Unnamed Spring, FR-150	VA-366	07/17/91	3.9	10	2.6	1.15	<0.01	1.95	1.18	<0.01	19.5	3.79	0.32	0.03	<0.02	<0.01	0.0	40.6	0.342	0.417	-0.1980
86	Unnamed Spring #2, FR-150	VA-367	07/17/91	13.7	14	3.0	1.05	<0.01	3.17	0.68	<0.01	25.6	1.84	0.61	0.08	<0.02	<0.01	0.0	60.5	0.395	0.481	-0.1954
87	Chupadero Creek	VA-368	07/18/91	11.3	19	8.6	1.98	0.04	5.27	1.22	<0.01	47.6	4.52	0.66	0.19	<0.02	<0.01	0.0	89.0	0.859	0.904	-0.0511
88	Canyon de la Loba Creek	VA-369	07/18/91	14.4	24	9.3	2.03	0.06	6.07	1.46	<0.01	43.9	8.35	1.41	0.08	<0.02	<0.01	0.0	97.8	0.989	0.947	0.0229
72	Homestead Spring	VA-381	03/31/92	7.8	37	10.1	2.99	0.06	8.69	2.87	<0.01	33.0	8.08	12.6	0.05	<0.02	<0.05	0.0	119.1	1.506	1.066	0.3419
73	Indian Spring	PP93-6	05/12/93	19.8	49.9	36.7	2.74	0.60	28.8	2.71	0.05	126	7.72	34.3	0.42	0.06	0.06	0.0	294.0	3.411	3.272	0.0417
89	Unnamed Spring north of Ice Rink	PP93-31	09/10/93	14.0	60.1	11.4	2.90	0.10	16.2	2.49	0.03	80.8	4.04	4.38	0.34	0.02	<0.05	0.0	185.8	1.685	1.577	0.0663
90	Chaquehui Creek below TA-33	PP93-33	10/23/93	13.3	3.0	4.0	0.73	0.04	1.95	2.69	<0.01	15.4	2.18	1.93	0.09	0.01	<0.05	0.0	33.2	0.455	0.364	0.2208
91	2 mile Creek dwnstrm of Van de Graff	PP93-34	10/19/93	6.0	49.6	11.8	2.92	0.24	33.1	2.78	<0.01	75.1	11.2	27.4	0.27	0.05	0.26	0.0	217.4	2.550	2.267	0.1177
92	2 mile Crk upstm 50m frm PP93-34	PP93-35	10/19/93	7.4	48.6	12.1	3.18	0.10	32.6	2.90	<0.01	87.0	11.8	20.9	0.20	0.07	0.08	0.0	221.1	2.466	2.281	0.0780
80	Sino Spring	VA 396	08/16/93	-	76.0	12.0	3.28	0.08	14.1	1.18	0.03	83.6	3.58	3.17	0.58	0.05	0.05	0.0	199.1	1.522	1.583	-0.0393
SWAB SAMPLES, SHB-3 COREHOLE, TA-16																						
93	Fawcet at SM 205, Drilling Water	SHB92-1	07/07/93	16.9	88.2	16.0	3.53	0.09	11.8	2.2	0.03	64.1	2.00	2.50	0.28	<0.02	0.36	6.3	199.9	1.695	1.431	0.1691
94	In-situ sample SHB-3 Well 258m.	SHB93-2	07/20/93	16.9	82.4	16.0	0.85	0.20	24.0	15.5	0.04	0.00	7.54	7.54	0.28	0.02	0.09	41.6	205.7	2.330	2.284	0.0198
94	Run 1, Swab SHB-3 Well	SHB93-3	08/28/93	16.4	73.6	11.0	0.46	0.19	28.6	13.1	0.04	0.00	10.0	8.41	0.19	0.03	<0.05	35.0	192.3	2.208	2.222	-0.0065
94	Run 2, Swab SHB-3 Well	SHB93-4	08/28/93	16.6	53.3	20.5	0.17	0.39	20.7	14.0	0.03	0.00	6.74	3.97	0.19	0.03	0.27	20.4	166.4	2.341	2.352	-0.0050
94	Run 3, Swab SHB-3 Well	SHB93-5	08/28/93	16.9	50.5	11.6	0.85	0.18	12.2	7.7	0.01	0.20	2.78	2.43	0.11	0.02	<0.05	39.1	129.9	1.389	1.469	-0.0556
94	Run 4, Swab SHB-3 Well	SHB93-6	08/29/93	16.9	53.5	16.7	1.15	0.16	12.3	6.0	0.02	26.8	2.28	2.65	0.11	0.03	<0.05	34.2	157.8	1.631	1.735	-0.0619
94	Run 5, Swab SHB-3 Well	SHB93-7	08/29/93	16.9	50.3	21.9	0.68	0.21	12.2	7.0	0.02	0.00	2.59	1.99	0.10	0.03	<0.05	35.7	144.3	1.875	1.901	-0.0138

* Analyses by Dale Counce

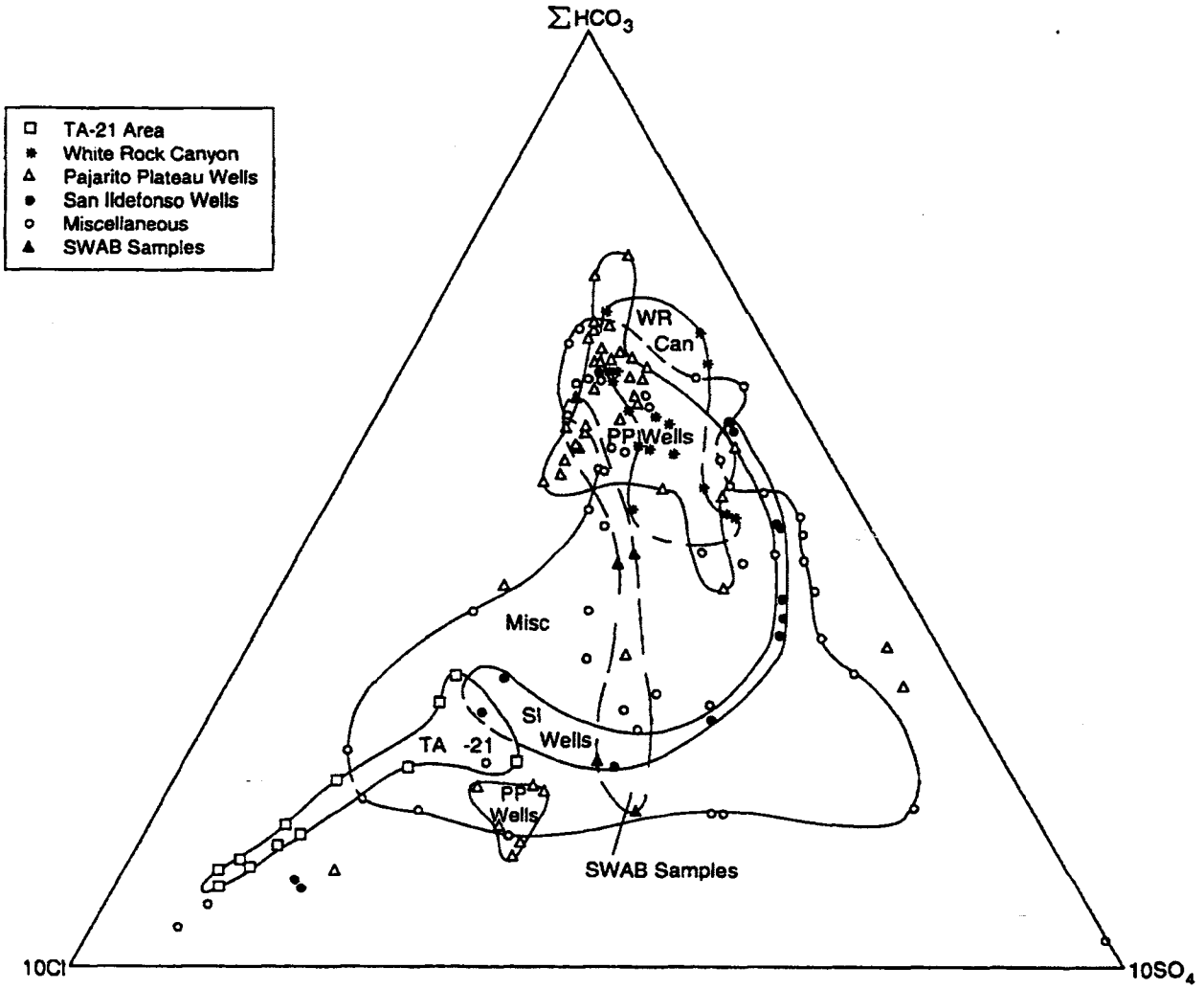

Figure 2: Triangular plot of weight percent bicarbonate, chloride, and sulfate, with chloride and sulfate concentrations multiplied by 10. Most waters in the study are calcium-bicarbonate waters.

Another possible reason for this observation is that the San Ildefonso area may be more effected than the Pajarito Plateau by deep mineralized water rising along faults in the Rio Grande rift. High concentrations of arsenic, fluoride, and chloride are specifically characteristic of thermal waters of deep origin (Goff and Sayer 1980). Arsenic, except in the PM-3 well, is below detection limits for every sample in this study, but high arsenic concentrations have been reported for wells that operated in the past on the Pajarito Plateau and have since been capped. Fluoride and chloride concentrations, however, are actually higher in the San Ildefonso samples (Table 2), which suggests that those samples are no less effected by rising deep thermal waters than Pajarito Plateau samples. This question of rising thermal water distribution between the Pajarito Plateau and the San Ildefonso area, then, remains unresolved. Samples from one well in the San Ildefonso region, Don Juan Playhouse Well, have the unusual combination of high temperatures and low soluble-element concentrations. This situation could be a result of sampling error, or an unusual pumping mechanism, among other possible explanations. In any event, the well apparently provides good drinking water.

Lithium concentrations within the Pajarito Plateau region vary more consistently with temperature, increasing as temperatures increase, than bromide, boron, or chloride concentrations in the same area. This could result from the fact that lithium was rarely used in industrial processes at the laboratory; so its anthropogenic effect on the surrounding groundwater has been minimal, and thus it should only vary with

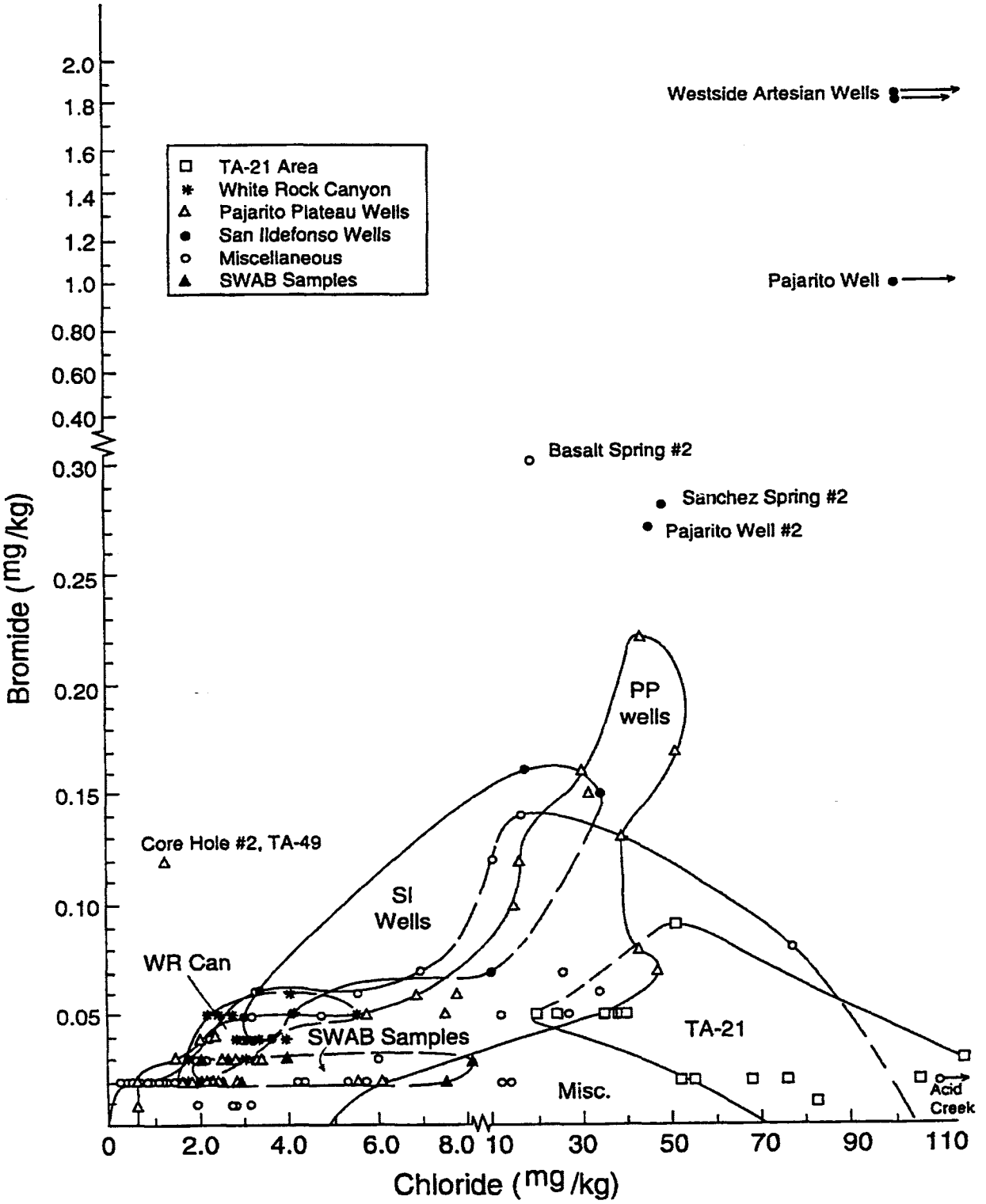

Figure 3: Bromide concentration plotted against chloride concentration in mg/kg for each sample in the study. As is also true in Figures 4 and 5 for boron and lithium concentrations, the typical concentrations of bromide and chloride in the Pajarito Plateau and San Ildefanso well samples are higher than they are in the White Rock Canyon and miscellaneous samples taken from surface sources. This observation is due to the higher temperatures at depth increasing the deeper waters' solubility. The deeper waters are also older, which means they have been exposed to dissolvable matter for a longer period of time, thus further increasing their dissolved constituent content.

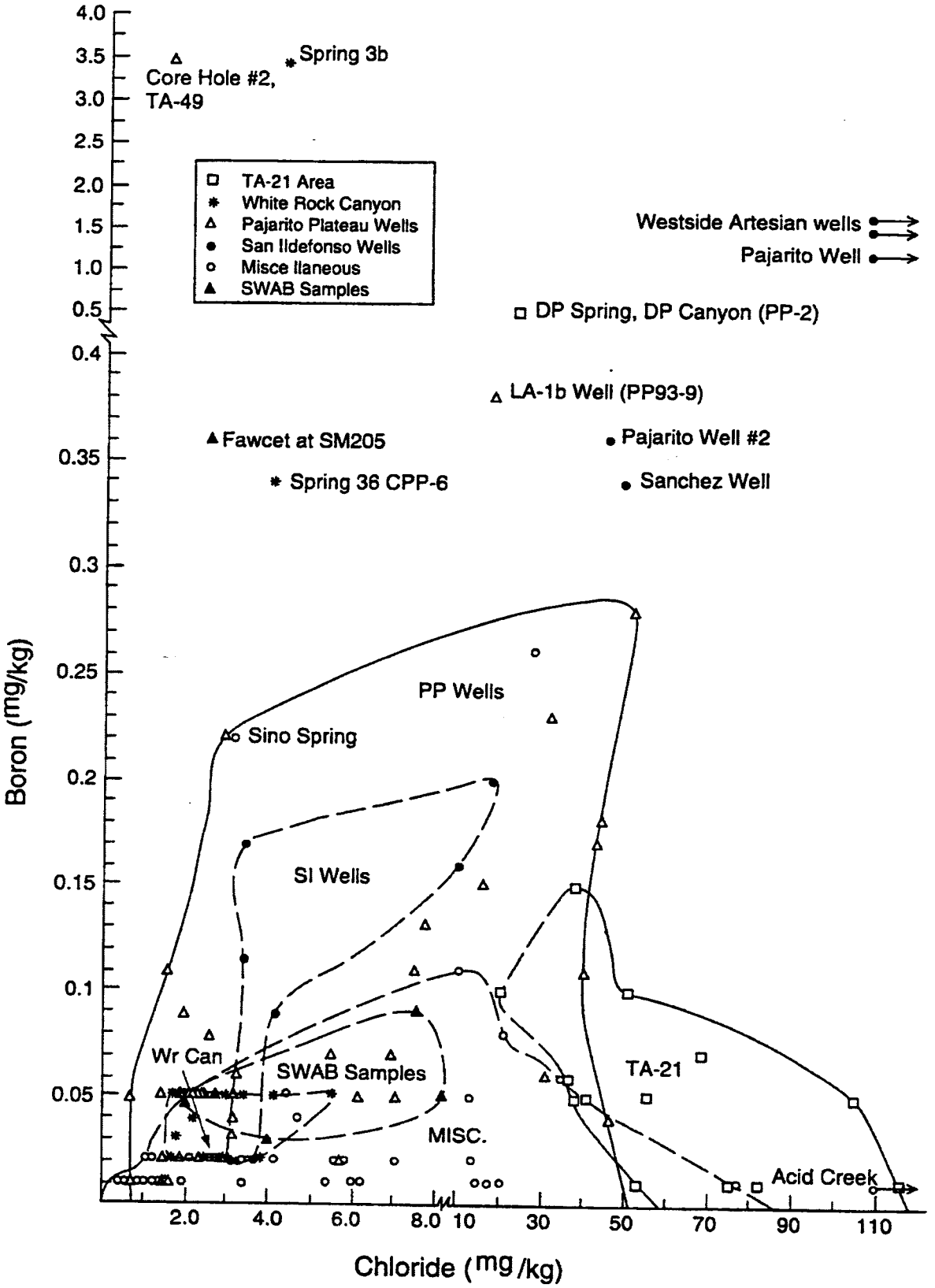

Figure 4: Boron concentration plotted against chloride concentration in mg/kg for each sample in the study.

natural processes. Boron, bromide, and chloride concentrations, in contrast, can increase in highly impacted areas. Left to the effects of natural processes exclusively, as with bromide, boron, and chloride, lithium usually increases in deeper waters because they are warmer and older. Figure 5 shows lithium concentration versus chloride concentration for each sample in the study. As expected, San Ildefonso well samples are higher in lithium than the surface samples because they come from deeper sources; however, the Pajarito Plateau well samples do not contain similarly elevated lithium concentrations. This discrepancy may be related to different proximities to lithium-rich source rocks: lithium, like SiO_2, typically increases in fluids in equilibrium with intermediate to silicic volcanic reservoir rocks, like Bandelier Tuff (White et al., 1984). The ability of different source rocks to release soluble constituents has not been studied for rocks of the Española Basin.

Sulfate is the dominant anion of acid-sulfate waters found west of the resurgent dome of the Valles Caldera. These waters are characterized by a high concentration of sulfate anions, a pH between 0.6 and 5, and low concentrations of boron and trace elements (Vuataz and Goff, 1986). Two samples in the study match all of these characterizations and are therefore considered relatives of acid-sulfate waters: VA-327 and 328 from Sulfur Creek at Baca Gate and Corbin's Cistern. They were both sampled in an area in the western caldera near Sulphur Springs.

B. Trace Element Analysis

Trace element analyses of the samples in this study are presented in Table 3. A common use of trace element data is to determine the presence of contaminants at a given location. Elevated levels of nitrate, phosphate, lead, chlorate, and one major anion, sulfate, are typically the best indicators of environmental impact. It is worth noting that no samples analyzed, except PP-3 and PP-13 in nitrate and PP93-18, VA-374, PP93-26, and SHB93-2 in lead, exceed the EPA drinking water limits for any of these elements; many samples, however, contain anomalously high quantities of one or more of these elements which, though not in excess of EPA limits, can most likely be explained by anthropogenic input. Those samples with such elevated quantities of sulfate, nitrate, phosphate, chlorate, or lead are mapped in Figures 6 through 10 respectively. Experience indicates that sulfate levels above 20 mg/kg, nitrate levels above 5 mg/kg, phosphate levels above 0.1 mg/kg, lead levels above 0.01 mg/kg, and any chlorate levels above threshold detection limits indicate some sort of unnatural influence on the groundwater chemistry (Shevenell et al., 1987; Goff et al., 1983; Adams et al., 1994).

Using concentrations of these elements as a measure of contamination, DP Site is the most impacted of the five areas in this study. Anomalously elevated levels of at least some of the listed cations and anions indicative of contamination were found in all of the samples from DP Spring, including: sulfate in PP-3, PP-13, and VA-346, nitrate in PP-1, PP-3, PP-13, PP93-28, PP93-29, PP93-30, and VA-345, phosphate in all the samples, lead in PP93-29, and chlorate in VA-345, VA-363, VA-364, PP93-29, PP93-30, and PP93-32. Measured nitrate levels in PP-3 and PP-13, both from the TA-21 outfall, exceed maximum levels allowed by the EPA for drinking water. From tracer studies in the area, we know the source for the contaminants at DP Site is not the sewage outfall in a side canyon upstream of the spring, but rather from either up the main canyon or from the mesa north of the spring (Adams et al., 1994).

