University of Nevada

Reno

Hydrochemical Response of the Moana Geothermal Area

to Development Stress

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by

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ABSTRACT

The Moana geothermal area is experiencing declining aquifer pressures due to development stress. Hydrochemical and temperature relationships are used to examine the thermal effects of development stress. Temperature-concentration relationships of the Moana thermal waters are examined for the chemical constituents boron, chloride, fluoride, lithium, arsenic and bicarbonate. Decreasing concentrations of boron, chloride, fluoride, and lithium with a corresponding decrease in temperature indicate mixing of thermal and nonthermal waters in the geothermal aquifer. Bicarbonate concentration is inversely proportional to temperature in the thermal waters. The chemistry data indicate that mixing between thermal and nonthermal waters is an important control on temperature in the Moana resource area. The concentrations of boron, chloride and the bicarbonate-chloride ratio are considered temperature analogs at individual well locations. Monthly sampling at two constantly discharging commercial wells indicate that temperatures are constant and independent of well discharge rate. Fifteen year variations in thermal water chemistry suggest that temperatures are changing in portions of the resource area. No correlation is apparent between the locations of thermal change and portions of the resource area experiencing declining aquifer pressures. Continued sampling of the thermal waters is recommended to better define changing aquifer conditions.

INTRODUCTION

The Moana geothermal aquifer in Reno, Nevada has been used for space heating purposes for over fifty years. Today, the aquifer supports the largest direct use application of a low to moderate temperature (< 150 °C) geothermal resource in the State of Nevada (Flynn and Ghusn, 1984). Development of the geothermal area has progressed in an uncoordinated manner which may affect the quality of the resource. Cessation of flowing artesian conditions in the resource area was observed by Ghusn (1982) during the early 1980's. The reduction in aquifer pressure suggests that the resource area is experiencing some degree of development stress.

This paper examines the relationships between temperature and the concentration of several chemical constituents in the Moana thermal waters. These relationships are used to explore the thermal effects of development stress on the geothermal aquifer. The primary objective of this investigation is to determine whether or not development of the resource has reduced geothermal aquifer temperatures. Temperature is, in part, related to the degree of mixing between nonthermal and thermal waters in the geothermal aquifer. Development stress may affect the rate of mixing between the two water types by inducing additional leakage of overlying nonthermal water. Temperatures in the geothermal aquifer will decline in response to the additional leakage. The differences in chemical composition of nonthermal and thermal waters of the area are used to identify mixing in the geothermal aquifer. Temporal variations in water chemistry are examined and are believed to correspond to changing thermal conditions in the resource area.