Because they supply the drinking water for local communities, waters from the Pajarito Plateau and the San Ildefonso areas necessitate special attention. Though few contaminant levels in waters from these areas are in violation of EPA drinking water requirements, (lead levels in Deep Test Well 5a and PP93-18 from Test Well 1 being the only exceptions,) as with other areas in the study relatively elevated amounts of sulfate, nitrate, phosphate, lead, and chloride in a number of the wells reflect anthropogenic contribution (Figures 6-10). On the Pajarito Plateau, the most impacted well is the Test Well 1, White Rock "Y", which has relatively elevated levels of nitrate, lead, and sulfate. In Test Well 1a, White Rock "Y", higher relative amounts of phosphate and sulfate, but not lead are present, as is true for sample PP93-17 taken from Test Well 2a, Pueblo Canyon. In the San Ildefonso area, the only sample with elevated amounts of more than one contaminant is PP93-12 from Martinez Well, with slightly higher amounts of nitrate, phosphate, and sulfate. Nine other samples from the Pajarito Plateau and seven other samples from the San Ildefonso area show relatively elevated amounts of one of these cations or anions; these include, from the Pajarito Plateau: VA-371, PP93-9, PP93-17, and TW-2a in sulfate, PP93-17 and PP93-20 in phosphate, PP93-21, VA-374, PP93-

TABLE 3. Trace Element Analyses for Waters in the Pajarito Plateau and Outlying Areas, New Mexico (Values in (mg/kg)[a]

Map No.	Description	Sample No.	Date	Temp. (°C)	Ag	Al	As	Ba	Cd	ClO3	Co	Cr	Cs	Cu	Fe	Hg	I	Mn	Mo	NH4	Ni	NO2	NO3	Pb	PO4	Rb	Sb	Se	U	Zn
DP SPRING (TA-21)																														
1	DP Spring, DP Canyon		05/30/90	8.4	<0.001	<0.1	<0.1	0.05	<0.002	—	<0.002	0.003	<0.005	0.011	0.12	<0.1	0.03	<0.01	0.007	0.12	0.004	—	5.78	<0.002	1.17	0.007	<0.1	<0.1	<0.1	0.05
1	DP Spring, DP Canyon	PP-2	08/10/90	9.8	<0.001	0.92	<0.05	0.04	<0.001	—	<0.002	<0.002	<0.002	0.008	0.43	<0.1	0.03	<0.01	0.013	0.06	<0.002	<0.05	3.41	0.009	1.10	0.006	<0.1	<0.1	<0.1	0.02
1	DP Spring, DP Canyon	PP-4	09/06/90	10.5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	<0.05	2.45	—	1.16	—	—	—	—	—
1	DP Spring, DP Canyon	VA-345	05/15/91	11.4	<0.001	0.2	<0.05	0.09	<0.001	0.78	<0.002	<0.002	<0.005	0.006	0.34	<0.1	0.03	<0.02	0.004	0.10	<0.002	<0.02	4.29	<0.002	0.47	0.006	<0.1	<0.1	<0.1	<0.01
1	DP Spring, DP Canyon	VA-363	06/26/91	8.0	<0.001	<0.1	<0.05	0.06	0.001	0.43	<0.002	<0.002	<0.005	0.006	0.17	<0.1	0.01	0.05	0.004	0.04	<0.002	<0.02	3.64	0.002	0.60	0.004	<0.1	<0.1	<0.1	<0.01
1	DP Spring, DP Canyon	VA-364	07/11/91	8.4	<0.001	0.6	<0.05	0.02	0.001	0.21	<0.002	<0.002	<0.002	0.006	0.22	—	0.02	<0.01	0.006	0.14	<0.002	<0.02	4.35	0.002	0.62	0.003	<0.1	—	—	0.03
1	DP Spring, DP Canyon	VA-383	05/18/92	9.5	<0.002	<0.1	<0.1	0.11	<0.001	<0.1	0.002	0.003	0.007	0.005	0.05	—	<0.02	<0.01	0.007	0.08	0.003	<0.02	1.84	<0.002	0.48	0.024	<0.1	—	—	0.02
1	DP Spring, DP Canyon	PP93-28	05/26/93	7.3	<0.001	0.1	<0.05	0.06	0.001	<0.2	<0.002	<0.002	<0.002	0.005	0.01	—	<0.01	0.02	0.004	<0.02	0.007	<0.01	14.5	0.002	0.43	0.004	<0.1	—	—	0.02
1	DP Spring, DP Canyon	PP93-29	06/23/93	5.8	<0.001	0.3	0.0020	0.05	0.003	0.30	<0.002	<0.002	<0.002	0.021	0.14	<0.001	0.02	<0.01	0.004	0.02	0.006	1.02	14.6	0.014	0.44	0.003	0.001	<0.001	-	<0.01
1	DP Spring, DP Canyon	PP93-30	07/23/93	6.3	<0.0005	3.50	0.0030	0.06	<0.0002	0.12	<0.002	0.002	<0.002	0.003	1.65	<0.0002	0.01	<0.01	0.002	0.09	<0.002	<0.01	10.5	0.002	0.36	0.004	<0.002	<0.002	-	<0.01
1	DP Spring, DP Canyon	PP93-32	10/06/93	9.6	<0.0005	0.84	0.0027	0.05	0.0005	0.11	<0.002	0.003	<0.002	0.005	0.36	<0.0002	0.02	<0.01	0.005	0.08	0.006	<0.01	3.03	0.003	0.58	0.008	<0.002	<0.002	-	0.02
2	Outfall at TA-21	PP-3	08/10/90	12.3	<0.001	<0.05	<0.05	0.04	<0.001	—	0.003	<0.002	<0.002	0.031	0.03	<0.1	<0.01	<0.01	0.013	0.05	0.003	<0.05	153	<0.002	12.1	0.013	<0.1	<0.1	<0.1	0.16
2	Outfall at TA-21	PP-13	10/22/90	18.5	<0.001	<0.1	<0.05	0.10	<0.001	—	<0.002	0.003	<0.002	0.042	0.04	<0.1	<0.01	<0.01	0.010	0.10	0.007	—	184	0.002	17.1	0.012	<0.1	<0.1	<0.1	0.09
2	Outfall at TA-21	VA-346	05/15/91	12.3	<0.001	<0.1	<0.05	0.04	<0.001	<0.05	<0.002	0.002	<0.005	0.018	0.79	<0.1	<0.01	0.05	0.022	0.28	0.005	0.83	17.9	0.002	18.7	0.023	<0.1	<0.1	<0.1	0.05
WHITE ROCK CANYON SPRINGS																														
3	Spring 2	Spring2	11/91	<20	<0.001	<0.1	<0.05	0.02	0.002	—	<0.002	<0.002	0.006	0.012	<0.01	—	<0.02	<0.01	0.004	0.09	<0.002	<0.01	0.19	0.003	<0.02	0.006	—	—	—	0.01
4	Spring 3	PP-5	09/24/90	<20	<0.001	<0.1	<0.05	0.04	<0.001	—	<0.002	0.004	<0.002	<0.002	<0.01	<0.1	<0.01	<0.01	0.009	0.05	0.003	—	3.59	<0.002	<0.1	0.009	<0.1	<0.1	<0.1	0.02
4	Spring 3	Spring 3	11/91	<20	<0.001	<0.1	<0.05	0.03	<0.001	—	<0.002	0.002	<0.002	0.005	0.03	—	<0.02	<0.01	<0.002	0.05	<0.002	<0.01	3.84	0.006	<0.02	0.005	—	—	—	0.01
5	Spring 3b	PP-6	09/24/90	<20	<0.001	<0.1	<0.05	0.04	<0.001	—	<0.002	0.004	<0.002	0.024	<0.01	<0.1	<0.01	<0.01	0.010	0.13	<0.002	—	6.90	<0.002	<0.1	0.006	<0.1	<0.1	<0.1	0.01
5	Spring 3b	Spring 3b	11/91	<20	<0.001	<0.1	<0.05	0.03	<0.001	—	<0.002	0.004	<0.002	<0.002	<0.01	—	<0.02	<0.01	0.005	0.04	<0.002	<0.01	10.7	0.003	<0.02	0.006	—	—	—	<0.01
6	Spring 4a	Spring 4a	11/91	<20	<0.001	<0.1	<0.05	0.04	<0.001	—	<0.002	0.004	<0.002	0.003	0.13	—	<0.02	<0.01	<0.002	0.04	<0.002	<0.01	3.43	0.003	<0.02	0.006	—	—	—	0.02
7	Spring 6	Spring 6	11/91	<20	<0.001	<0.1	<0.05	0.02	<0.001	—	<0.002	0.006	0.005	<0.002	0.02	—	<0.02	<0.01	<0.002	0.04	<0.002	<0.01	1.09	0.003	<0.02	0.006	—	—	—	<0.01
8	Spring 6a	PP-7	09/25/90	<20	<0.001	<0.1	<0.05	0.02	<0.001	—	<0.002	0.004	<0.002	<0.002	<0.01	<0.1	<0.01	<0.01	0.002	0.04	<0.002	—	1.25	<0.002	<0.1	0.006	<0.1	<0.1	<0.1	<0.01
8	Spring 6a	Spring 6a	11/91	<20	<0.001	<0.1	<0.05	0.02	<0.001	—	<0.002	0.004	<0.002	0.007	0.06	—	<0.02	<0.01	<0.002	<0.04	0.002	0.08	1.44	<0.002	<0.02	0.005	—	—	—	0.01
9	Spring 7	PP-8	09/25/90	<20	<0.001	<0.1	<0.05	0.03	<0.001	—	<0.002	0.004	<0.002	0.004	<0.01	<0.1	<0.01	<0.01	0.002	0.07	0.006	—	2.68	<0.002	<0.1	0.009	<0.1	<0.1	<0.1	0.05
9	Spring 7	Spring 7	11/91	<20	<0.001	<0.1	<0.05	0.02	<0.001	—	<0.002	0.004	<0.002	0.004	<0.02	—	<0.02	<0.01	<0.002	<0.04	<0.002	0.04	1.05	0.002	<0.02	0.006	—	—	—	0.01
10	Spring 8	PP-9	09/25/90	<20	<0.001	<0.1	<0.05	0.05	<0.001	—	<0.002	0.003	<0.002	0.022	<0.01	<0.1	<0.01	<0.01	0.002	0.04	<0.002	—	3.51	<0.002	0.09	0.008	<0.1	<0.1	<0.1	<0.01
10	Spring 8	Spring 8	11/91	<20	<0.001	<0.1	<0.05	0.04	<0.001	—	<0.002	0.004	<0.002	0.007	<0.02	—	<0.02	<0.01	<0.002	<0.04	<0.002	<0.01	3.33	0.003	0.09	0.007	—	—	—	0.01
11	Spring 8b	PP-10	09/26/90	<20	<0.001	<0.1	<0.05	0.03	<0.001	—	<0.002	0.003	<0.002	<0.002	<0.01	<0.1	<0.01	<0.01	0.002	0.03	0.007	—	2.03	<0.002	<0.1	0.005	<0.1	<0.1	<0.1	<0.01
12	Spring 9a	Spring 9a	11/91	<20	<0.001	<0.1	<0.05	0.01	<0.001	—	<0.002	0.003	<0.002	0.006	0.07	—	<0.02	<0.01	<0.002	<0.04	<0.002	<0.01	0.78	0.002	<0.02	0.004	—	—	—	<0.01
13	Doe Spring	PP-11	09/25/90	<20	<0.001	<0.1	<0.05	0.03	<0.001	—	<0.002	<0.002	<0.002	<0.002	<0.01	<0.1	<0.01	<0.01	0.002	0.05	0.002	—	0.84	<0.002	<0.1	0.005	<0.1	<0.1	<0.1	<0.01
14	Ancho Spring	PP-12	09/25/90	<20	<0.001	<0.1	<0.05	0.03	<0.001	—	<0.002	0.004	<0.002	<0.002	<0.01	<0.1	<0.01	<0.01	<0.002	0.04	<0.002	—	1.26	<0.002	<0.1	0.005	<0.1	<0.1	<0.1	<0.01
14	Ancho Spring	Ancho Spring	11/91	<20	<0.001	<0.1	<0.05	0.02	<0.001	—	<0.002	0.005	<0.002	0.005	0.04	—	<0.02	<0.01	<0.002	0.15	<0.002	<0.01	0.80	0.004	<0.02	0.005	—	—	—	0.01
PAJARITO PLATEAU WELLS																														
15	Pajarito Mesa Well #1	VA-373	10/23/91	28.2	<0.001	<0.1	<0.05	0.06	0.001	<0.05	<0.002	0.005	0.006	0.011	<0.02	—	<0.02	<0.01	<0.002	0.04	<0.002	<0.02	2.08	<0.002	<0.02	0.009	<0.1	—	—	<0.01
15	Pajarito Mesa Well#1	PM-1	08/18/92	27.5	<0.001	<0.1	0.07	0.07	<0.001	—	<0.002	0.004	<0.002	0.004	0.07	—	<0.02	<0.01	<0.002	<0.05	<0.002	<0.02	1.62	<0.002	<0.05	0.010	<0.1	—	—	0.01
16	Pajarito Mesa Well #2	PM-2	08/18/92	23.3	<0.001	<0.1	<0.05	0.03	<0.001	—	<0.002	0.002	0.003	<0.002	0.07	—	<0.02	<0.01	<0.002	1.01	<0.002	<0.02	0.53	<0.002	<0.05	0.006	<0.1	—	—	0.02
16	Pajarito Mesa Well#2	PP93-15	05/19/93	22.4	<0.001	<0.1	<0.05	0.02	<0.001	<0.05	<0.002	0.003	<0.002	<0.002	<0.01	—	<0.01	<0.01	<0.002	<0.02	<0.002	<0.01	1.46	<0.002	0.06	0.005	<0.1	—	—	<0.01
17	Pajarito Mesa Well #3	PM-3	08/18/92	24.4	<0.001	<0.1	<0.05	0.05	<0.001	—	<0.002	<0.002	<0.002	0.003	0.06	—	<0.02	<0.01	<0.002	<0.05	<0.002	<0.02	1.32	0.005	<0.05	0.009	<0.1	—	—	0.01
17	Pajarito Mesa Well #3	PP93-20	05/19/93	27.7	<0.001	<0.1	<0.05	0.10	<0.001	<0.05	<0.002	0.007	<0.002	0.005	<0.01	—	<0.01	<0.01	<0.002	<0.02	<0.002	<0.01	1.99	0.006	0.19	0.010	<0.1	—	—	0.02
18	Pajarito Mesa Well #5	VA-372	10/23/91	24.7	<0.001	<0.1	<0.05	<0.01	<0.001	<0.05	<0.002	0.006	<0.002	0.007	<0.02	—	<0.02	<0.01	<0.002	0.13	<0.002	0.03	1.33	0.003	<0.02	0.005	<0.1	—	—	0.02
18	Pajarito Mesa Well #5	PM-5	08/18/92	26.6	<0.001	<0.1	<0.05	0.03	<0.001	—	<0.002	0.007	0.005	<0.002	0.21	—	<0.02	<0.01	<0.002	<0.05	<0.002	<0.02	0.55	0.004	<0.05	0.004	<0.1	—	—	0.01
19	Guaje Canyon Well #1	G-1	08/18/92	26.9	<0.001	<0.1	<0.05	0.06	<0.001	—	<0.002	0.008	<0.002	0.002	0.07	—	<0.02	<0.01	<0.002	<0.05	<0.002	<0.02	1.43	0.003	<0.05	0.008	<0.1	—	—	<0.01
20	Guaje Canyon Well #1a	G-1a	08/18/92	26.3	<0.001	<0.1	<0.05	0.04	<0.001	—	<0.002	0.007	0.003	<0.002	<0.01	—	<0.02	<0.01	0.002	<0.05	<0.002	<0.02	1.80	0.002	<0.05	0.006	<0.1	—	—	0.34
21	Guaje Canyon Well #2	G-2	08/18/92	29.8	<0.001	<0.1	<0.05	0.06	<0.001	—	<0.002	0.008	<0.002	<0.002	<0.01	—	<0.02	<0.01	<0.002	<0.05	<0.002	<0.02	1.71	<0.002	<0.05	0.005	<0.1	—	—	<0.01
22	Guaje Canyon Well #4	G-4	08/18/92	24.3	<0.001	<0.1	<0.05	0.01	<0.001	—	<0.002	0.008	<0.002	<0.002	<0.01	—	<0.02	<0.01	<0.002	0.07	<0.002	<0.02	2.49	<0.002	<0.05	0.004	<0.1	—	—	<0.01
23	Guaje Canyon Well #5	VA-370	10/22/91	25.7	<0.001	<0.1	<0.05	<0.01	<0.001	<0.05	<0.002	0.005	<0.002	0.005	<0.02	—	<0.02	<0.01	<0.002	0.10	0.002	<0.02	2.76	0.002	<0.02	0.006	<0.1	—	—	<0.01
23	Guaje Canyon Well #5	G-5	08/18/92	30.3	<0.001	<0.1	<0.05	<0.01	<0.001	—	<0.002	0.006	<0.002	<0.002	<0.01	—	<0.02	<0.01	<0.002	<0.05	<0.002	<0.02	2.68	0.002	<0.05	0.004	<0.1	—	—	<0.01
24	Guaje Canyon Well #6	G-6	08/18/92	30.3	<0.001	<0.1	<0.05	<0.01	<0.001	—	0.002	0.004	<0.002	<0.002	<0.01	—	<0.02	<0.01	<0.002	<0.05	<0.002	<0.02	1.74	0.002	<0.05	0.004	<0.1	—	—	<0.01
25	Water Canyon Gallery	WCG	08/18/92	15.3	<0.001	<0.1	<0.05	0.01	<0.001	—	<0.002	0.003	<0.002	<0.002	<0.01	—	<0.02	<0.01	0.009	<0.05	<0.002	<0.02	0.48	0.004	<0.05	0.004	<0.1	—	—	0.02
25	Water Canyon Gallery	PP93-27	05/20/93	11.3	<0.001	0.2	<0.05	0.02	0.001	<0.05	<0.002	<0.002	<0.002	0.002	0.05	—	<0.01	<0.01	<0.002	<0.02	<0.002	<0.01	0.98	0.005	0.07	0.006	<0.1	—	—	0.05

Map No.	Description	Sample No	Date	Temp. (C)	Ag	Al	As	Ba	Cd	ClO3	Co	Cr	Cs	Cu	Fe	Hg	I	Mn	Mo	NH4	Ni	NO2	NO3	Pb	PO4	Rb	Sb	Se	U	Zn
26	LA-1 Well	PP93-8	05/12/93	—	<0.001	<0.1	<0.05	<0.01	<0.001	<0.05	<0.002	<0.002	<0.002	<0.002	0.33	—	0.01	<0.01	0.003	0.11	<0.002	<0.01	0.04	0.003	<0.02	0.002	<0.1	—	—	<0.01
27	LA-1b Well	VA-371	10/22/91	31.8	<0.001	<0.1	<0.05	0.02	<0.001	<0.05	<0.002	0.023	<0.002	0.009	<0.02	—	<0.02	<0.01	0.009	0.06	<0.002	<0.02	2.97	0.003	<0.02	0.004	<0.1	—	—	0.02
27	LA-1b Well	PP93-9	05/12/93	31.5	<0.001	<0.1	<0.05	0.04	<0.001	<0.05	<0.002	0.027	<0.002	<0.002	0.01	—	<0.01	<0.01	0.010	0.04	<0.002	<0.01	2.26	0.003	<0.02	0.004	<0.1	—	—	0.02
28	LA-2 Well	PP93-7	05/12/93	—	<0.001	<0.1	<0.05	0.06	<0.001	<0.05	<0.002	0.011	<0.002	<0.002	0.01	—	<0.01	<0.01	0.002	0.05	<0.002	<0.01	2.06	0.004	<0.02	0.003	<0.1	—	—	<0.01
29	LA-5 Well	PP93-10	05/12/93	19.3	<0.001	<0.1	<0.05	0.06	<0.001	<0.05	<0.002	0.008	<0.002	<0.002	0.03	—	<0.01	<0.01	<0.002	0.05	<0.002	0.07	1.75	0.002	<0.02	0.004	<0.1	—	—	0.31
30	Test Well #1, White Rock Y	TW-1	10/08/92	14.0	<0.001	<0.1	<0.05	0.08	<0.001	—	<0.002	<0.002	<0.002	0.002	0.01	—	<0.02	0.03	<0.002	0.09	0.002	<0.02	25.3	0.011	<0.05	0.006	<0.1	—	—	0.80
30	Test Well #1, White Rock Y	PP93-18	05/19/93	14.1	<0.001	<0.1	<0.05	0.08	<0.001	<0.5	<0.002	<0.002	<0.002	<0.002	<0.01	—	<0.01	0.03	<0.002	0.02	<0.002	<0.01	25.7	0.015	<0.02	0.005	<0.1	—	—	0.71
31	Test Well #1a, White Rock Y	TW-1a	10/08/92	8.0	<0.001	<0.1	<0.05	0.07	<0.001	—	<0.002	<0.002	<0.002	<0.002	0.03	—	<0.02	0.19	0.009	0.66	0.004	<0.02	13.6	0.002	0.16	0.012	<0.1	—	—	0.81
31	Test Well #1a, White Rock Y	PP93-19	05/19/93	15.1	<0.001	<0.1	<0.05	0.08	<0.001	<0.5	<0.002	0.002	<0.002	0.005	0.42	—	<0.01	0.09	0.003	0.10	0.005	0.31	26.1	0.006	6.92	0.015	<0.1	—	—	0.50
32	Test Well #2, Pueblo Canyon	TW-2	10/08/92	15.9	<0.001	<0.1	<0.05	0.02	<0.001	—	<0.002	<0.002	<0.002	0.002	0.06	—	<0.02	0.04	<0.002	0.09	<0.002	<0.02	0.89	0.004	<0.05	0.003	<0.1	—	—	0.16
32	Test Well #2, Pueblo Canyon	PP93-16	05/19/93	17.4	<0.001	<0.1	<0.05	0.02	<0.001	<0.05	<0.002	<0.002	<0.002	<0.002	0.10	—	<0.01	0.06	0.003	0.02	<0.002	<0.01	0.92	0.002	<0.02	0.003	<0.1	—	—	0.09
33	Test Well #2a, Pueblo Canyon	TW-2a	10/08/92	11.6	<0.001	<0.1	<0.05	0.04	<0.001	—	<0.002	<0.002	<0.002	<0.002	<0.01	—	<0.02	0.26	<0.002	0.14	<0.002	0.75	11.6	0.005	<0.05	0.003	<0.1	—	—	6.93
33	Test Well #2a, Pueblo Canyon	PP93-17	05/19/93	14.5	<0.001	<0.1	<0.05	0.04	<0.001	<0.2	<0.002	<0.002	<0.002	<0.002	0.05	—	<0.01	0.11	<0.002	0.05	<0.002	<0.01	15.7	<0.002	0.17	0.003	<0.1	—	—	0.65
34	Test Well #3	PP93-23	05/20/93	21.3	<0.001	<0.1	<0.05	0.03	<0.001	<0.05	<0.002	0.003	<0.002	0.002	0.03	—	<0.01	0.02	0.002	0.02	<0.002	<0.01	2.61	0.004	0.04	0.007	<0.1	—	—	0.07
35	Test Well #4	PP93-21	05/19/93	11.0	<0.001	<0.1	<0.05	0.06	<0.001	<0.05	<0.002	<0.002	<0.002	0.003	0.02	—	<0.01	0.25	<0.002	0.06	<0.002	<0.01	0.02	0.014	<0.02	0.018	<0.1	—	—	0.31
36	Deep Test Well, #5a	VA-374	10/23/91	17.6	<0.001	<0.1	<0.05	<0.01	0.001	<0.05	<0.002	0.003	0.002	0.004	0.06	—	<0.02	<0.01	<0.002	0.03	<0.002	0.19	1.02	0.030	<0.02	0.005	<0.1	—	—	0.25
36	Deep Test Well, #5a	PP93-26	05/20/93	18.1	<0.001	0.9	<0.05	0.02	0.001	<0.05	<0.002	0.002	<0.002	<0.002	0.04	—	<0.01	0.02	<0.002	<0.02	<0.002	<0.01	1.40	0.037	0.06	0.007	<0.1	—	—	0.78
37	Deep Test Well #9	PP93-25	05/20/93	15.4	<0.001	<0.1	<0.05	0.02	<0.001	<0.05	<0.002	0.003	<0.002	0.003	<0.01	—	<0.01	<0.01	<0.002	0.02	0.002	<0.01	1.41	0.003	0.06	0.004	<0.1	—	—	0.18
38	Deep Test Well #10	PP93-24	05/20/93	16.6	<0.001	0.1	<0.05	<0.01	0.001	<0.05	<0.002	0.002	<0.002	0.002	0.47	—	<0.01	<0.01	<0.002	0.02	<0.002	<0.01	0.72	0.004	<0.02	0.007	<0.1	—	—	0.42
39	Otowi #4 Well	OT-4	03/02/93	28.8	<0.001	<0.1	<0.05	0.05	<0.001	—	<0.002	0.007	<0.002	0.004	<0.01	—	<0.01	<0.01	<0.002	0.06	<0.002	<0.02	<0.02	0.005	<0.02	0.008	<0.1	—	—	0.15
39	Otowi #4 Well	PP93-22	05/20/93	27.5	<0.001	0.1	<0.05	0.05	<0.001	<0.05	<0.002	0.007	<0.002	<0.002	<0.01	—	<0.01	<0.01	<0.002	0.02	<0.002	<0.01	1.58	0.006	0.04	0.010	<0.1	—	—	0.02
40	Core Hole #2, TA-49	CH-2	05/07/93	—	<0.001	<0.1	<0.05	<0.01	<0.001	—	<0.002	0.003	<0.002	0.003	0.03	—	<0.01	<0.01	0.003	0.82	<0.002	<0.02	0.33	0.010	<0.02	0.021	<0.1	—	—	0.13
74	LADP-3 Well at 320 ft.	PP93-36	12/01/93	9.0	<0.0005	0.21	<0.001	0.02	<0.001	<0.02	0.004	0.003	0.002	0.008	0.13	<0.002	<0.01	0.44	0.022	0.32	0.026	0.37	1.21	<0.002	<0.02	0.046	<0.001	<0.001	-	0.16
75	Test Well #8	PP93-37	12/06/93	—	<0.0005	<0.05	<0.001	<0.01	0.0023	<0.02	<0.002	0.013	<0.002	0.006	0.07	<0.0005	<0.01	<0.01	<0.002	0.04	0.031	0.02	0.22	0.010	<0.02	0.006	<0.001	<0.001	—	0.82
SAN ILDEFANSO WELLS																														
41	East Side Artesian Well	VA-376	03/05/92	14.8	<0.001	<0.1	<0.05	0.02	<0.001	—	<0.002	<0.002	<0.002	0.006	0.18	—	<0.01	<0.01	0.011	0.12	<0.002	<0.01	0.04	0.005	<0.05	0.003	<0.1	—	—	<0.01
41	East Side Artesian Well	PP93-2	05/12/93	14.4	<0.001	<0.1	<0.05	<0.01	<0.001	<0.05	0.002	0.002	<0.002	<0.002	0.12	—	0.02	<0.01	0.005	0.14	<0.002	<0.01	0.02	0.003	<0.02	0.002	<0.1	—	—	<0.01
42	Westside Artesian Well	VA-380	03/05/92	17.7	<0.001	<0.1	<0.05	0.03	<0.001	—	<0.002	<0.002	<0.002	0.002	0.03	—	0.16	<0.01	0.020	0.04	<0.002	<0.01	<0.02	<0.002	<0.05	0.002	<0.1	—	—	<0.01
42	Westside Artesian Well	PP93-11	05/18/93	17.8	<0.001	<0.1	<0.05	0.05	<0.001	<0.05	<0.002	<0.002	<0.002	0.004	0.10	—	0.16	0.01	0.023	0.05	<0.002	<0.01	0.12	0.004	<0.02	0.003	<0.1	—	—	0.03
43	Don Juan Playhouse Well	VA-377	03/05/92	19.1	<0.001	<0.1	<0.05	<0.01	<0.001	—	<0.002	0.011	<0.002	<0.002	<0.01	—	<0.01	<0.01	0.004	0.04	<0.002	<0.01	7.72	<0.002	<0.05	0.003	<0.1	—	—	<0.01
43	Don Juan Playhouse Well	PP93-3	05/12/93	19.2	<0.001	<0.1	<0.05	<0.01	<0.001	<0.1	<0.002	0.013	<0.002	<0.002	<0.01	—	<0.01	<0.01	0.002	0.19	<0.002	<0.01	8.69	0.003	<0.02	<0.002	<0.1	—	—	<0.01
44	Halliday House Well	VA-378	03/05/92	15.7	<0.001	<0.1	<0.05	0.03	<0.001	—	<0.002	0.013	0.003	<0.002	<0.01	—	<0.01	<0.01	0.003	0.05	<0.002	<0.01	2.31	<0.002	<0.05	<0.002	<0.1	—	—	<0.01
44	Halliday House Well	PP93-5	05/12/93	17.2	<0.001	<0.1	<0.05	0.04	<0.001	<0.05	<0.002	0.018	<0.002	<0.002	0.03	—	<0.01	<0.01	0.002	0.13	<0.002	<0.01	2.25	0.003	<0.02	<0.002	<0.1	—	—	<0.01
45	Pajarito Well	VA-379	03/05/92	16.4	<0.001	<0.1	<0.05	0.08	<0.001	—	<0.002	0.003	0.003	0.002	<0.01	—	<0.01	<0.01	0.008	0.04	<0.002	<0.01	0.83	<0.002	<0.05	0.004	<0.1	—	—	0.05
45	Pajarito Well #2	PP93-14	05/18/93	16.6	<0.001	<0.1	<0.05	0.11	<0.001	<0.1	<0.002	0.003	<0.002	0.004	0.04	—	<0.01	<0.01	0.006	<0.02	<0.002	<0.01	7.03	<0.002	0.04	<0.002	<0.1	—	—	<0.01
46	New Comm. Well, S.I. Pueblo	PP93-1	05/12/93	13.4	<0.001	<0.1	<0.05	0.03	<0.001	<0.1	<0.002	0.003	<0.002	0.003	0.01	—	<0.01	<0.01	<0.002	0.04	<0.002	<0.01	4.66	0.006	<0.02	0.003	<0.1	—	—	0.03
47	Otowi House Well	PP93-4	05/12/93	15.5	<0.001	<0.1	<0.05	0.28	<0.001	<0.05	<0.002	0.002	<0.002	0.002	0.01	—	<0.01	0.02	<0.002	0.09	<0.002	<0.01	1.13	0.005	<0.02	0.002	<0.1	—	—	0.13
48	Martinez Well	PP93-12	05/18/93	16.4	<0.001	<0.1	<0.05	0.18	<0.001	<0.5	<0.002	0.002	<0.002	0.010	<0.01	—	<0.01	<0.01	0.006	0.02	<0.002	<0.01	38.9	<0.002	0.12	<0.002	<0.1	—	—	0.04
49	Sanchez Well	PP93-13	05/18/93	16.5	<0.001	<0.1	<0.05	0.12	<0.001	<0.05	<0.002	<0.002	<0.002	0.011	0.01	—	<0.01	<0.01	0.009	0.02	<0.002	<0.01	4.21	<0.002	0.06	0.002	<0.1	—	—	0.06
MISC. WATERS AND SPRINGS																														
50	LANL TA-33 Drain, TA-33-86 Outfall	TA-33-1	02/08/91	10.6	<0.001	<0.1	<0.05	0.02	<0.001	—	<0.002	0.006	<0.002	0.004	0.03	<0.1	<0.01	<0.01	0.003	0.09	0.004	—	0.99	<0.002	<0.02	0.009	<0.1	<0.1	<0.1	0.03
50	LANL TA-33 Drain, TA-33-86 Outfall		02/22/91	10.6	<0.001	<0.1	<0.05	0.03	<0.001	—	<0.002	<0.002	<0.002	0.003	0.11	<0.1	<0.01	0.02	0.002	0.13	<0.002	—	0.04	<0.002	<0.02	0.005	<0.1	<0.1	<0.1	0.01
51	LANL TA-33 Drain, 30 ft. E. of TA-33-1	TA-33-2	02/08/91	0.1	<0.001	<0.1	<0.05	0.02	<0.001	—	<0.002	<0.002	<0.002	0.004	0.06	<0.1	<0.01	0.01	0.002	0.09	<0.002	—	0.05	<0.002	<0.02	0.007	<0.1	<0.1	<0.1	0.02
51	LANL TA-33 Drain, 30 ft. E. of TA-33-3	TA-33-4	02/22/91	0.1	<0.001	<0.1	<0.05	0.02	<0.001	—	<0.002	0.005	<0.002	0.002	0.02	<0.1	<0.01	<0.01	<0.002	0.04	<0.002	—	0.06	<0.002	<0.02	0.007	<0.1	<0.1	<0.1	0.01
52	Sulfur Creek at Baca Gate	VA-327	05/07/91	8.1	<0.001	4.7	<0.05	0.04	<0.001	<0.05	<0.002	<0.002	<0.005	0.004	6.31	<0.1	<0.01	3.00	<0.002	0.06	<0.002	<0.02	0.03	<0.002	<0.05	0.012	<0.1	<0.1	<0.1	0.03
53	Corbet's Cistern	VA-328	05/07/91	8.2	<0.001	<0.1	<0.05	0.04	<0.001	<0.05	<0.002	<0.002	<0.005	0.004	<0.02	<0.1	<0.01	<0.02	0.003	0.09	<0.002	<0.02	0.10	<0.002	<0.05	0.007	<0.1	<0.1	<0.1	0.01
54	Pajarito Spring	VA-330	05/09/91	22.2	<0.001	<0.1	<0.05	0.04	<0.001	<0.05	<0.002	0.005	<0.005	<0.002	<0.02	<0.1	<0.01	<0.02	<0.002	0.04	<0.002	<0.02	2.95	<0.002	<0.05	0.040	<0.1	<0.1	<0.1	<0.01
55	Rio Grande Spring	VA-331	05/09/91	16.8	<0.001	<0.1	<0.05	0.04	<0.001	<0.05	<0.002	0.003	<0.005	<0.002	0.06	<0.1	<0.01	<0.02	<0.002	0.03	<0.002	<0.02	2.34	<0.002	<0.05	0.020	<0.1	<0.1	<0.1	<0.01
56	LA Creek above Reservoir	VA-332	05/09/91	9.4	<0.001	0.4	<0.05	0.01	<0.001	<0.05	<0.002	0.061	<0.005	0.003	1.03	<0.1	<0.01	0.01	<0.002	0.05	<0.002	<0.02	<0.02	<0.002	<0.05	0.014	<0.1	<0.1	<0.1	<0.01
76	Seven Springs	VA-333	05/10/91	11.5	<0.001	<0.1	<0.05	0.01	<0.001	<0.05	<0.002	0.011	<0.005	<0.002	0.52	<0.1	<0.01	<0.02	<0.002	0.04	<0.002	<0.02	0.47	<0.002	<0.05	0.020	<0.1	<0.1	<0.1	0.01

Map No	Description	Sample No.	Date	Temp. (°C)	Ag	Al	As	Ba	Cd	ClO3	Co	Cr	Cs	Cu	Fe	Hg	I	Mn	Mo	NH4	Ni	NO2	NO3	Pb	PO4	Rb	Sb	Se	U	Zn
77	Horseshoe Spring	VA-335	05/10/91	9.6	<0.001	<0.1	<0.05	0.10	0.001	<0.05	<0.002	0.005	<0.005	<0.002	0.03	<0.1	<0.01	<0.02	<0.002	0.03	<0.002	<0.02	0.77	0.002	<0.05	0.007	<0.1	<0.1	<0.1	1.70
78	Redondo Creek	VA-336	05/10/91	15.8	<0.001	0.2	<0.05	0.01	<0.001	<0.05	<0.002	0.002	<0.005	0.005	0.92	<0.1	<0.01	0.07	<0.002	0.07	<0.002	<0.02	<0.02	<0.002	<0.05	0.006	<0.1	<0.1	<0.1	0.02
79	Panorama Spring	VA-340	05/13/91	13.2	<0.001	<0.1	<0.05	0.13	<0.001	<0.05	<0.002	<0.002	<0.005	0.003	0.18	<0.1	<0.01	0.09	0.005	0.06	<0.002	<0.02	0.51	<0.002	<0.05	0.017	<0.1	<0.1	<0.1	0.01
80	Sino Spring	VA-341	05/13/91	15.6	<0.001	<0.1	<0.05	0.02	<0.001	<0.05	<0.002	<0.002	<0.005	<0.002	<0.02	<0.1	<0.01	<0.02	<0.002	0.06	<0.002	<0.02	<0.02	0.002	<0.05	0.008	<0.1	<0.1	<0.1	0.01
80	Sino Spring	VA-393	06/08/92	19.1	<0.002	<0.1	<0.05	<0.01	<0.002	—	<0.002	<0.002	<0.002	<0.002	<0.01	—	<0.02	<0.01	<0.002	0.03	<0.002	<0.02	1.30	<0.002	<0.05	0.003	<0.1	—	—	<0.01
81	San Antonio Creek	VA-342	05/14/91	10.4	<0.001	0.2	<0.05	0.02	<0.001	<0.05	<0.002	<0.002	<0.005	<0.002	1.16	<0.1	<0.01	0.24	<0.002	0.15	<0.002	<0.02	<0.02	0.002	<0.05	0.010	<0.1	<0.1	<0.1	0.02
82	E. Fork Jemez River	VA-344	05/14/91	14.0	<0.001	0.3	<0.05	0.01	<0.001	<0.05	<0.002	0.003	<0.005	0.004	1.08	<0.1	<0.01	0.06	<0.002	0.19	<0.002	<0.02	0.06	0.003	<0.05	0.005	<0.1	<0.1	<0.1	0.02
57	Los Alamos Creek	VA-347	05/15/91	10.8	<0.001	<0.1	<0.05	0.05	<0.001	<0.05	<0.002	0.003	<0.005	0.005	0.16	<0.1	<0.01	<0.02	0.210	0.05	<0.002	<0.02	<0.02	<0.002	0.12	0.005	<0.1	<0.1	<0.1	<0.01
58	Sacred Spring	VA-348	05/16/91	12.9	<0.001	<0.1	<0.05	0.05	0.001	<0.05	0.003	0.002	<0.005	0.007	<0.02	<0.1	<0.01	<0.02	0.004	0.17	<0.002	<0.02	0.08	<0.002	<0.05	0.003	<0.05	<0.1	<0.1	0.05
59	Turkey Springs	VA-349	05/17/91	16.5	<0.001	<0.1	<0.05	0.02	<0.001	<0.05	0.002	<0.002	<0.005	<0.002	<0.02	<0.1	<0.01	<0.02	<0.002	0.11	<0.002	<0.02	2.17	0.002	<0.05	0.004	<0.05	<0.1	<0.1	0.07
60	Apache Spring	VA-350	05/20/91	8.3	<0.001	0.2	<0.05	0.06	<0.001	<0.05	<0.002	<0.002	<0.005	0.003	0.16	<0.1	<0.01	<0.02	<0.002	0.09	<0.002	<0.02	1.55	<0.002	0.10	0.007	<0.05	<0.1	<0.1	0.03
61	Armistead Spring	VA-351	05/17/91	7.1	<0.001	1.7	<0.05	0.06	<0.001	<0.05	<0.002	<0.002	<0.005	0.003	3.73	<0.1	<0.01	<0.02	0.003	0.11	<0.002	0.02	0.62	<0.002	0.05	0.005	<0.05	<0.1	<0.1	0.05
62	Frijoles Spring #49	VA-352	05/22/91	6.4	<0.001	1.0	<0.05	0.06	<0.001	<0.05	<0.002	<0.002	<0.005	0.003	2.12	<0.1	<0.01	<0.02	<0.002	0.09	<0.002	<0.02	0.30	<0.002	<0.05	0.006	<0.05	<0.1	<0.1	<0.01
63	Frijoles Spring #50	VA-353	05/22/91	10.6	<0.001	0.5	<0.05	0.03	<0.001	<0.05	<0.002	<0.002	<0.005	0.003	1.08	<0.1	<0.01	<0.02	<0.002	0.08	<0.002	<0.02	0.71	<0.002	0.11	0.007	<0.05	<0.1	<0.1	0.02
64	Pajarito Creek	VA-354	05/22/91	10.9	<0.001	0.5	<0.05	0.02	<0.001	<0.05	<0.002	<0.002	<0.005	0.004	1.01	<0.1	<0.01	<0.02	<0.002	0.16	<0.002	0.02	0.16	<0.002	<0.05	0.008	<0.05	<0.1	<0.1	0.02
65	Upper Guaje Creek	VA-355	05/23/91	10.0	<0.001	0.2	<0.05	0.01	0.001	<0.05	<0.002	<0.002	<0.005	0.010	0.58	<0.1	<0.01	<0.02	<0.002	0.17	<0.002	<0.02	0.17	<0.002	<0.05	0.011	<0.05	<0.1	<0.1	0.03
66	Pine Spring	VA-356	05/24/91	12.6	<0.003	1.4	<0.05	0.05	<0.001	<0.05	<0.002	0.004	0.006	0.004	4.17	<0.1	<0.01	<0.02	<0.002	0.24	<0.002	<0.02	0.04	0.003	<0.05	0.007	<0.05	<0.1	<0.1	0.07
67	Unnamed Spring near Apache Spring	VA-357	05/28/91	15.7	<0.001	3.8	<0.05	0.08	0.001	<0.05	<0.002	0.004	0.007	0.007	13.4	<0.1	<0.01	<0.02	<0.002	0.38	<0.002	<0.02	0.09	0.005	<0.05	0.010	<0.05	<0.1	<0.1	0.06
68	Basalt Spring #2	VA-358	06/11/91	12.1	<0.001	<0.1	<0.05	0.04	<0.001	<0.05	<0.002	0.007	0.005	0.002	<0.02	<0.1	<0.01	<0.02	0.002	0.08	<0.002	<0.02	15.5	0.002	<0.05	0.008	<0.1	<0.1	<0.1	0.01
69	Basalt Spring #1	VA-359	06/11/91	11.8	<0.001	<0.1	<0.05	0.04	<0.001	<0.05	<0.002	0.004	0.006	0.004	<0.02	<0.1	<0.01	<0.02	<0.002	0.07	<0.002	<0.02	19.1	<0.002	2.73	0.007	<0.1	<0.1	<0.1	<0.01
70	Black Canyon Spring	VA-360	06/13/91	8.1	<0.001	0.2	<0.05	0.02	<0.001	<0.05	<0.002	<0.002	<0.005	0.004	0.74	<0.1	<0.01	<0.02	<0.002	0.07	<0.002	<0.02	0.03	0.002	<0.05	<0.002	<0.1	<0.1	<0.1	0.01
71	Acid Creek	VA-362	06/23/91	8.2	<0.001	<0.1	<0.05	0.04	<0.001	0.23	<0.002	<0.002	0.005	0.003	<0.02	<0.1	<0.01	<0.02	<0.002	0.02	<0.002	<0.02	4.63	<0.002	0.72	0.003	<0.1	<0.1	<0.1	<0.01
84	Santa Fe Lake	VA-365	07/17/91	13.5	<0.001	<0.1	<0.05	<0.01	<0.001	<0.05	<0.002	<0.002	<0.002	0.007	<0.01	—	<0.01	<0.01	<0.002	0.09	<0.002	<0.02	0.02	<0.002	<0.05	<0.002	<0.1	—	—	<0.01
85	Unnamed Spring, FR-150	VA-366	07/17/91	3.9	<0.001	<0.1	<0.05	<0.01	0.001	<0.05	<0.002	<0.002	<0.002	0.004	<0.01	—	<0.01	<0.01	<0.002	0.04	<0.002	<0.02	0.42	<0.002	<0.05	<0.002	<0.1	—	—	<0.01
86	Unnamed Spring #2, FR-150	VA-367	07/17/91	13.7	<0.001	<0.1	<0.05	<0.01	<0.001	<0.05	<0.002	<0.002	<0.002	0.002	<0.01	—	<0.01	<0.01	<0.002	0.07	<0.002	<0.02	0.07	<0.002	<0.05	<0.002	<0.1	—	—	<0.01
87	Chupadero Creek	VA-368	07/18/91	11.3	<0.001	<0.1	<0.05	<0.01	<0.001	<0.05	<0.002	<0.002	<0.002	0.002	0.05	—	<0.01	<0.01	<0.002	0.05	<0.002	<0.02	<0.02	<0.002	<0.05	<0.002	<0.1	—	—	<0.01
88	Canyon de la Loba Creek	VA-369	07/18/91	14.4	<0.001	0.2	<0.05	<0.01	<0.001	<0.05	<0.002	<0.002	<0.002	0.002	0.18	—	<0.01	<0.01	<0.002	0.06	<0.002	<0.02	0.51	<0.002	<0.05	<0.002	<0.1	—	—	<0.01
72	Homestead Spring	VA-381	04/07/92	7.8	<0.002	2.2	<0.1	0.04	<0.001	—	0.002	0.003	0.004	0.008	0.89	—	<0.01	<0.01	<0.002	0.13	0.032	<0.01	<0.02	<0.002	<0.05	0.009	<0.1	—	—	0.09
73	Indian Spring	PP93-6	05/12/93	19.8	<0.001	<0.1	0.050	0.10	<0.001	<0.05	<0.002	0.006	<0.002	<0.002	<0.01	—	<0.01	<0.01	<0.002	0.05	<0.002	<0.01	3.47	0.002	<0.02	0.005	<0.1	—	—	0.25
89	Unnamed Spring north of Ice Rink	PP93-31	09/10/93	14.0	<0.0005	0.60	0.0060	0.03	<0.0002	<0.05	<0.002	0.003	<0.002	0.008	0.44	<0.0002	<0.01	<0.01	<0.002	0.16	<0.002	<0.01	1.62	0.002	<0.02	0.007	<0.002	<0.002	—	0.10
90	Chaquehui Creek below TA-33	PP93-33	10/23/93	13.3	<0.0005	0.06	0.0008	0.01	<0.0002	<0.02	<0.002	<0.002	<0.002	0.008	0.02	<0.0002	<0.01	0.01	<0.002	0.56	0.006	<0.01	0.43	<0.002	<0.02	0.002	<0.002	<0.002	—	0.03
91	2 mile Creek dnstrm of Van de Graff	PP93-34	10/19/93	6.0	<0.0005	1.41	0.0006	0.05	<0.0002	<0.02	<0.002	0.003	<0.002	0.012	0.67	<0.0002	<0.01	0.02	0.004	0.17	0.039	<0.01	0.18	0.002	<0.02	0.007	<0.002	<0.002	—	0.04
92	2 mile Crk upstrm 50m frm PP93-34	PP93-35	10/19/93	6.0	<0.0005	0.74	0.0004	0.04	<0.0002	<0.02	<0.002	<0.002	<0.002	0.007	0.30	<0.0002	<0.01	<0.01	0.003	0.14	0.029	<0.01	0.31	<0.002	<0.02	0.004	<0.002	<0.002	—	<0.01
80	Sino Spring	VA-396	06/16/93	21.5	<0.001	<0.05	0.0010	0.01	<0.0005	—	<0.002	<0.002	<0.002	0.006	<0.01	<0.001	<0.01	<0.01	0.002	0.06	<0.002	0.12	0.75	0.004	<0.05	0.004	<0.001	<0.001	—	<0.01
SWAB SAMPLES, SHB-3 COREHOLE, TA-16																														
93 [a]	Faucet at SM 205, Drilling Water	SHB92-1	07/07/93	16.9	<0.001	<0.1	<0.05	0.03	<0.001	—	<0.002	0.007	<0.002	0.008	0.02	—	<0.02	<0.01	0.002	0.11	<0.002	<0.02	1.53	0.005	<0.05	0.007	<0.1	—	—	0.74
94	In-situ sample SHB-3 Well 258m.	SHB93-2	07/20/93	16.9	<0.001	<0.05	<0.001	0.08	<0.0005	—	<0.002	0.005	0.002	0.014	0.08	<0.001	<0.01	<0.01	0.11	0.48	0.005	<0.02	0.52	0.022	0.02	0.069	<0.001	<0.001	—	0.14
94	Run 1, Swab SHB-3 Well	SHB93-3	08/93	16.4	<0.0005	<0.05	<0.002	0.04	<0.0005	<0.05	<0.002	<0.002	<0.002	<0.002	0.11	<0.0002	<0.01	<0.01	0.10	0.38	<0.002	0.17	0.59	0.014	<0.02	0.090	<0.002	<0.002	—	0.11
94	Run 2, Swab SHB-3 Well	SHB93-4	08/93	16.6	<0.0005	0.06	<0.002	0.03	<0.0005	<0.05	<0.002	<0.002	<0.002	0.011	0.02	<0.0002	<0.01	<0.01	0.060	0.38	<0.002	0.06	1.63	0.007	0.02	0.110	<0.002	<0.002	—	0.05
94	Run 3, Swab SHB-3 Well	SHB93-5	08/93	16.9	<0.0005	<0.05	<0.002	0.01	<0.0005	<0.05	<0.002	<0.002	<0.002	<0.002	0.02	<0.0002	<0.01	<0.01	0.11	0.10	<0.002	0.03	1.77	0.005	0.10	0.060	<0.002	<0.002	—	0.01
94	Run 4, Swab SHB-3 Well	SHB93-6	08/93	16.9	<0.0005	<0.05	<0.002	<0.01	<0.0005	<0.05	<0.002	<0.002	<0.002	<0.002	0.04	<0.0002	<0.01	<0.01	0.006	0.09	<0.002	0.04	1.68	0.003	<0.02	0.050	<0.002	<0.002	—	<0.01
94	Run 5, Swab SHB-3 Well	SHB93-7	08/93	16.9	<0.0005	<0.05	<0.002	0.01	<0.0005	<0.05	<0.002	<0.002	<0.002	0.009	0.02	<0.0002	<0.01	<0.01	0.010	0.12	<0.002	0.01	1.59	0.005	<0.02	0.060	<0.002	<0.002	—	<0.01