Background

The Moana geothermal area is located in northwestern Nevada, mostly within the City of Reno (Figure 1).
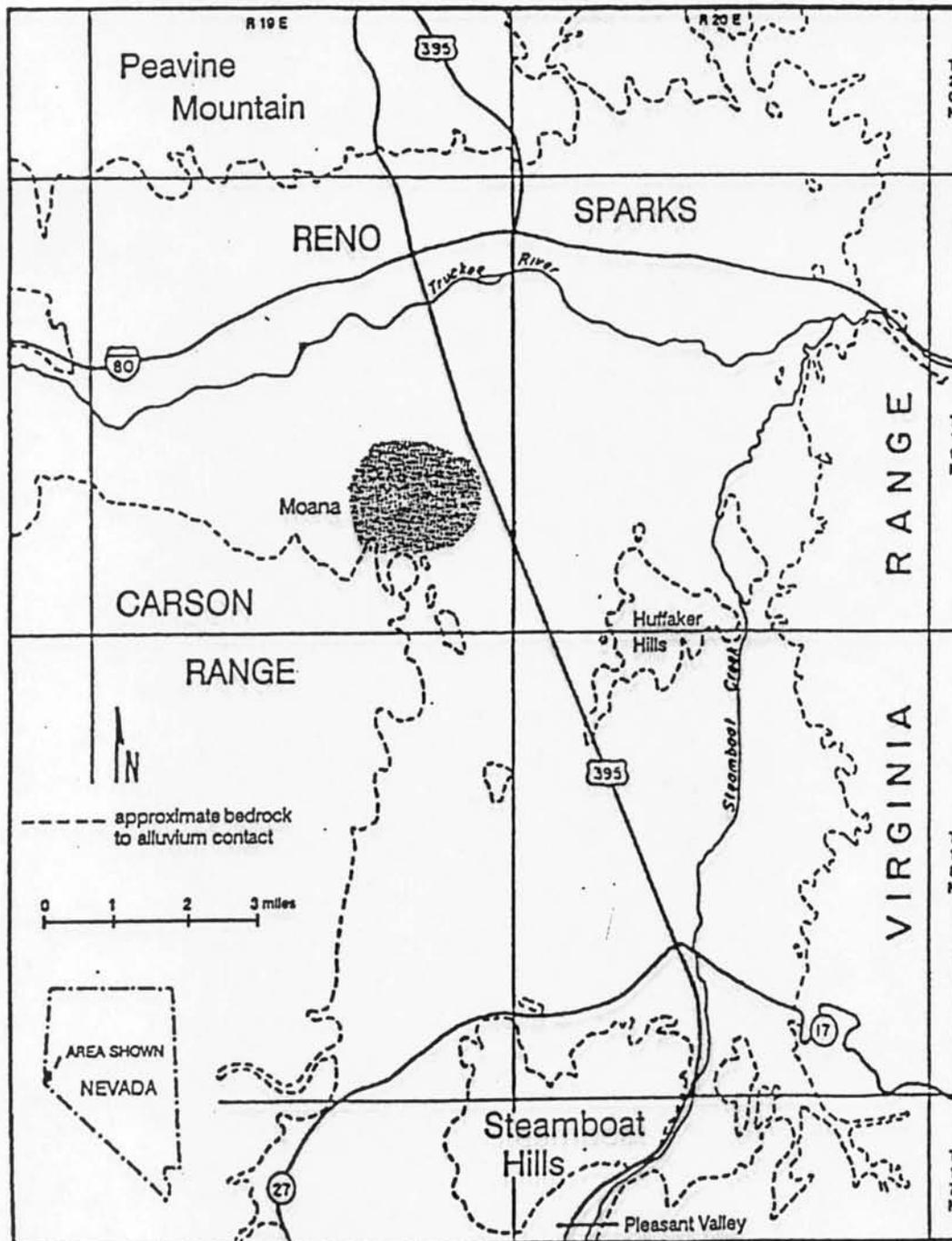
Figure 1.   Location of the Moana Geothermal Area (after Bateman and Scheïbach, 1975)

A shallow (100 to 1200 feet), low to moderate temperature (45 to 98 °C), geothermal aquifer is utilized for purposes of residential and commercial heating. Currently, more than 160 wells extract heat and hot water from the geothermal aquifer in an area of less than five square miles.

Development of the geothermal aquifer was limited through 1975 when 35 homes and 3 businesses utilized the resource (Bateman and Scheibach, 1975). However, during the late 1970's and early 1980's the Moana area experienced a boom in geothermal development. Numerous domestic geothermal wells were completed and two district heating systems were brought on line during this period. Today the resource is utilized by over 200 residences, numerous businesses and several churches.

The majority of geothermal wells are used for residential heating. Generally, each residence has its own well. Well construction is similar to ordinary water wells with a six or eight inch casing the entire depth of the well. The well casing is commonly perforated at the bottom in the area of the maximum temperature (Flynn and Ghusn, 1984). The upper fifty feet of casing is usually cemented in place as a sanitary seal and to prevent leakage of nonthermal water into the geothermal aquifer. Most residential wells use simple loop, downhole, heat exchangers. The heat exchangers consist of two strings of pipe connected by a reverse bend at the bottom. City water is circulated through the loop and extracts heat from the geothermal water in the well. Over 90% of the residences intermittently pump off geothermal water to maintain high temperatures in the wells. The pumped geothermal water is usually discharged to the storm drain or sanitary sewer.