[a] Analyses by Dale Counce

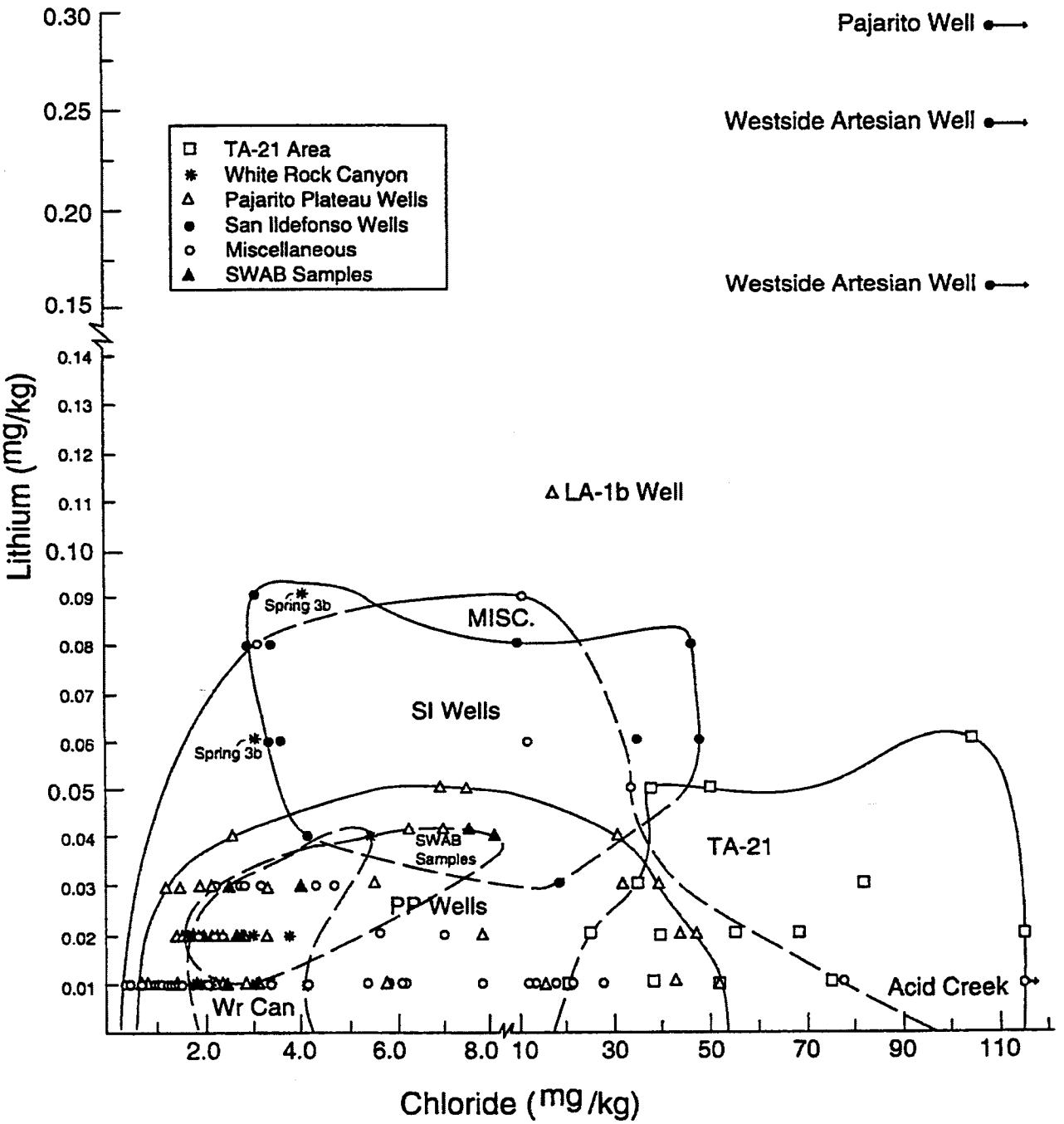

Figure 5: Lithium concentration plotted against chloride concentration in mg/kg for each sample in the study.

26, CH-2, and PP93-37 in lead, and, from the San Ildefonso area, VA-380, PP93-11, VA-379, PP93-14, PP93-1, PP93-4, and PP93-13 in sulfate (Figures 6-10).

Figures 6 through 10 provide clues as to the source of contaminants in the study area. In Figure 6, most of those samples highest in sulfate are from the San Ildefonso Reservation northeast of the lab. Elevated sulfate levels in groundwater commonly result from fertilizer use (Mazor, 1991); thus active farming on the San Ildefonso Reservation seems the most likely cause of sulfate in local waters. Further, because contaminants are more concentrated at their source, one would expect to find higher sulfate concentrations in wells near the laboratory if it were the only sulfate source, and this is not observed. Similar to sulfate, elevated nitrate levels in groundwater (Fig.7) often result from fertilizer use or from stock (Mazor, 1991).

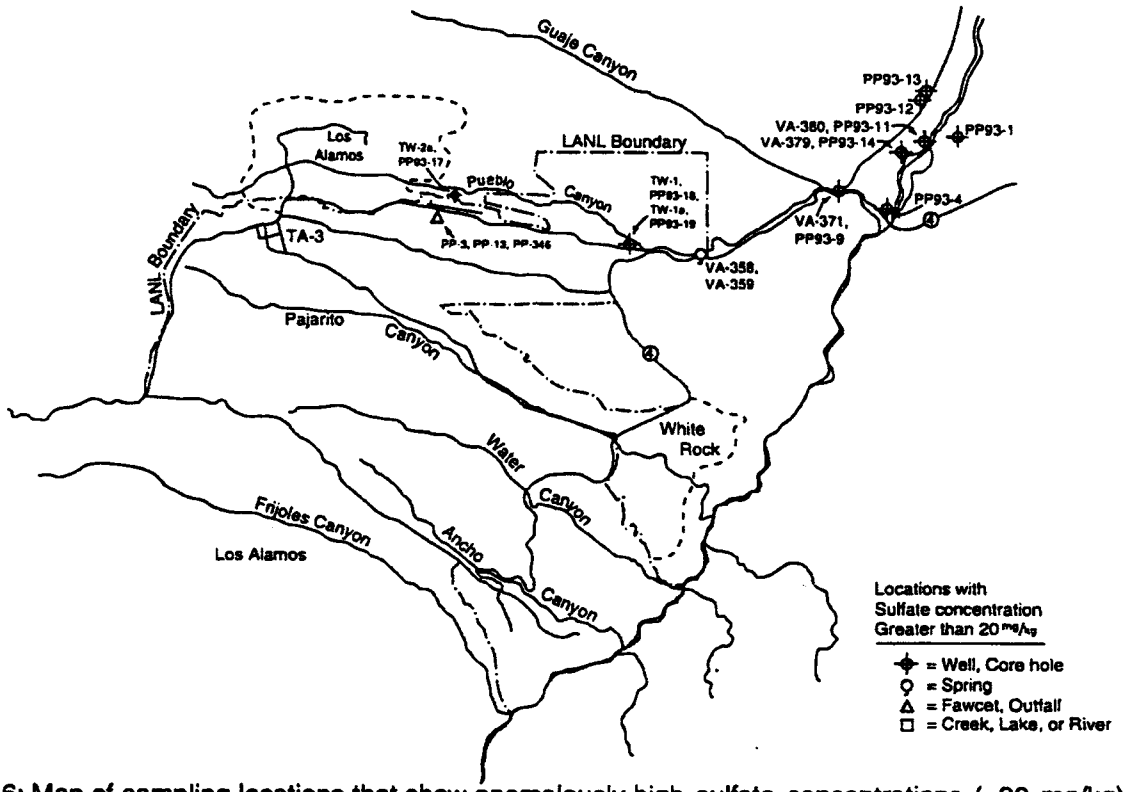

Figure 6: Map of sampling locations that show anomalously high sulfate concentrations (>20 mg/kg). The large number of such locations in the San Ildefonso Reservation is most likely due to fertilizer use in that area (Mazor, 1991). Relatively high sulfate, nitrate, and phosphate in Pueblo and DP Canyons probably come from original Laboratory facilities upstream of those canyons on the mesas.

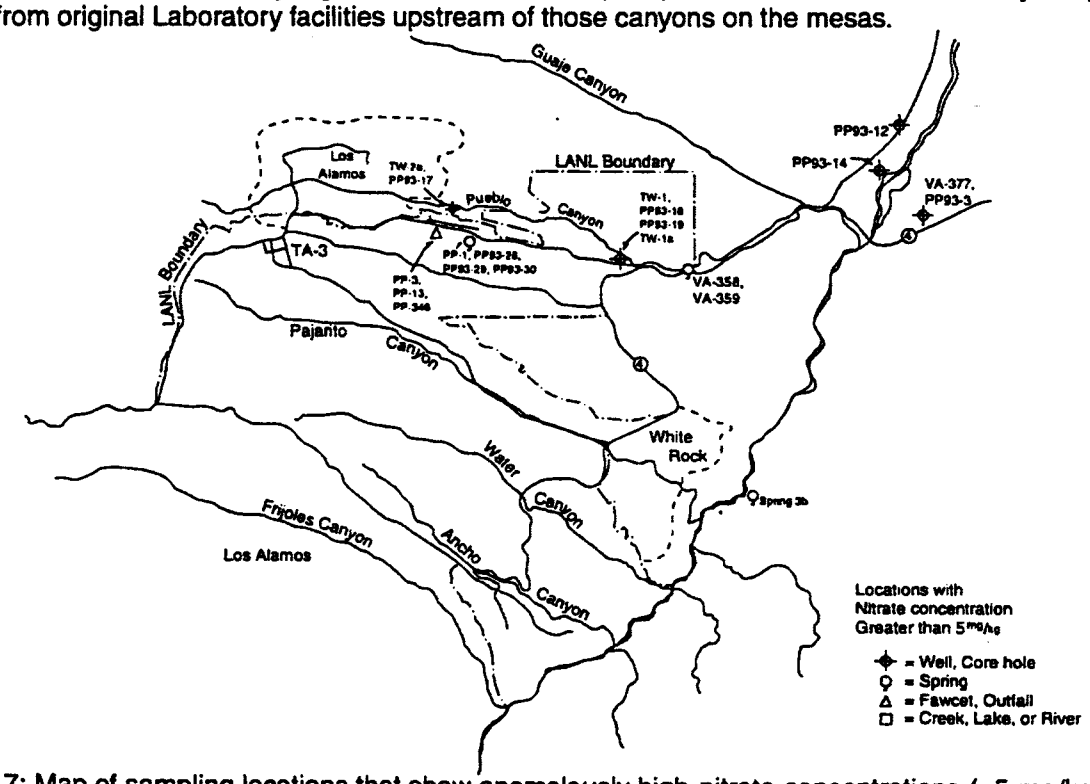

Figure 7: Map of sampling locations that show anomalously high nitrate concentrations (>5 mg/kg). Those locations northeast and east of the Laboratory probably have elevated levels because of nearby fertilizer use and stock grazing (Mazor, 1991).

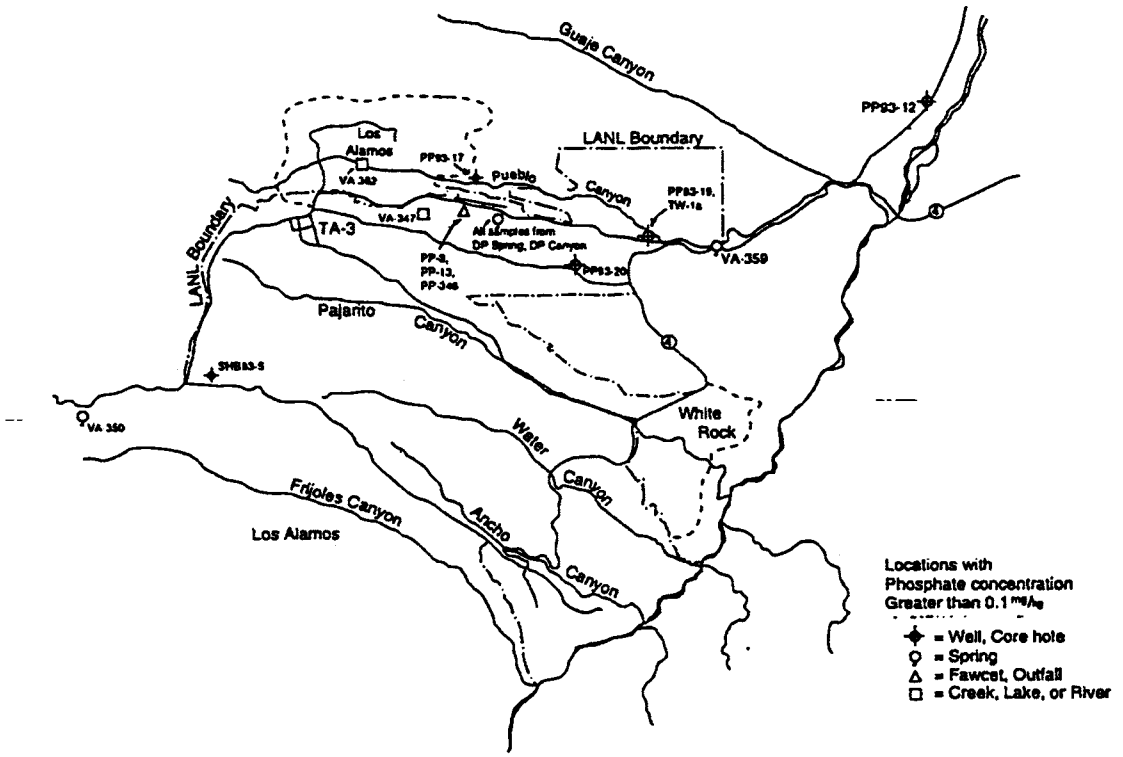

Figure 8: Map of sampling locations that show anomalously high phosphate concentrations (>0.1 mg/kg).

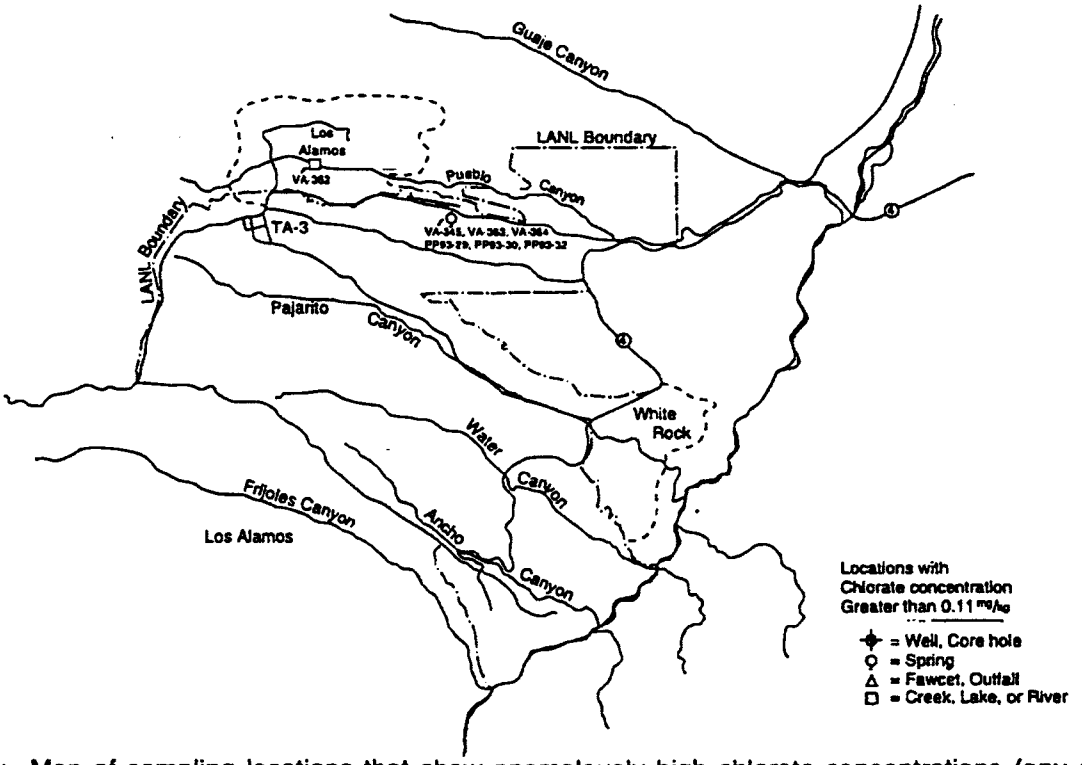

Figure 9: Map of sampling locations that show anomalously high chlorate concentrations (any amount above threshold detection limits). Chlorate is almost exclusively associated with previous weapons development as a remnant of anthropogenic activity.

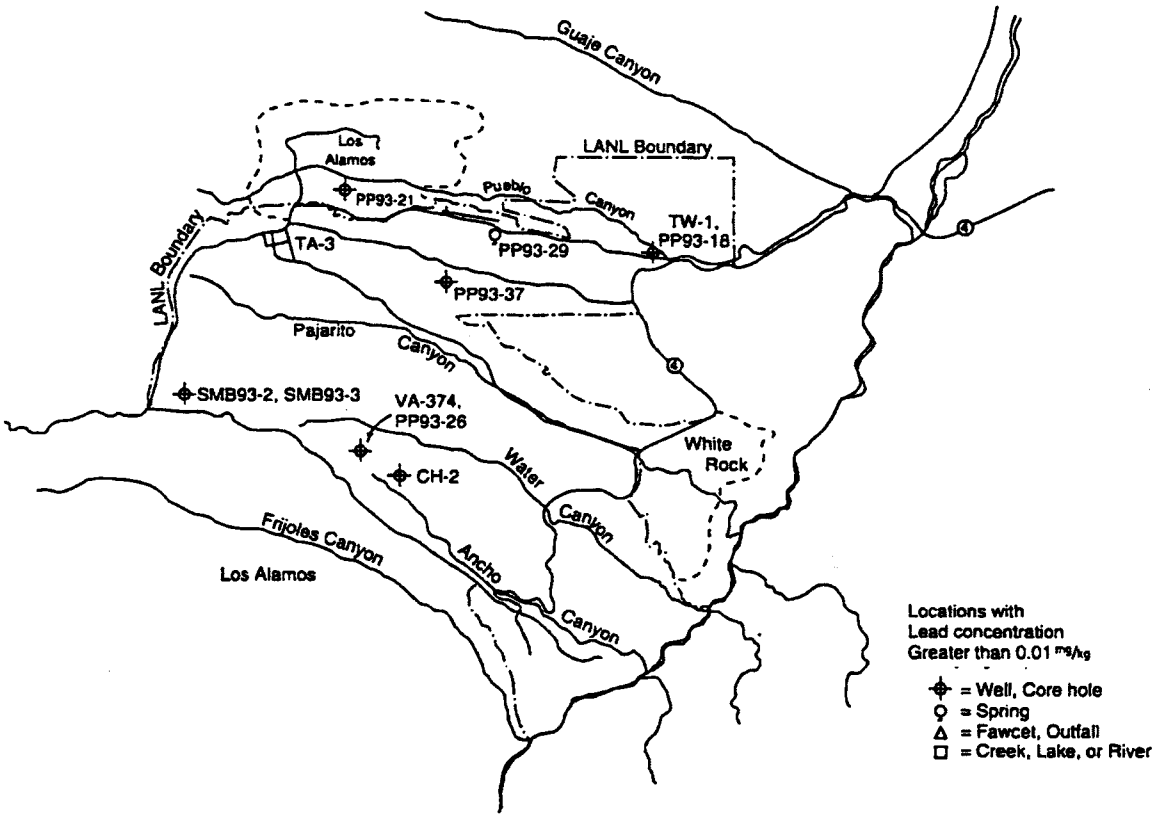

Figure 10: Map of sampling locations that show anomalously high lead concentrations (>0.010 mg/kg). Five of the mapped samples are located in the southwestern part of the Laboratory. The lead in this area may be due to lead used during the early years of the Laboratory finding its way into the local groundwater, or groundwater leaching lead out of the Bandelier Tuff through which the surface groundwater flows (Longmire, 1993).

Those samples with anomalous nitrate concentrations located on the reservation probably also result from farming. Spring 3b is high in nitrate but not sulfate because cattle but not crop raising takes place upstream of the spring in the area east of the Rio Grande opposite White Rock.

Closer to Los Alamos National Laboratory, Lab-related processes are the most likely cause of the elevated trace element concentrations in waters. The most contaminated samples from the Pajarito Plateau and DP Site, listed earlier, were from locations close to the Lab. In addition to these, other samples from sites close to the Laboratory with anomalously high amounts of one or more contaminant trace elements include the sample from Basalt Spring #1, in nitrate and sulfate, the sample from Basalt Spring #2, in nitrate, sulfate, and phosphate, SHB93-4, VA-350, VA-347, and VA-362, in phosphate, SHB93-2 and 3, in lead, and VA-362, in chlorate. The Laboratory appears the most likely source for these anomalies because no other human activity upstream of these sampling locations, such as farming, could account for the elevated concentrations, and no comparable concentrations are found in samples from locations upstream of the Lab, such as in Pajarito and Upper Guaje Creeks. In addition, one would expect impacted areas from diverse industrial processes, such as what occurs at the Laboratory, to have waters anomalously high in more than one contaminant. Data for samples taken close to the Lab bear this out: some samples are relatively high in sulfate, nitrate, and phosphate (Figs 6-8), and eleven of the fifteen samples taken close to the Lab are anomalously high in both nitrate and phosphate.

Figures 6-10 provide clues to the origin of the contaminants specifically attributed to the Lab. Three of the most impacted sites studied near the Lab, Test Well 2a, Test Wells 1 and 1a at the White Rock "Y", and Basalt Spring #1, are located in Pueblo Canyon, which runs north of the airport into the town of Los Alamos. Farther south, two of most impacted sites, DP Spring and the outfall at TA-21, lie in DP Canyon. All of these sites are located downstream from old Laboratory facilities near the airport and farther uphill on the town

mesa. Much of the weapons development activity during the early years of the Laboratory were concentrated in this area. Possibly because of remnant waste sites from those activities or because of human activity in the present-day townsite, many of the contaminant trace species in the canyons probably originated at locations in and near the old Laboratory on the town mesa. Chlorate, found to be in elevated concentrations in Acid Creek and DP Site (Fig. 9), is an interesting trace species because it is almost exclusively associated with weapons development as a remnant of anthropogenic activity, as opposed to most trace species which can result from a number of industrial or residential uses. Samples SHB93-1 through 7 were taken from the Seismic Hazards Borehole #3 which is located at S-Site where many kinds of experiments were performed. This may explain the high phosphate and lead concentrations of some samples.

Another observation involving trace elements concentrations in this study is high ammonium levels in some of the SWAB, SHB-3 Core hole samples (Fig.11). These could be caused by any of a number of reasons including drilling fluids contamination. Rubidium measurements in the study are also interesting (Fig.12). Normally, rubidium concentrations increase in warmer, deeper waters, but in the studied area rubidium concentrations are higher in White Rock Canyon samples, taken from surface sources, than in the samples from the San Ildefonso wells. In the Pajarito Plateau wells, rubidium content seems to increase with increasing chloride content, which is because concentrations of rubudium, like chloride, are highly influenced by temperature, residence time, and source rocks (Bandelier Tuff) potentially high in rubidium (Goff et al., 1988).

C. Lead Concentrations

Sampling locations producing waters with greater than 0.010 mg/kg lead are mapped in Figure 10. The Environmental Protection Agency allows a maximum concentration of 0.015 kg/mg for lead in drinking water. Four analyzed samples contain lead concentrations in excess of these requirements: PP93-18, VA-374, PP93-26, and SHB93-2. Three of these samples, along with CH-2 and SHB93-3, which contained lead concentrations greater than 0.010 kg/mg, were taken from locations in the southwest part of the Laboratory (Fig. 10). It has been suggested that lead shielding used for an underground nuclear experiment in this part of the Laboratory during the early years of the Lab may be finding its way into the local groundwater (Longmire, 1993). However, more research on the transport properties of lead is neccessary to determine if such a process would be possible. Another possible explanation for the lead under this part of the Pajarito Plateau is that it may be leached from the Bandelier Tuff through which some of the groundwater there flows (Longmire, 1993). Of course, both processes could be simultaneous contributors. Those samples relatively high in lead from the northeast parts of the Lab could have been effected by contamination resulting from the same processes that produced elevated nitrate, sulfate, and phosphate, as discussed above.

D. Stable Isotope Analyses and Mean Recharge Elevations

Stable isotope ($\delta D/\delta^{18}O$) results for waters of this investigation appear in Table 4 and are plotted on Fig. 13. In general, the data points fall on or near the world meteoric water line (WMWL) of Craig (1961) and near the parallel Jemez Mountains line of Vuataz and Goff (1986). Most waters plot between δD values of -70 and -100‰ (per mil). Some waters show apparent $\delta^{18}O$ enrichments of +2‰ due to evaporation or, possibly, analytical uncertainty. Because no waters of this study are distinctly thermal (≥30°C) or chemically resemble formation waters and geothermal brines, the $\delta^{18}O$ enrichments are not caused by rock-water isotopic exchange in higher temperature environments (Hoefs, 1973).

Stable isotope variations in cold natural groundwaters and precipitation are caused primarily by variations in latitude, precipitation elevation, and weather patterns (Hoefs, 1973). Higher latitude, higher recharge elevation, and greater distance from the ocean source of precipitation will result in more depleted (more negative) isotopic compositions within a given suite of waters. A restricted region, such as encompassed by this study, displays isotopic variations reflecting variations in recharge elevation and weather patterns. For example, the cluster of points from the TA-21 site, primarily from DP Spring (Fig. 13), tend to show more enriched isotope values than the cluster of points from the San Ildefonso area. By and large, the San Ildefonso area waters are recharged at higher average elevation than the TA-21 waters even though the discharge elevations of the San Ildefonso sites are lower than the TA-21 sites.

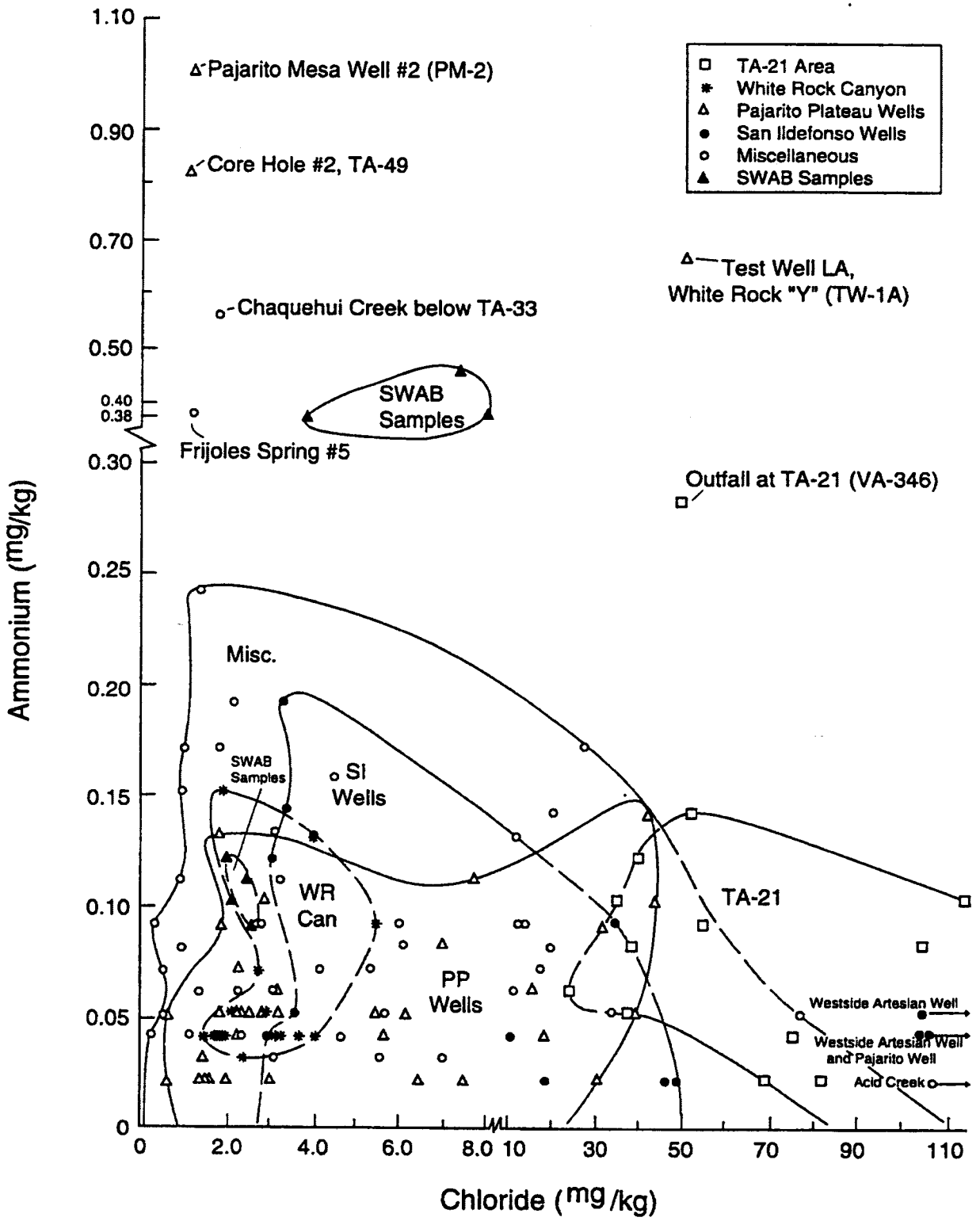

Figure 11: Ammonium concentration plotted against chloride concentration in mg/kg for each sample in the study. High levels in the SWAB, SHB-3 Core hole samples could have any of a number of causes, including contamination from drilling fluids.

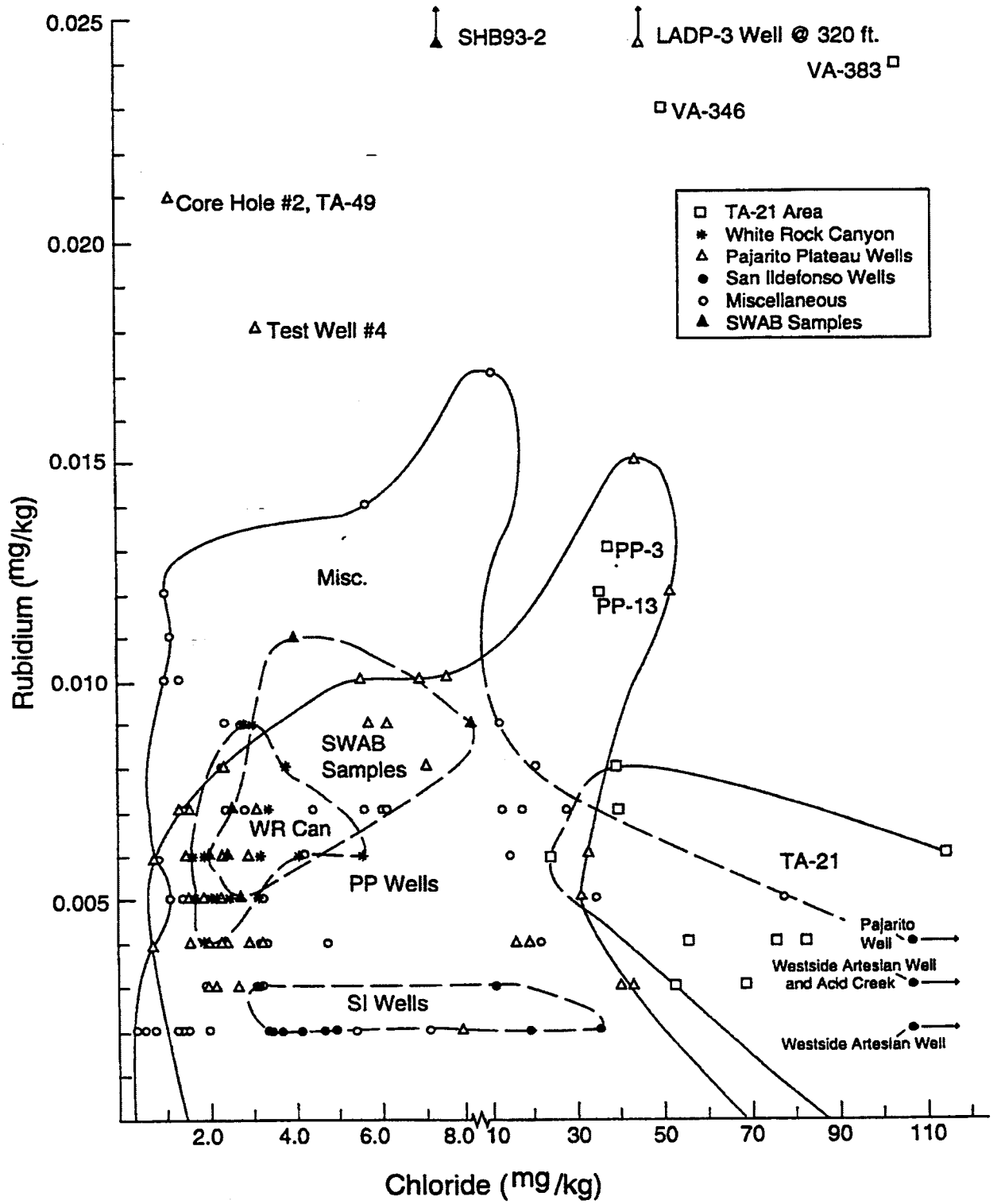

Figure 12: Rubidium concentration plotted against chloride concentration in mg/kg for each sample in the study.

Isotopic variations due to the weather are best demonstrated by the data points for DP Spring. High flow rates are observed after the spring thaw and the summer thunderstorms. Isotope values range from -60 to -100‰ during the four year period of study (1990-1993), generally with more depleted values after the spring thaw. The data indicate that DP Spring has a short recharge path from local sources near TA-21, responding to precipitation primarily from Pacific Ocean sources in winter months and from Gulf of Mexico sources in summer months.

The isotopic difference between a spring water having limited (shallow) recharge (responding to weather) and a spring water having deep recharge (independent of weather) can be observed by comparing data from DP Spring with data from the series of springs in White Rock Canyon. Whereas DP Spring displays a 40‰ range in δD, individual springs in White Rock Canyon show no more than a 3‰ range in δD. Springs in White Rock Canyon are fed from different horizons at the top of the Main Aquifer, residing in sediments of the Sante Fe Group; thus, the waters are relatively homogenized through mixing and long residence time and are buffered from short-term climatic effects. The same consistency in isotopic composition is displayed by most deep well waters from the Pajarito Plateau and San Ildefonso areas indicating relatively large, homogeneous sources that are independent of near surface climate.

The quantitative relation between stable isotope composition and recharge elevation for the Jemez Mountains region was determined by Vuataz and Goff (1986). Using their equations, the mean recharge elevation for the waters listed in Table 4 have been calculated for both parameters (δD and $\delta^{18}O$). It has not been clearly demonstrated that the equations are valid for sites in the Rio Grande rift or Sangre de Critsto Range east of Los Alamos. However, the results are consistent with the Jemez Mountains calculations, and the calculated recharge elevations provide interesting insights regarding possible recharge sources for the various waters of the region. For example, the mean recharge elevation of water that discharges from DP Spring is about 2240±530 m (n=22 isotopic measurements), or about 165 m higher than the discharge point. Recharge from precipitation falling on the Pajarito Plateau is reasonable based on this simple calculation. Note that using calculations for individual data points is meaningless for this site because DP Spring responds rapidly to climatic variations in isotopic composition.

Springs in White Rock Canyon have rather consistent isotopic values, and their calculated mean recharge elevations with one notable exception (Spring 3b) are ≤2450 m; in fact, the average mean recharge elevation for this group is 2235±140 m (n=32), whereas the mean discharge elevation is about 1650 m. Recharge elevations this low (2235 m or 7330 ft) exist only on the Pajarito Plateau and upland areas within the Rio Grande rift. Most likely, a substantial amount of recharge for these springs, which issue from horizons at the top of the Main Aquifer, comes from relatively low elevation sources and not from high elevation sources such as the Valles Caldera (Goff and Sayer, 1980; Vuataz and Goff, 1986).

A similar observation can be made regarding the production water wells on the Pajarito Plateau, which produce large volumes of drinking water for Los Alamos townsite and Los Alamos National Laboratory. The major production wells (Pajarito Mesa and Guaje Canyon wells) obtain water from horizons within the Main Aquifer. The average mean recharge elevation for this group of wells is 2290±150 m (n=30) or about 7500 ft. This calculation includes data for wells Guaje #1a and #2, which are somewhat more depleted isotopically than other members of this group and, therefore, have a higher recharge elevation. However, the calculation indicates that production well waters from the Main Aquifer are recharged primarily from sources within the Española Basin (or possibly from sources north of the region of study for which we have no data), and not from the mountains flanking the basin.