Commercial users of the geothermal resource include the Peppermill Hotel-Casino, Virginia Lake Townhouses, Mark Twain Motel, Moana Lane Nursery, Century Office Building and the two district heating systems, Warren Estates and Sierra Geothermal. All commercial users pump the geothermal water to surface heat

exchangers because of the large heat requirements. Following the heat exchange process the cooled geothermal water in reinjected down gradient from the production wells.

Previous investigators working in the Moana geothermal area include Scheibach (1975), Bateman and Scheibach (1975), Ghusn (1982) and Flynn and Ghusn (1984). Scheibach (1975) collected baseline water chemistry data for the resource area. He identified mixing between nonthermal and thermal waters by examining sulfate concentration in ground waters of the Moana area. Ghusn (1982) and Flynn and Ghusn (1984) conducted the first isotopic investigations of the thermal waters. Tritium data collected by Flynn and Ghusn (1984) confirms Scheibachs mixing observations. Thermal waters show increasing tritium content with decreasing temperature. This indicates that colder, modern, tritium enriched waters are mixing in the geothermal aquifer with the thermal waters.

The Desert Research Institute (DRI) conducted a geothermal aquifer monitoring program from October, 1988 to January 1990 (Jacobson and Johnston, 1991). Thermal, water level, and water chemistry data were collected at numerous locations in the Moana resource area during the course of the study. This work confirmed the decline in aquifer pressures first identified by Ghusn (1982). A five to eighteen foot decline in potentiometric head has occurred in the central portion of the resource area since the early 1980's. Several homeowners reported decreased heat output from their wells during the late 1980's.

The presence of downhole heat exchangers in most wells makes it difficult to collect unbiased temperature data. Generally, downhole heat exchangers place a thermal load on the well throughout the year. Direct temperature measurements in operating geothermal wells are, therefore, a poor way to assess the thermal effects of development stress. An alternative to direct temperature measurements in wells is desirable.

The temperature-chemical composition relationships provide an alternative method of identifying thermal changes in the geothermal aquifer. The DRI water chemistry data are examined in the attempt to identify stress induced, thermal changes in the Moana geothermal area.

GEOLOGIC SETTING

The Moana geothermal area is located in the Truckee Meadows, a north-south trending basin at the western edge of the Basin and Range province. The Truckee Meadows are bounded on the west by the Carson Range, a spur of the Sierra Nevada, and on the east by the Virginia Range (Figure 1). Stratigraphic evidence suggests that the basin has been in existence since the early or middle Pliocene (Scheibach, 1975).

The Moana area abuts the eastern flank of the Carson Range. Structural relief in the resource area is believed to be associated with the uplift of this range. Uplift of the northern Carson Range is by flexure, possibly related to concealed Tertiary intrusions, and forms a partial dome (Thompson and White, 1964). The domical structure is broken by many normal faults most of which are antithetic; that is, the displacement is down on the mountain side of the faults. The structural relief produced by antithetic faulting therefore subtracts from the uplift.

Most faults of the Moana area display Pleistocene movement, but very few fault planes offset known Holocene deposits (Bingler, 1975). Two fault trends were recognized by Flynn and Ghusn (1984), one trending north 20° east and the other north 10° west. The fault system in the Moana area is believed to be one of the principal conduits for thermal fluid migration (Bateman and Scheibach, 1975).

Stratigraphy

The geology of the area has been mapped by Bonham and Rogers (1983). Three major rock units in the Moana area have been identified from outcrops and well log data (Flynn and Ghusn, 1984). The rock units are, from oldest to youngest, Pliocene Kate Peak Formation, Pliocene Sandstone of Hunter Creek, and Quaternary alluvium.