In contrast to these spring and well waters recharged from sources within or north of the basin, a distinct group of waters exists within the Main Aquifer that is recharged from considerably higher elevations. Waters within this group include Spring 3b, wells LA-1b and LA-6 (data from the latter reported in Goff and Sayer, 1980), and several wells in the San Ildefonso area. These sites produce water from the Confined Aquifer as defined by Purtymun and Johanson (1974), an aquifer within the Main Aquifer that commonly produces artesian fluids from wells. The average mean recharge elevation of this group of waters is 3180±320 m (n=28) or about 10,400 ft. Because the Confined Aquifer is contained within westward dipping strata of the Santa Fe Group, Goff and Sayer (1980) postulated that this aquifer is recharged from high elevation sources to the east, most likely the Sangre de Cristo Range. The geohydrology and recharge calculations are consistent with this hypothesis since maximum elevations in the Sangres approach 4000 m. At this time, we have only five samples of spring and creek waters from the lower western flank of the Sangre de Cristo

TABLE 4. Stable Isotope Analyses of Waters in the Pajarito Plateau and Outlying Areas, New Mexico[a]

Map No.	Description	Sample No.	Date	Elevation (m)	Temp (°C)	Del D (‰)	Del O-18 (‰)	13C-HCO3 (‰)	87Sr/86Sr	Tritium (T.U.)	Max age (years)	Min age (years)	Recharge elev. (m from δD)	Recharge elev. (m from $\delta^{18}O$)
DP SPRING (TA-21)														
1	"DP Spring, DP Canyon	PP-1	05/30/90	2076	8.4	- 77.3	-9.60	- 11.5	—	845	—	—	2317	1853
1	"DP Spring, DP Canyon	PP-2	08/10/90	2076	9.8	- 64.2	-8.44	- 10.2	—	332	—	—	1729	1489
1	"DP Spring, DP Canyon	PP-4	09/06/90	2076	10.5	- 62.1	-8.62	—	—	405	—	—	1634	1546
1	"DP Spring, DP Canyon	VA-345	05/15/91	2076	11.4	- 89.2	-12.00	—	—	563	—	—	2851	2607
1	"DP Spring, DP Canyon	VA-363	06/26/91	2076	8.0	- 64.5	-9.64	—	—	325	—	—	1742	1866
1	"DP Spring, DP Canyon	VA-364	07/11/91	2076	8.4	- 70.6	-10.00	—	—	260	—	27	2016	1979
1	"DP Spring, DP Canyon	VA-383	05/18/92	2076	9.5	-100.3	-13.78	—	—	343	—	—	3349	3166
1	"DP Spring, DP Canyon	VA-395a	11/92	2076	—	—	—	—	—	146	—	28	—	—
1	"DP Spring, DP Canyon	PP93-28	05/26/93	2076	7.3	- 85.5	-11.93	- 16.7	0.708474	188	—	29	2685	2585
1	"DP Spring, DP Canyon	PP93-29	06/23/93	2076	5.8	- 79.9	-11.39	—	—	195	—	29	2434	2415
1	"DP Spring, DP Canyon	PP93-30	07/23/93	2076	6.3	- 75.4	-10.88	—	—	147	—	28	2231	2255
1	"DP Spring, DP Canyon	PP93-32	10/06/93	2076	9.6	- 57.0	-8.75	—	—	119.9	—	28	1405	1587
2	Outfall at TA-21	PP-3	08/10/90	2162	12.3	- 81.3	-11.29	-9.2	—	2786	—	—	2496	2384
2	Outfall at TA-21	PP-13	10/22/90	2162	18.5	—	—	—	—	—	—	—	—	—
2	Outfall at TA-21	VA-346	05/15/91	2162	12.3	- 90.4	-12.35	—	—	1011	—	—	2905	2717
WHITE ROCK CANYON SPRINGS														
3	Spring 2	Spring 2	11/91	1707	<20	- 75.3	-10.07	- 12.3	—	1.30	1500	38	2227	2001
4	Spring 3	PP-5	09/24/90	1695	<20	- 73.8	-10.57	- 11.9	—	1.05	1750	37	2160	2158
4	Spring 3	Spring 3	11/91	1695	<20	- 72.1	-10.60	- 11.6	—	0.51	3500	44	2083	2167
5	Spring 3b	PP-6	09/24/90	1676	<20	- 93.1	-12.68	-13.3	—	0.28	6500	55	3026	2821
5	Spring 3b	Spring 3b	11/91	1676	<20	- 92.4	-13.26	-7.5	—	0.04	>10000	90	2995	3003
6	Spring 4a	Spring 4a	11/91	1683	<20	- 74.6	-10.42	-11.2	—	0.74	2500	38	2196	2111
7	Spring 6	Spring 6	11/91	1640	<20	- 75.6	-10.68	-14.1	—	0.55	3000	43	2240	2193
8	Spring 6a	PP-7	09/25/90	1638	<20	- 73.2	-11.05	—	—	0.02	>10000	100	2133	2309
8	Spring 6a	Spring 6a	11/91	1638	<20	- 76.8	-11.23	-13.2	—	0.01	>10000	110	2294	2365
9	Spring 7	PP-8	09/25/90	1637	<20	- 75.8	-10.94	-7.1	—	0.45	4000	45	2249	2274
9	Spring 7	Spring 7	11/91	1637	<20	- 72.7	-11.03	-10.3	—	0.65	2500	46	2110	2302
10	Spring 8	PP-9	09/25/90	1637	<20	- 78.3	-11.51	—	—	1.80	1000	39	2362	2453
10	Spring 8	Spring 8	11/91	1637	<20	- 78.3	-11.24	-6.6	—	2.19	750	39	2362	2368
11	Spring 8b	PP-10	09/26/90	1637	<20	- 77.9	-11.19	-12.4	—	1.44	1250	39	2344	2353
12	Spring 9a	Spring 9a	11/91	1684	<20	- 75.8	-10.77	-12.8	—	0.55	3000	43	2249	2221
13	Doe Spring	PP-11	09/25/90	1707	<20	- 77.9	-9.58	-5.9	—	5.47	300	37	2344	1847
13	Doe Spring	ER-E	—	1707	—	—	—	—	—	1.07	1500	40	—	—
14	Ancho Spring	PP-12	09/25/90	1737	<20	- 77.8	-9.93	—	—	1.05	1750	39	2339	1957
14	Ancho Spring	Ancho Spg.	11/91	1737	<20	- 80.6	-10.87	-14.9	—	1.30	1500	39	2465	2252
PAJARITO PLATEAU WELLS														
15	Pajarito Mesa Well #1	VA-373	10/23/91	1981	28.2	- 74.7	-10.66	-9.2	0.708931	0.51	3500	44	2200	2186
15	Pajarito Mesa Well #1	PM-1	08/18/92	1981	27.5	- 75.6	-10.73	-9.1	—	0.69	2500	39	2240	2208
16	Pajarito Mesa Well #2	PM-2	08/18/92	2048	23.3	- 77.1	-11.19	-14.4	—	0.15	>10000	70	2308	2353
16	Pajarito Mesa Well #2	PP93-15	05/19/93	2048	22.4	- 78.5	-10.98	-14.3	—	0.49	3000	45	2371	2287
17	Pajarito Mesa Well #3	PM-3	08/18/92	2024	24.4	- 76.7	-10.74	-9.0	—	0.23	4500	60	2290	2211
17	Pajarito Mesa Well #3	PP93-20	05/19/93	2024	27.7	- 76.8	-10.56	-8.9	—	6.67	200	37	2294	2165
18	Pajarito Mesa Well #5	VA-372	10/23/91	2163	24.7	- 74.2	-10.78	-14.3	0.707822	0.09	10000	85	2178	2224
18	Pajarito Mesa Well #5	PM-5	08/18/92	2163	26.6	- 75.9	-10.82	-13.3	—	0.39	4500	49	2254	2236
19	Guaje Canyon Well #1	G-1	08/18/92	1823	26.9	- 75.4	-9.96	-11.4	—	0.34	5000	50	2231	1966
20	Guaje Canyon Well #1a	G-1a	08/18/92	1835	26.3	- 85.7	-11.96	-10.9	—	0.28	6000	55	2694	2594
21	Guaje Canyon Well #2	G-2	08/18/92	1847	29.6	- 83.5	-11.83	-10.0	—	0.28	6000	55	2595	2554
22	Guaje Canyon Well #4	G-4	08/18/92	1902	24.3	- 75.7	-10.90	-12.7	—	0.19	9000	65	2245	2262
23	Guaje Canyon Well #5	VA-370	10/22/91	1926	25.7	- 74.9	-10.70	-12.9	0.707035	0.08	10000	80	2209	2199
23	Guaje Canyon Well #5	G-5	08/18/92	1926	30.3	- 76.5	-10.78	-13.1	—	0.43	4000	47	2281	2224
24	Guaje Canyon Well #6	G-6	08/18/92	1963	30.3	- 78.0	-10.91	-12.7	—	0.56	3000	43	2348	2265
25	Water Canyon Gallery	WCG	08/18/92	2439	15.3	- 82.9	-12.17	-15.9	—	4.28	350	37	2568	2660
25	Water Canyon Gallery	PP93-27	05/20/93	2439	11.3	- 84.6	-12.33	-14.1	0.706931	12.8	100	10	2645	2711
26	LA-1 Well	PP93-8	05/12/93	1714	—	- 86.5	-11.00	-7.1	0.707180	19.7	50	20	2730	2293
27	LA-1b Well	VA-371	10/22/91	1716	31.8	-101.9	-14.05	-5.8	0.708009	0.02	10000	100	3421	3251
27	LA-1b Well	PP93-9	05/12/93	1716	31.5	-105.8	-14.12	—	—	0.18	9000	60	3596	3273
28	LA-2 Well	PP93-7	05/12/93	1722	—	- 83.5	-11.58	—	—	4.04	350	38	2595	2475
29	LA-5 Well	PP93-10	05/12/93	1780	19.3	- 81.7	-11.13	-12.4	0.707837	0.25	6000	60	2514	2334
30	Test Well #1, White Rock "Y"	TW-1	10/08/92	1941	14.0	- 77.6	-10.71	-12.0	—	109	—	27	2330	2202

Map No.	Description	Sample No.	Date	Elevation (m)	Temp (°C)	Del D (‰)	Del O-18 (‰)	13C-HCO3 (‰)	87Sr/86Sr	Tritium (T.U.)	Max age (years)	Min age (years)	Recharge elev. (m from δD)	Recharge elev. (m from $\delta^{18}O$)
30	Test Well #1, White Rock "Y"	PP93-18	05/19/93	1941	14.1	- 78.6	-10.69	—	—	113	—	28	2375	2196
31	Test Well #1, White Rock "Y"	TW-1A	10/08/92	1941	8.0	- 76.8	-10.86	-11.4	—	41.3	—	21	2294	2249
31	Test Well #1, White Rock "Y"	PP93-19	05/19/93	1941	15.1	- 76.4	-10.95	-12.9	0.708766	45.8	—	23	2276	2277
32	Test Well #1, Pueblo Canyon	TW-2	10/08/92	2026	15.9	- 73.6	-10.73	-13.8	—	0.22	10000	60	2151	2208
32	Test Well #1, Pueblo Canyon	PP93-16	05/19/93	2026	17.4	- 73.8	-10.57	-12.6	—	0.85	2000	40	2160	2158
33	Test Well #1, Pueblo Canyon	TW-2a	10/08/92	2027	11.6	- 78.9	-10.60	- 10.65	—	698	—	—	2389	2167
33	Test Well #1, Pueblo Canyon	PP93-17	05/19/93	2027	14.5	- 76.3	-10.54	—	—	699	—	—	2272	2149
34	Test Well #3	PP93-23	05/20/93	2010	21.3	- 74.9	-10.62	-10.5	—	0.89	2000	40	2209	2174
35	Test Well #4	PP93-21	05/19/93	2208	11.0	- 75.2	-10.95	-10.1	0.707948	3.34	400	38	2222	2277
36	Deep Test Well #5a	VA-374	10/23/91	2175	17.8	- 81.8	-11.37	-14.2	0.707948	0.00	>10000	>100	2519	2409
36	Deep Test Well #5a	PP93-26	05/20/93	2175	18.1	—	—	—	0.707573	0.07	>10000	80	—	—
37	Deep Test Well #9	PP93-25	05/20/93	2114	15.4	- 80.1	-11.41	-13.6	0.707802	0.14	>10000	70	2442	2422
38	Deep Test Well #10	PP93-24	05/20/93	2140	16.8	- 81.3	-10.37	-13.2	0.707432	0.41	4000	48	2496	2095
39	Otowi #4 Well	OT-4	03/02/93	2020	28.8	- 77.2	-11.34	-9.2	0.706948	***	—	—	2312	2400
39	Otowi #4 Well	PP93-22	05/20/93	2020	27.5	- 70.7	-10.78	-8.9	0.706993	***	—	—	2020	2224
40	"Core Hole #2	TA-49"	CH-2	05/07/93	2195	—	- 70.6	-10.14	-16.2	—	90.3	—	27	2016
74	LADP-3 Well at 320 ft.	PP93-36	12/01/93	2061	9.0	- 77.2	-10.73	—	—	1871	—	—	2312	2208
75	Test Well #8	PP93-37	12/06/93	—	—	- 74.2	-10.53	—	—	27.6	—	20	2178	2145
SAN ILDEFANSO WELLS														
41	East Side Artesian Well	VA-376	03/05/92	1677	14.8	-109.9	-15.05	-8.5	—	0.00	>10000	>100	3781	3565
41	East Side Artesian Well	PP93-2	05/12/93	1677	14.4	-111.2	-14.85	-10.2	0.708152	0.31	5000	55	3839	3502
42	Westside Artesian Well	VA-380	03/05/92	1680	17.7	-99.8	-13.19	-6.6	—	0.13	>10000	70	3327	2981
42	Westside Artesian Well	PP93-11	05/18/93	1680	17.8	-95.9	-12.80	-5.9	—	0.12	>10000	70	3152	2858
43	Don Juan Playhouse Well	VA-377	03/05/92	1677	19.1	-107.6	-14.68	-9.3	—	0.00	>10000	>100	3677	3449
43	Don Juan Playhouse Well	PP93-3	05/12/93	1677	19.2	- 98.0	-11.99	-9.2	0.707793	0.16	9500	65	3246	2604
44	Halliday House Well	VA-378	03/05/92	1695	15.7	- 94.1	-12.99	-12.0	—	0.00	>10000	>100	3071	2918
44	Halliday House Well	PP93-5	05/12/93	1695	17.2	- 95.3	-12.96	-11.9	0.707282	0.29	5500	55	3125	2908
45	Pajarito Well	VA-379	03/05/92	1680	16.4	- 96.1	-13.39	-6.6	—	0.00	>10000	>100	3161	3043
45	Pajarito Well #2	PP93-14	05/12/93	1680	16.8	- 89.9	-12.30	-8.3	—	0.94	1500	40	2883	2701
46	New Comm. Well, S.I. Pueblo	PP93-1	05/12/93	1680	13.4	- 78.6	-10.12	- 11.5	0.708565	8.00	150	37	2375	2017
47	Otowi House Well	PP93-4	05/12/93	1677	15.5	- 79.7	-10.74	—	—	44.9	—	23	2425	2211
48	Martinez Well	ER-C	—	1689	—	—	—	—	—	2.40	750	39	—	—
48	Martinez Well	PP93-12	05/18/93	1689	16.4	- 82.6	-11.59	—	—	1.81	750	38	2555	2478
49	Sanchez Well	ER-B	—	1689	—	—	—	—	—	7.39	200	37	—	—
49	Sanchez Well	PP93-13	05/18/93	1689	16.5	- 87.9	-12.06	—	—	6.90	200	37	2793	2626
MISC. WATERS AND SPRINGS														
50	LANL TA-33 Drain, TA33-86 Outfall	TA33-1	02/08/91	1994	10.6	—	—	—	—	1620	—	—	—	—
50	LANL TA-33 Drain, TA33-86 Outfall	TA33-3	02/22/91	1994	10.6	—	—	—	—	4751	—	—	—	—
51	LANL TA-33 Drain, 30 ft. E. of TA33-1	TA33-2	02/08/91	1994	0.1	—	—	—	—	4574	—	—	—	—
51	LANL TA-33 Drain, 30 ft. E. of TA33-1	TA33-4	02/22/91	1994	0.1	—	—	—	—	1562	—	—	—	—
52	Sulfur Creek at Baca Gate	VA-327	05/07/91	2591	8.1	- 82.5	-11.74	—	—	14.4	100	8	2550	2525
53	Corbin's Cistern	VA-328	05/07/91	2591	8.2	- 85.0	-11.41	—	—	12.9	100	6	2663	2422
54	Pajarito Spring	VA-330	05/09/91	1680	22.2	- 77.4	-10.55	—	—	0.09	>10000	>110	2321	2152
55	Rio Grande Spring	VA-331	05/09/91	1655	16.8	- 79.3	-10.63	—	—	26.2	35	19	2407	2177
56	LA Creek above Reservoir	VA-332	05/09/91	2317	9.4	- 83.4	-11.49	—	—	35.7	—	19	2591	2447
76	Seven Springs	VA-333	05/10/91	2480	11.5	- 97.9	-13.40	—	—	10.8	150	2	3242	3047
77	Horseshoe Spring	VA-335	05/10/91	2420	9.6	- 90.3	-12.29	—	—	1.69	1000	38	2900	2698
78	Redondo Creek	VA-336	05/10/91	2440	15.8	- 84.1	-11.92	—	—	16.4	75	11	2622	2582
79	Panorama Spring	VA-340	05/13/91	2070	13.2	- 90.2	-11.35	—	—	0.36	5000	50	2896	2403
80	Sino Spring	VA-341	05/13/91	2300	15.6	- 87.1	-12.11	—	—	0.33	5000	50	2757	2642
80	Sino Spring	VA-393	06/08/92	2300	19.1	- 88.5	-12.10	—	—	0.08	>10000	80	2820	2638
81	San Antonio Creek	VA-342	05/14/91	2570	10.4	- 86.2	-12.01	—	—	8.07	200	38	2716	2610

Map No.	Description	Sample No.	Date	Elevation (m)	Temp (°C)	Del D (‰)	Del O-18 (‰)	13C-HCO3 (‰)	87Sr/86Sr	Tritium (T.U.)	Max age (years)	Min age (years)	Recharge elev. (m from δD)	Recharge elev. (m from $\delta^{18}O$)
60	Apache Spring	VA-350	05/20/91	2530	8.3	- 84.3	-12.19	—	—	23 7	35	19	2631	2667
61	Armistead Spring	VA-351	05/17/91	2506	7.1	- 81.2	-11.18	—	—	47.0	—	20	2492	2350
62	Frijoles Spring #49	VA-352	05/22/91	2671	6.4	- 79.1	-11.49	—	—	0.00	>10000	>110	2398	2447
63	Frijoles Spring #50	VA-353	05/22/91	2500	10.6	- 83.8	-11.49	—	—	17.4	75	12	2609	2447
64	Pajarito Creek	VA-354	05/22/91	2654	10.9	- 82.9	-11.84	—	—	0.00	>10000	>110	2568	2557
65	Upper Guaje Creek	VA-355	05/23/91	2146	10.0	- 84.2	-11.39	—	—	22.7	50	19	2627	2415
66	Pine Spring	VA-356	05/24/91	2200	12.6	- 80.2	-10.86	—	—	42.3	—	20	2447	2249
67	Unnamed Spring near Apache Spring	VA-357	05/28/91	2561	15.7	- 75.7	-10.73	—	—	43.4	—	20	2245	2208
68	Basalt Spring #2	VA-358	06/11/91	1830	12.1	- 81.2	-10.40	—	—	0.14	>10000	70	2492	2105
69	Basalt Spring #1	VA-359	06/11/91	1830	11.8	- 79.6	-10.69	—	—	37.9	—	19	2420	2196
69	Basalt Spring #1	ER-A	—	1830	—	—	—	—	—	50.1	—	24	—	—
70	Black Canyon Spring	VA-360	06/13/91	2200	8.1	- 83.0	-11.07	—	—	15.2	100	9	2573	2315
71	Acid Creek	VA-362	06/23/91	2119	8.2	- 65.6	-9.57	—	—	77.5	75	25	1791	1844
83	La Mesita Spring	ER-D	—	—	—	—	—	—	—	0.37	4000	50	—	—
84	Santa Fe Lake	VA-365	07/17/91	3567	13.5	- 78.5	-11.15	—	—	14.9	100	9	2371	2340
85	Unnamed Spring, FR-150	VA-366	07/17/91	—	3.9	- 84.5	-11.49	—	—	16.9	75	11	2640	2447
86	Unnamed Spring #2, FR-150	VA-367	07/17/91	—	13.7	- 91.5	-11.72	—	—	16.4	75	10	2954	2519
87	Chupadero Creek	VA-368	07/18/91	—	11.3	- 90.6	-12.09	—	—	19.8	50	15	2914	2635
88	Canyon de la Loba Creek	VA-369	07/18/91	—	14.4	- 91.2	-12.75	—	—	17.8	75	13	2941	2843
72	Homestead Spring	VA-381	04/07/92	2226	7.8	- 88.6	-12.53	—	—	38.1	—	20	2824	2773
73	Indian Spring	PP93-6	05/12/93	1723	19.8	- 81.5	-11.28	- 13.3	0.707555	1.30	1250	39	2505	2381
89	Unnamed Spring north of Ice Rink	PP93-31	09/10/93	2226	14.0	- 73.5	-10.90	—	—	—	—	—	2146	2262
90	Chaquehui Creek below TA-33	PP93-33	10/23/93	1860	13.3	- 48.6	-7.45	—	—	11.7	100	8	1028	1178
91	2 mile Creek downstream of Van de Graff	PP93-34	10/19/93	2159	6.0	- 70.3	-9.56	—	—	62.8	—	26	2002	1841
92	2 mile Creek upstm 50m frm PP93-34	PP93-35	10/19/93	2159	6.0	- 71.3	-9.98	—	—	44.9	—	23	2047	1973
80	Sino Spring	VA-396	06/16/93	2300	21.5	—	—	—	—	1.14	1500	39	—	—
SWAB SAMPLES, SHB-3 COREHOLE, TA-16														
93	Faucet at SM205, Drilling Water	SHB92-1	07/07/93	2317	16.9	- 78.4	-11.02	—	—	0.18	8500	60	2366	2299
94	In-situ sample SHB-3 Well 258m.	SHB93-2	07/20/93	2317	16.9	- 75.1	-11.28	—	—	0.88	2000	40	2218	2381
94	Run 1, Swab SHB-3 Well	SHB93-3	08/28/93	2317	16.4	- 79.4	-10.73	—	—	—	—	—	2411	2208
94	Run 1, Swab SHB-3 Well	SHB93-4	08/28/93	2317	16.6	—	—	—	—	—	—	—	—	—
94	Run 1, Swab SHB-3 Well	SHB93-5	08/28/93	2317	16.9	—	—	—	—	—	—	—	—	—
94	Run 1, Swab SHB-3 Well	SHB93-6	08/28/93	2317	16.9	—	—	—	—	—	—	—	—	—
94	Run 1, Swab SHB-3 Well	SHB93-7	08/28/93	2317	16.9	- 77.8	-11.80	—	—	—	—	—	2339	2544

* Stable isotope analyses by M. Colucci, Southern Methodist University; tritium analyses by H. Gote Ostlund, University of Miami; carbon-13 analyses by Geochron Laboratories, Cambridge; Strontium isotope ratios by Geology Department, University of New Mexico

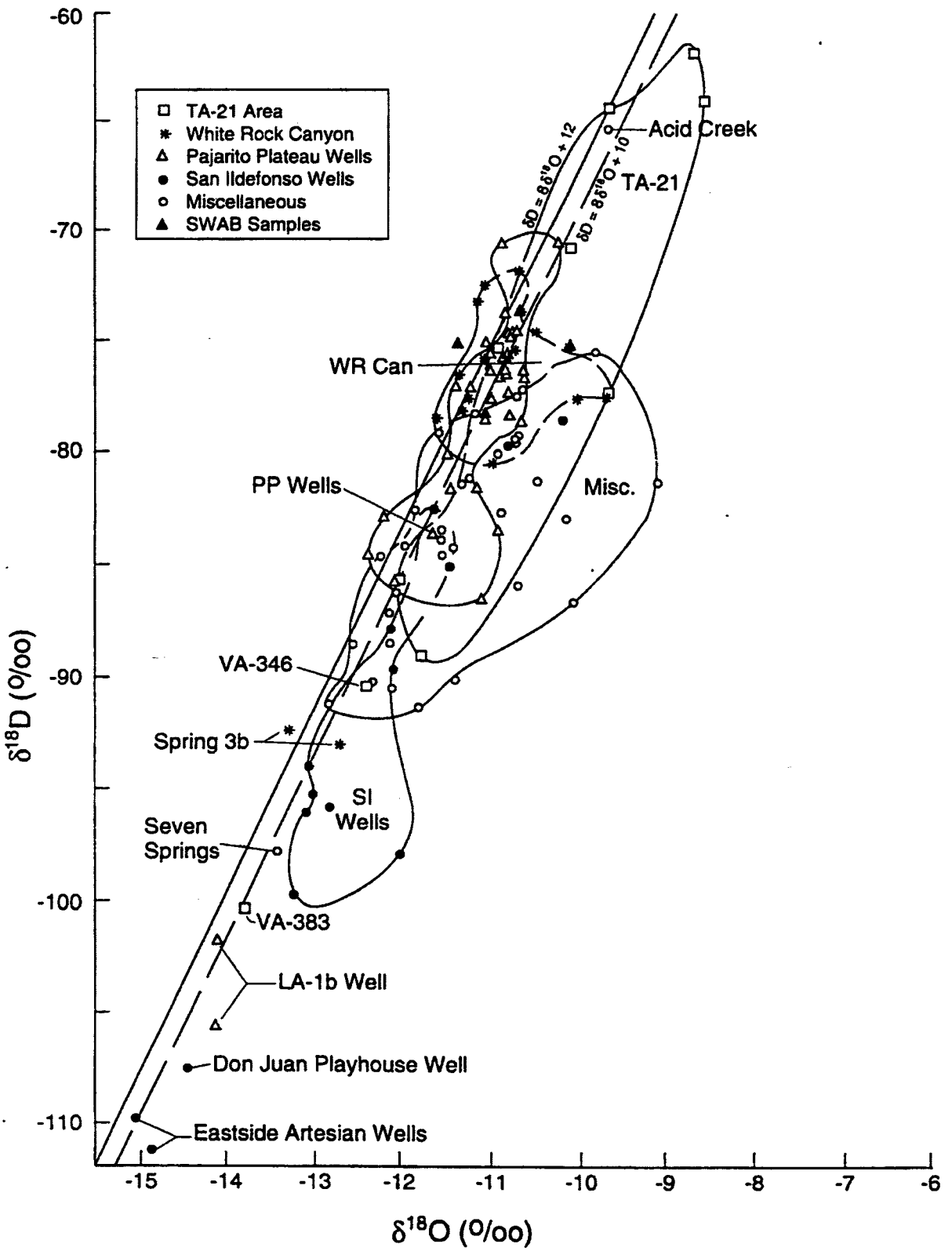

Figure 13: Plot of δD versus $\delta^{18}O$ for each sample in the study. The world meteoric line, $\delta D = 8\delta^{18}O + 10$ (Craig, 1961), is shown on the figure as is the local meteoric line for the Jemez Mountains, $\delta D = 8\delta^{18}O + 12$ (Vuataz and Goff, 1986). Variations in cold natural groundwaters and precipitation in a restricted area such as the one studied are caused primarily by variations in recharge elevation and weather patterns.

Range (Black Canyon Spring, two unnamed springs on FR 150, Chupadero Creek, and Canyon de la Loba Creek) and they have an average mean recharge elevation of 2680±225 m or about 8800 ft. If recharge to the Confined Aquifer comes from the Sangres, the set of five waters we have so far sampled is not representative.

Eight samples of spring and creek waters were collected from sites on the eastern flank of the Sierra de los Valles, west and south of Los Alamos (LA Creek above reservoir, Apache Spring, Armistead Spring, Pajarito Creek, Upper Guaje Creek, and Pajarito Ski Hill Well, the latter data from Meeker et al., 1990). These samples have a mean recharge elevation of 2530±100 m. Vuataz and Goff (1986) stated that fluids in the geothermal reservoir within Valles Caldera were recharged from mean elevations between 2530 and 2890 m, supporting geothermal models that show recharge of the geothermal system from precipitation within and adjacent to the caldera depression (Faust et al., 1984; Truesdell and Janik, 1986; Goff et al., 1988). The combined isotope data from these various projects do not indicate that recharge to the Main Aquifer comes from sources at higher elevations in the Jemez Mountains, from within Valles Caldera, or from the flanks of the Sierra de los Valles. On the other hand, waters from the Confined Aquifer originate from elevations higher than nearly all waters we have sampled in the Jemez Mountains; thus, the Confined Aquifer more reasonably originates from sources in the Sangre de Cristo Range or from sources to the north.

E. Tritium Analyses and Mean Residence Times

Tritium (^3H) is useful for tracing groundwater movement of young hydrologic systems and for determining the relative ages of groundwaters because it has a short half-life of 12.4 yr. and because it was produced in large amounts during atmospheric nuclear tests in the 1950s and 1960s (Fontes, 1980). Tritium values for this investigation (Table 4) are reported in tritium units (T.U.) where 1 T.U. = 1 ^3H atom in 10^{18} H atoms ≅3.2 pCi/kg H_2O.

Tritium is produced in a variety of ways, some of it naturally. Natural fission of U, Th, and other radioactive elements in rocks can produce very low levels of ^3H in coexisting pore waters, usually much less than 0.01 T.U. (Andrews et al., 1989). Cosmic-ray production of ^3H in water vapor occurs in the atmosphere; thus precipitation contains a natural background level of ^3H which varies with latitude, season of year, and position within the continent (Fontes, 1980; Shevenell and Goff, in press). The natural ("pre-bomb") level of ^3H in New Mexico precipitation averaged about 6 T.U.

Tritium is also produced by anthropogenic processes. Atmospheric nuclear testing resulted in a mean value of about 2800 T.U. in 1963 New Mexico precipitation (Vuataz and Goff, 1986). After the Nuclear Test-ban Treaty, this value steadily decreased to present levels of about 10 T.U. (Shevenell and Goff, in press). Because water is an effective neutron absorber, ^3H can be produced near many types of radioactive materials or processes and can, therefore, easily enter the environment. The Environmental Protection Agency (EPA) has established a threshhold level of 6200 T.U. for drinking water.

To make quantitative estimates of mean residence times of water in underground reservoirs or circulation systems, Goff et al. (1987, 1991) derived analytical solutions as a function of ^3H content for two end-member types of reservoirs, piston-flow and well-mixed, following the methods first outlined by Pearson and Truesdell (1978). A detailed explanation of the equations and input functions for these methods can be found in Shevenell (1991) and Shevenell and Goff (in press). Calculation of input functions for a given region requires knowledge of the yearly weighted mean ^3H content of precipitation for that region. Input functions for the Los Alamos region have been calculated by Shevenell and Goff (in press) who have also presented tables showing mean residence times as functions of tritium content. Tables 5A and 5B show such tables for base years 1990 to 1994.

The piston-flow model yields a minimum estimated mean residence time (age), and the well-mixed model yields a maximum estimated mean residence time; thus, the two age calculations can provide boundaries or age limits for a given water, reservoir, or hydrologic system. Groundwater ages determined from ^3H data are excellent for hydrologic systems less than 100 yr. in age and are subject to uncertainty for hydrologic systems greater than 1000 yr. in age. Confidence in older ages is greatly enhanced if additional knowledge of the geology/hydrology of groundwaters is known and if ages by alternative methods such as ^{14}C are available. However, groundwaters containing ^3H significantly above present background levels in precipitation clearly indicate young, anthropogenic impact or contamination ≤50 years old.

Some general trends in the regional tritium data can be viewed in Figs. 14 and 15. Most groundwaters become more concentrated in soluble constituents such as chloride as their residence time underground increases; thus, it is typical for a large suite of natural waters to show decreasing ^3H with increasing Cl. Some waters from the San Ildefonso area contain considerably more Cl than most other waters of this study (up to 350 mg/kg) but have very low ^3H contents (<0.5 T.U.). These waters are obviously old, in contrast to many dilute cold spring, well, and stream waters that have more than 5 T.U. ^3H (Table 4) and are obviously young (or have a young component). A few notable exceptions stand out on the two plots. For example, DP Spring at TA-21 shows a rough pattern of decreasing ^3H (≤845 T.U.) with decreasing Cl (≤115 mg/kg). Both constituents are much higher than background levels in natural cold waters. Some of the drain waters at TA-33 (where the old tritium building stands) contain <4 mg/kg Cl but >1500 T.U. ^3H. Waters of this type are impacted with ^3H from Laboratory activities.

As mentioned above, present background levels of ^3H in precipitation from the Los Alamos region are about 10 T.U. Groundwaters that contain between 5 and 20 T.U. are probably very young, have relatively simple flow paths, and are best modeled as piston-flow reservoirs. Calculated ages of groundwaters falling within this range of ^3H contents is ≤35 yr. (Shevenell and Goff, in press). Examples of waters falling in this range are many cold spring, well, and stream samples throughout the region (Table 4). Interestingly, some springs with young water contain quite different ^3H in different years, for example, Water Canyon Gallery (4.3 T.U. in 1992 and 12.8 T.U. in 1993). A spring like Water Canyon Gallery is not fed by a simple piston-flow aquifer but, instead, has multiple recharge points to the aquifer (even though the combined water is relatively young).

There are many examples of old water in the Los Alamos region, and most originate from springs and wells from the Main Aquifer in the White Rock Canyon, Pajarito Plateau, and San Ildefonso areas. Waters consistently containing ≤0.5 T.U. are probably old, have relatively complicated flow paths with multiple recharge points, and are best modeled as well-mixed reservoirs. Calculated ages of groundwaters having ≤0.5 T.U. ^3H are ≥3,000 yr (Shevenell and Goff, in press), but the error on the age calculation becomes larger as the tritium value decreases. Waters having ≤0.15 T.U. ^3H have model ages ≥10,000 yr., pushing the limit of age determinations with ^3H. A time-series experiment (Table 6) was conducted during a pump test on the relatively new Otowi-4 production well in Los Alamos Canyon. During a period of about 40 days, 18 samples contained an average of 0.32±0.19 ^3H, which translates to a model age of about 5,000 yr. The error on this age calculation is +2,000 and -5,000 yr.

Figures 14 and 15 and the data in Table 4 show that there are many waters in the Los Alamos area with ^3H levels much higher than present background. Examples from DP Spring and the drains at TA-33 have been mentioned above. Other examples include the sewage outfall water at TA-21 (2800 T.U. ^3H) and water residing in Test Well 2A (700 T.U. ^3H in 1992 and 1993), which is produced from a perched aquifer at about 40 m depth in Pueblo Canyon. Waters containing ≥300 T.U. ^3H and collected after about 1990 can not be modeled for age, and their ^3H can only come from nearby Laboratory sources.

In contrast to the "high-tritium" waters, there are several waters in the Los Alamos area that have above background levels of ^3H whose origin is not uniquely identifiable from ^3H data alone. Waters in this group include those in Test Well 1 (110 T.U. ^3H in 1992 and 1993), Test Well 1A (41 to 46 T.U. in 1992 and 1993, respectively), several springs and streams flowing from the east side of the Sierra de los Valles (30 to 80 T.U.), and Test Well 4, producing from the Main Aquifer in Acid Canyon (3.3 T.U.). Test Wells 1 and 1A were drilled near the junction of Los Alamos and Pueblo Canyons. Test Well 1 penetrates the top of the Main Aquifer at about 190 m depth and this well contains more ^3H than nearby Test Well 1A which bottoms in a perched aquifer at only 68 m depth. These wells also have anomalous concentrations of chemical components such as chloride and nitrate (mentioned above) indicating an impact from Laboratory processes. Model ages can be calculated for these waters (≤35 yr., piston-flow case), but the ages are definite upper limits. Test Well 4 produces fluid from the top of the Main Aquifer at about 365 m depth. A model age of 40 yr (piston-flow case) or 500 yr. (well-mixed case) can be calculated. However, since Main Aquifer fluids generally contain <1 T.U. ^3H, both Test Wells 1 and 4 contain some young waters, probably related to Laboratory activities.

Some areas around Los Alamos contain streams that show dramatic increases in ^3H going downstream. An excellent example of this comes from data collected in Los Alamos Canyon. Los Alamos Creek water above (upstream) of the reservoir contained 34 T.U. ^3H in May 1991, but the creek water contained 1460 T.U. by the time it passed the Omega Site reactor during the same month. Water from 98 m depth in Well LADP-

TABLE 5A. Tritium Concentrations (T.U.) Calculated with the Piston-Flow Model for Recent Base Years in the Los Alamos Region, New Mexico (from Shevenell and Goff, in press)

Fluid Age (years)	1990	1991	1992	1993	1994
1	11	10	10	9.6	9.1
2	12	11	10	9.5	9.1
3	12	11	10	9.4	9.0
4	13	11	10	9.3	8.9
6	14	13	11	10	8.8
8	16	14	12	11	9.8
10	17	16	14	12	11
15	22	20	18	16	14
20	66	54	17	21	19
24	75	61	50	51	53
26	270	135	67	55	45
28	114	302	242	121	60
30	23	39	102	270	216
32	74	42	20	35	92
34	19	11	66	37	18
36	27	3.2	17	10	59
38	0.72	0.72	24	2.9	15
40	0.64	0.64	0.64	0.64	22
45	0.49	0.49	0.49	0.49	0.49
50	0.37	0.37	0.37	0.37	0.37
60	0.21	0.21	0.21	0.21	0.21
70	0.12	0.12	0.12	0.12	0.12
80	0.07	0.07	0.07	0.07	0.07
90	0.04	0.04	0.04	0.04	0.04
100	0.02	0.02	0.02	0.02	0.02

3, about 1 km downstream of Omega Site, contained 1880 T.U. ^3H in late 1993. In another example, Two Mile Creek water contains 45 T.U. ^3H at a point just 50 m upstream of the drain from the Van de Graff facility on the mesa north of the creek, but contains 63 T.U. at a point 50 m downstream of the drain.

Although it is relatively easy to find waters in the Los Alamos region that contain above background levels of ^3H from Laboratory activities, in all cases the waters we have analyzed contain levels below the EPA threshhold on drinking water (about 6200 T.U.).

F. Carbon Isotopes and Carbon Sources

Carbon isotopes are frequently used to trace fluid interactions with certain rock types and carbon sources (Hoefs, 1973; Goff et al., 1985). For reference, a diagram showing the carbon isotope distribution of some important carbon species is shown in Fig. 16. About 65 water samples from the Los Alamos region were analyzed for their carbon isotope ratios (reported as $d^{13}C$ values) in dissolved HCO_3 to see if correlations could be made with rock types, general locations, or other parameters. Most samples were collected from sites reflecting conditions in the Main Aquifer and the Confined Aquifer (White Rock Canyon, Pajarito Plateau wells, and San Ildefonso wells). The carbon isotope analyses listed in Table 4 range from -5.8 to -16.7 ‰ in $\delta^{13}C$-HCO_3 but the majority of samples have values less than -10‰. From the diagram, it appears that most of the waters contain dominantly organic carbon or some carbon dissolved from localized freshwater carbonates in the Sante Fe Group. Very little carbon is contributed from Paleozoic marine carbonate rocks that may occur beneath the floor of the Española Basin (Rio Grande rift) or that may occur as clastic fragments in sedimentary rocks of the Sante Fe Group. Carbon isotope values in Los Alamos region waters are more depleted than those found in geothermal waters within the Valles Caldera (-3 to -6 ‰ in $\delta^{13}C$-CO_2, Goff et al., 1985, 1992). However, some Los Alamos region waters contain dissolved carbon with isotope values overlapping the range of -3 to -10 ‰ generally ascribed to mantle carbon.

TABLE 5B. Tritium Concentrations (T.U.) Calculated with the Well-Mixed Model for Recent Base Years in the Los Alamos Region New Mexico (from Shevenell and Goff, in press)

Fluid Age (years)	1990	1991	1992	1993	1994
1	11	10	10	9.6	9.1
2	12	11	10	9.6	9.1
5	15	14	12	11	10
10	24	22	19	18	16
15	29	26	24	22	20
20	30	28	25	23	21
35	27	25	23	22	20
50	23	21	20	19	18
75	18	17	16	15	14
100	14	14	13	12	11
150	10	9.8	9.2	8.7	8.3
200	8.0	7.6	7.2	6.8	6.5
300	5.6	5.3	5.0	4.7	4.5
400	4.3	4.0	3.8	3.6	3.5
500	3.4	3.3	3.1	3.0	2.8
750	2.3	2.2	2.1	2.0	1.9
1000	1.8	1.7	1.6	1.5	1.4
1500	1.2	1.1	1.1	1.0	0.97
2000	0.89	0.85	0.81	0.77	0.73
3000	0.60	0.57	0.54	0.51	0.49
4000	0.45	0.43	0.41	0.39	0.37
5000	0.36	0.34	0.32	0.31	0.29
6000	0.30	0.29	0.27	0.26	0.24
7000	0.26	0.24	0.23	0.22	0.21
8000	0.23	0.21	0.20	0.19	0.18
9000	0.20	0.19	0.18	0.17	0.16
10,000	0.18	0.17	0.16	0.15	0.15

Most of the springs in White Rock Canyon contain waters with $\delta^{13}C$ values less than -10‰, but the values are not always reproducible from year to year. The springs flow from the top of the Main Aquifer, and the carbon data suggest that there is some mixing of waters with different carbon systematics at the top of the aquifer. In contrast, well waters from the Pajarito Plateau and San Ildefonso areas generally display consistent isotope results from year to year. Most waters from the Pajarito Plateau have $\delta^{13}C$-HCO_3 values of less than -10‰; exceptions are well waters from PM #1 and #3, LA-1 and LA-1B, and Otowi-4, which may contain some mantle carbon. Wells LA-1 and LA-1B produce from the Confined Aquifer. Interestingly, most San Ildefonso waters also produce from the Confined Aquifer and have $\delta^{13}C$ values more enriched than -10‰. It appears that the Confined Aquifer may contain a higher proportion of mantle carbon than other waters in the Los Alamos region including the rest of the Main Aquifer. Contributions of carbon into the waters from Paleozoic carbonate fragments in Sante Fe Group rocks are apparently masked by carbon from organic and mantle sources.

G. Strontium Isotopes and Rock Types

Strontium isotopes are used for age determinations in rocks and for tracing interactions between rocks and waters (Faure and Powell, 1972; Vuataz et al, 1988; Goff et al, 1991). A diagram showing strontium isotope ($^{87}Sr/^{86}Sr$) ratios for various rock types in the Los Alamos region is shown in Fig. 17. A previous study of $^{87}Sr/^{86}Sr$ ratios in rocks of the Jemez Mountains and deep geothermal and derivative hot spring waters of the Valles Caldera was published by Vuataz et al. (1988), who found excellent correlations between the rocks and the waters. About 20 water samples from the Los Alamos region have been analyzed for $^{87}Sr/^{86}Sr$, and the values have a rather restricted range from 0.7069 to 0.7088. For comparison, Tertiary to Quaternary volcanic rocks in the Jemez Mountains range from 0.704 to 0.712, but most rock types have

TABLE 6. Time Series Tritium Data for the Otowi-4 Production Well, Los Alamos Canyon, New Mexico

Sample No.	Description	Date	Production Depth (m)	Temp (°C)	Tritium (T.U.)
OT-4-1	Otowi 4 Well	02/08/93	340-785	28.8	0.33±0.09
OT-4-2	Otowi 4 Well	02/09/93	340-785	28.8	0.96±0.11
OT-4-5	Otowi 4 Well	02/25/93	340-785	28.8	0.16±0.09
OT-4-6	Otowi 4 Well	02/26/93	340-785	28.8	0.20±0.09
OT-4-7	Otowi 4 Well	03/01/93	340-785	28.8	0.17±0.09
OT-4-8	Otowi 4 Well	03/02/93	340-785	28.8	0.34±0.09
OT-4-9	Otowi 4 Well	03/03/93	340-785	28.8	0.25±0.09
OT-4-10	Otowi 4 Well	03/04/93	340-785	28.8	0.39±0.09
OT-4-11	Otowi 4 Well	03/05/93	340-785	28.8	0.13±0.09
OT-4-12	Otowi 4 Well	03/08/93	340-785	28.8	0.14±0.09
OT-4-13	Otowi 4 Well	03/09/93	340-785	28.8	0.16±0.09
OT-4-14	Otowi 4 Well	03/10/93	340-785	28.8	0.36±0.09
OT-4-15	Otowi 4 Well	03/11/93	340-785	28.8	0.23±0.09
OT-4-16	Otowi 4 Well	03/12/93	340-785	28.8	0.35±0.09
OT-4-17	Otowi 4 Well	03/15/93	340-785	28.8	0.50±0.09
OT-4-18	Otowi 4 Well	03/16/93	340-785	28.8	0.45±0.09
OT-4-19	Otowi 4 Well	03/17/93	340-785	28.8	0.38±0.09
OT-4-20	Otowi 4 Well	03/18/93	340-785	28.8	0.25±0.09
Average value (n=18)					0.32±0.19 (1 σ)

values less than 0.706. In contrast, Precambrian rocks of the region range from 0.722 to 0.900 whereas Paleozoic carbonate and sedimentary rocks range from 0.7088 to 0.7569. The $^{87}Sr/^{86}Sr$ of marine carbonate rocks has fluctuated slightly through time; presently the value of seawater is about 0.709, but during the Carboniferous period (300 Ma), strontium isotope values for seawater ranged from 0.7075 to 0.7085. Los Alamos region waters have $^{87}Sr/^{86}Sr$ values that are influenced by either Tertiary volcanic or, possibly, Paleozoic carbonate rocks. They show no apparent influence from Precambrian rocks.

Carbonate rocks usually contain more total Sr than most volcanic and plutonic rocks because Sr substitutes easily in the Ca and Mg sites in calcite and dolomite. In addition, carbonates are relatively more soluble in cold, dilute, near neutral pH waters than most other rocks, especially igneous rocks comprised of silicates; thus the Sr in carbonate fragments within sedimentary rocks is more likely to influence the $^{87}Sr/^{86}Sr$ in coexisting waters than the Sr in igneous rock fragments. However, if glassy volcanic rocks are in contact with water, the glass reacts rapidly releasing silica, alkalis, and other dissolved cations.

Two spring waters from the Los Alamos region were chosen for analysis because they issue directly from the Bandelier Tuff: DP Spring and Water Canyon Gallery. Both issue from the Tshirege Member and have $^{87}Sr/^{86}Sr$ values of 0.7085 and 0.7069, respectively. In a study by Self et al. (1991), the Otowi Member was found to have a value of 0.7086±0.0033 (n=6), and the Tshirege Member had a value of 0.7067±0.0019 (n=9). All well waters from the Main Aquifer beneath the Pajarito Plateau have $^{87}Sr/^{86}Sr$ values falling within the range of values obtained from the Bandelier Tuff. It is possible that the Sr in these waters has come from slow recharge and dissolution of glass during fluid transit through the thick sections of Bandelier Tuff blanketing the Pajarito Plateau. This observation would be consistent with the stable isotope data mentioned above.

In contrast, most well waters in the San Ildefonso area produce from the Confined Aquifer and the stable isotopes of these waters suggest recharge from the east. In addition, no Bandelier Tuff overlies Santa Fe Group rocks at the San Ildefonso wells. Although our four $^{87}Sr/^{86}Sr$ measurements from San Ildefonso wells (0.7080±0.0005) also fall in the range of Bandelier Tuff, it is much more likely that the Sr in these well waters comes from dissolution of Paleozoic carbonate fragments or dissolution of volcanic ash (from abundant pre-Bandelier ash beds) found in the Sante Fe Group.

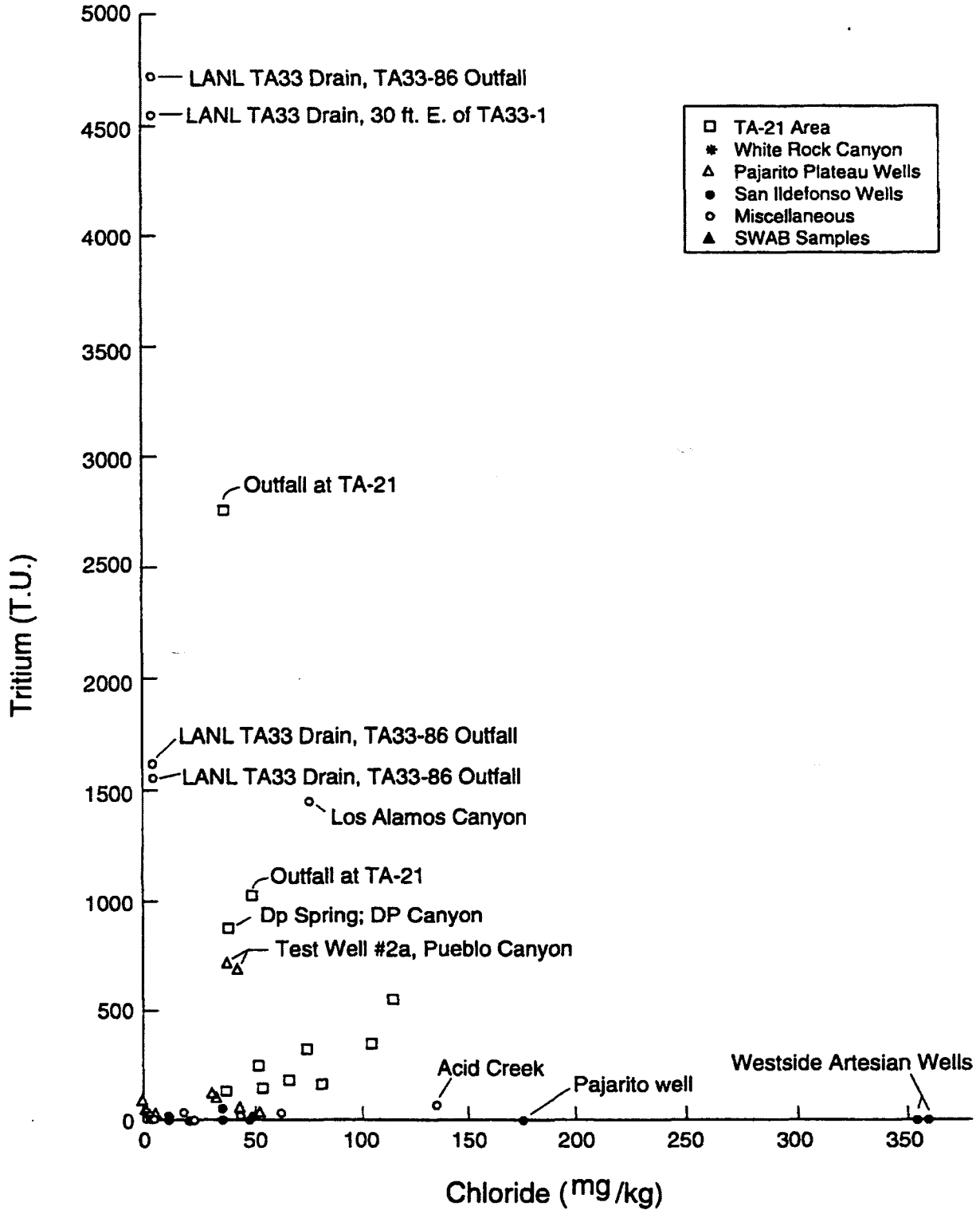

Figure 14: Tritium amounts in T.U. plotted against chloride concentration for each sample in the study, though at this scale the plotted locations for many different samples are undifferentiable. Present background levels of ^3H in precipitation from the Los Alamos region are about 10 T.U., though there are many waters in the Los Alamos area with ^3H levels much higher than background. Tritium levels above 300 T.U. in samples collected since about 1990 can only come from nearby Laboratory sources.

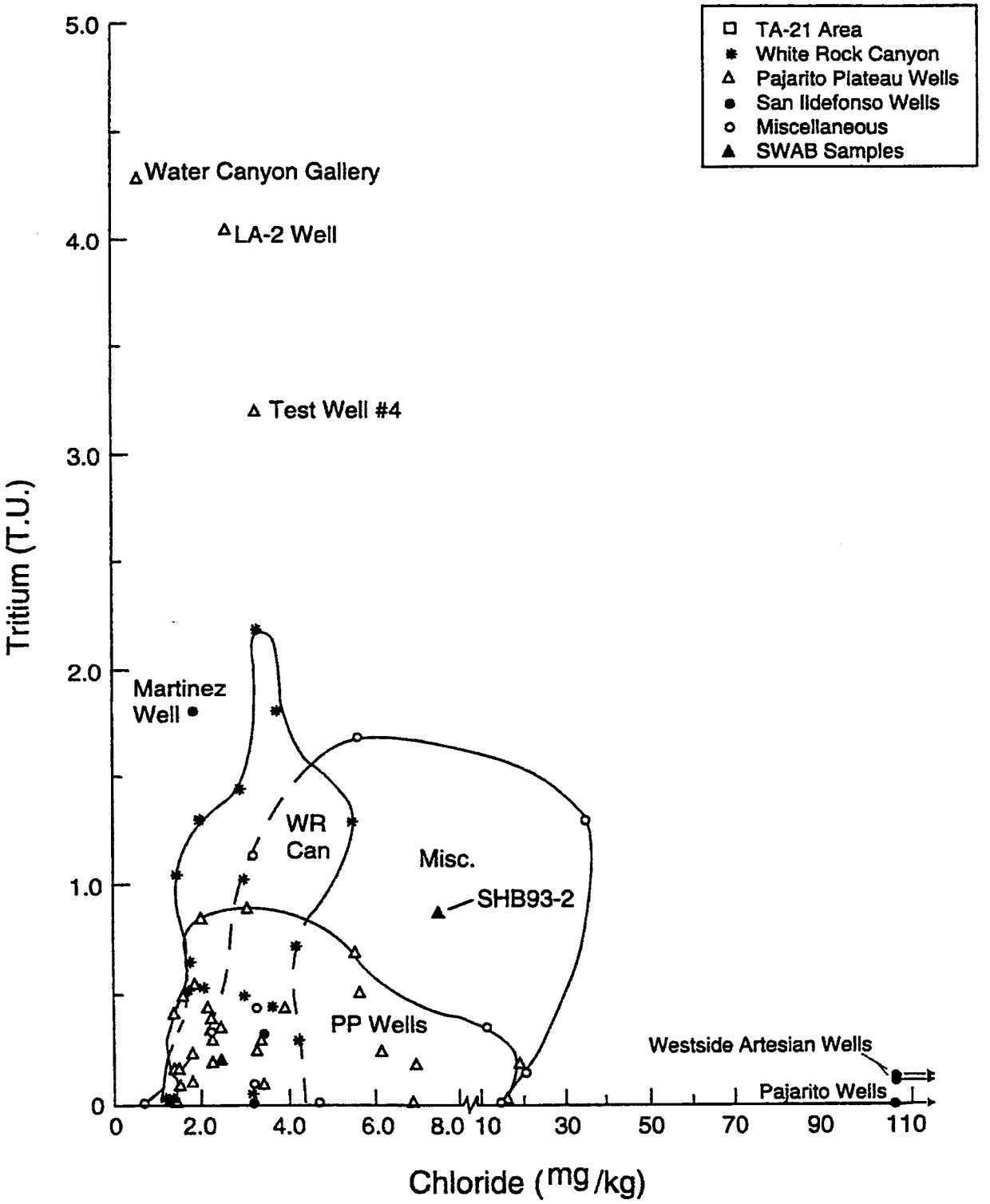

Figure 15: Tritium amounts between 0 and 5 T.U. plotted against chloride concentration for each sample whose tritium content falls within this range. Most groundwaters become more concentrated in soluble constituents as their residence time underground increases; thus it is common for natural waters to show decreasing ^{3}H with increasing Cl.

V. CONCLUSIONS

The data in this report provide background information for both broad investigations of the groundwater hydrology and geochemistry of the entire study area and for environmental projects at specific locations within this region. Many conclusions immediately apparent from the presented data are applicable for both uses. From the analysis of the waters' major cation/anion contents, most waters in the study are calcium or sodium bicarbonate waters. Also, it is apparent that well waters are likely to have a higher soluble constituent content than surface waters because of their increased temperature and age at depth. This depth/soluble constituent content relation breaks down, though, for some anions and cations when anthropogenic contamination, rising thermal waters, or notable subsurface water movement between aquifers is prominent in a given area.

From examination of trace elements, we know that locations within Pueblo and DP Canyon, including DP Spring and the outfall at TA-21 show the greatest anthropogenic impact. For contaminants located within those canyons, the older Laboratory facilities on the town mesa seem the most likely source. Sampling locations having elevated lead occur in the southwest portion of the lab, possibly because of remnant effects of lead-shielded nuclear experiments, or because of local groundwater leaching of lead from the surrounding bedrock. Unrelated to the Lab, fertilizer use and stock raising on the San Ildefonso Reservation seem responsible for the fairly elevated sulfate and nitrate levels found there.

The stable isotope analyses of waters in this study place the $\delta D/\delta^{18}O$ ratio of most samples on or near the World Meteoric Water Line of Craig (1961) and the parallel Jemez Mountains line of Vuataz and Goff (1986), with δD values mostly between -70‰ and -100‰. In the restricted region encompassed by this study, isotopic variations within these norms result primarily from variations in recharge elevations. Using this fact to calculate recharge elevations, it appears that most waters discharging in White Rock Canyon and located under the Pajarito Plateau and San Ildefonso Reservation have precipitated locally or migrated from the north and have not originated from the area of the Valles Caldera. This flow pattern would support our

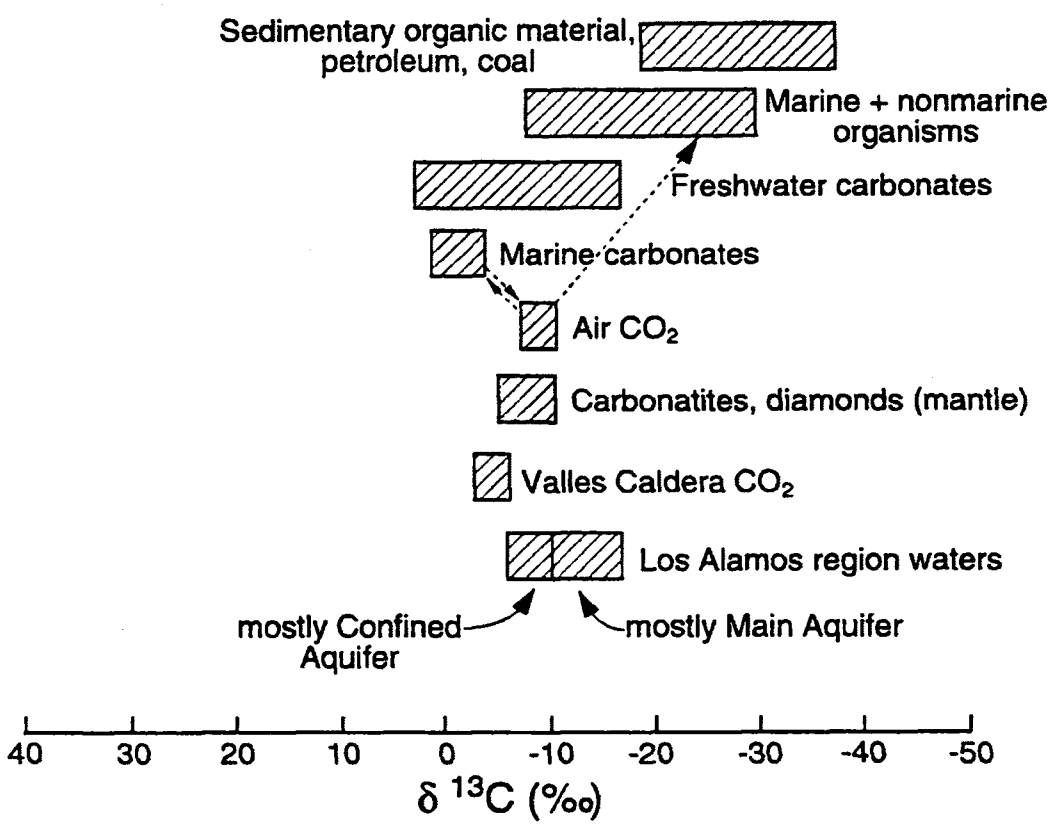

Figure 16: Carbon Isotope distribution of some important carbon species and waters in the study area.

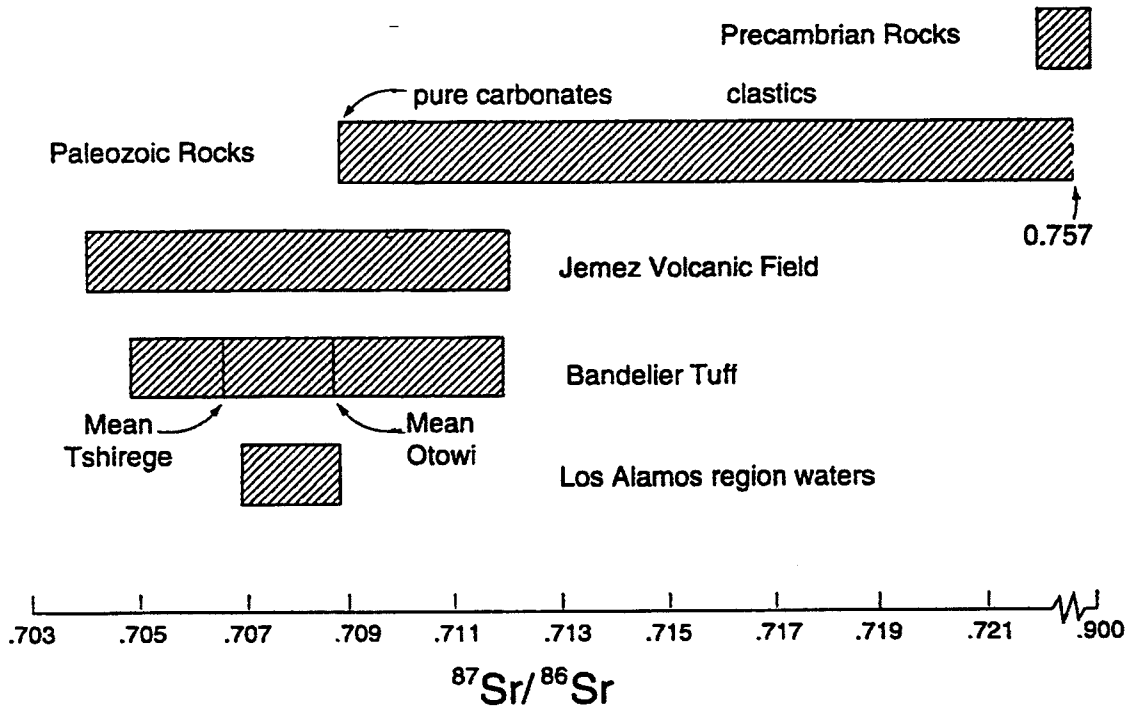

Figure 17: Strontium isotope ($^{87}Sr/^{86}Sr$) ratios for various rock types and waters in the Los Alamos region.

earlier assertion that relatively high sulfate and nitrate levels found northeast of the lab are not laboratory-related because the described water movement could not move contaminants in such a way. Also from these recharge elevations, it appears that waters in the confined aquifer as decribed by Purtymun and Johansen (1974) have moved into their present position from the Sangre de Cristo Mountains through western dipping strata that pass under the Española Basin.

The natural and anthropogenic impact histories of waters are also apparent from their tritium contents. Waters with less than 6 T.U. are generally assumed to be uncontaminated, and therefore their ages can be determined from their tritium contents. For instance, tritium concentrations below 0.5 T.U. denote a minimum age of 80 years and a maximum age as great as 3000 years. Higher tritium levels mark contamination, sometimes at completely different locations than those that appear impacted from trace element studies. For example, TA33-2 shows the highest tritium concentration of any sample in the study, though it is not high in any of the previously mentioned trace elements typically high in impacted waters. Most other locations high in tritium, though, are also high in sulfate, nitrate, phosphate, or lead, such as DP Spring, the outfall at TA-21, and Test Well 2A. At these places, probably the same Lab-related processes caused both the elevated tritium and trace element concentrations.

Two other sources of information on the past and present movement of the waters in this study come from the carbon and strontium isotopes. The variable carbon isotope values found in samples from White Rock Canyon suggest mixing of waters with different carbon systematics at the top of the aquifer. Waters in the Pajarito Plateau and San Ildefonso waters, however, have consistent carbon isotope values which suggest less mixing from lower in the aquifer where those waters lie. Some mantle carbon is likely in samples with greater than -10‰ $\delta^{13}C$-HCO_3, such as PM-1 and 3, Otowi-4 and most samples from the confined aquifer. Mantle carbon could be a sign of rising thermal waters, which were mentioned earlier as a possible cause of the irregular temperature/solubility-influenced constituent content relation within the Pajarito Plateau sample group. Strontium isotope compositions suggest that strontium comes from flow of water through Tertiary volcanic rocks and/or flow of water through sedimentary rock containing fragments of volcanic glass and Paleozoic carbonates. Further research is needed to investigate waters in the Sangre de Cristo Mountains and at other northern and eastern points to better analyze water movement from those regions and their impact on waters in the more immediate Laboratory area.

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