The Kate Peak Formation dates from the lower Pliocene and consists of a thick sequence of flows, flow breccias, tuffs, tuff-breccias, volcanic sandstone and

conglomerate, and shallow intrusive bodies (Bonham, 1969). The volcanic rocks range from andesite to rhyolite in composition, with dacite being the most common rock type. Under much of the Moana area, the upper most member of the Kate Peak Formation consists of a hydrothermally altered rhyodacite vitrophyre (Flynn and Ghusn, 1984). This altered vitrophyre, commonly refered to as "blue clay", is composed almost entirely of smectite, a structurally disordered clay (Flynn and Ghusn, 1984). Drillers' logs report a strong correlation between the blue clay and the occurence of thermal waters.

Overlying and interfingering with the Kate Peak Formation is the Sandstone of Hunter Creek, also of Pliocene age. The Sandstone of Hunter Creek is identified as the Truckee Formation by earlier authors (Cohen and Loeltz, 1964; Thompson and White, 1964; Scheibach, 1975). This paper will refer to the formation as the Sandstone of Hunter Creek as proposed by Bingler (1975) to be consistent with the more recent work of Flynn and Ghusn (1984). The Sandstone of Hunter Creek is described by Bingler (1975) as intercalated siltstone and fine sandstone, and moderately well sorted, texturally mature medium pebble to small cobble gravelly sand. The formation can be subdivided into three members: a lower greywacke member, a thick medial sequence of diatomaceous siltstone, and an upper member of sandstone (Flynn and Ghusn, 1984). The lower member is very gravelly with the mean size of clasts increasing toward the basal contact with volcanic rock. Lower most beds include abundant volcanic detritus, thin tuff beds and mudflows (Bingler, 1975). The medial member is composed almost entirely of diatomite and diatomaceous siltstones and sandstones. It may be as much as 1500 feet thick in the Moana area. The upper member is a complex sequence which grades upward from diatomaceous sandstone and volcanic arenite to well sorted dune deposits (Ghusn, 1982).

Quarternary deposits in the Moana area uncomformably overlie the Tertiary sedimentary and volcanic formations. These deposits were classified by Bingler (1975) into three general groups: (1) Pleistocene, alluvial fan deposits, consisting of poorly sorted sands and gravels, (2) Illinoian and Wisconsinan, outwash deposits composed of well rounded gravels and sands, (3) Holocene, fluvial and alluvial deposits of fine sands, silts, and clays derived from reworking of the earlier aluvial fan and outwash deposits.

Geothermal Aquifer

Bateman and Scheibach (1975) proposed a fault-charged model for the geothermal area. The model can be described as follows: (1) cool water originating in the Carson Range to the west percolates downward along permeable zones, probably through faults or joints, (2) a high regional heat flow gradient of 52 °C/km combined with deep ciculation heats the water, (3) the resultant decrease in density causes the thermal water to rise along normal faults in the Moana resource area, (4) the thermal water then diffuses laterally in permeable horizons away from the faults. Temperature data from drillers' logs supports this model. The highest reported temperatures in the geothermal aquifer are in the vicinity of known fault locations.

The geothermal aquifer occurs under leaky, confined conditions primarily within the Kate Peak Formation. Thermal water, usually of lower temperature, is also present in the sedimentary deposits above the Kate Peak. Drillers report thermal water at depths of 100 feet or less near the center of the resource area. This shallow occurrence of the geothermal aquifer corresponds to the presence of the Kate Peak Formation in the shallow subsurface. Well logs indicate that the formations comprising the geothermal aquifer extend to at least 3000 feet below land surface (Peppermill Hotel Engineer, Personal Communication, 1989). Within the geothermal aquifer,

thermal water moves preferentially through jointed and fractured units, and intraflow breccias of the Kate Peak Formation and in sand and gravel beds of the sedimentary formations. Flynn and Ghusn (1984) also identified the contact between the Kate Peak and the Sandstone of the Hunter Creek as an important conduit for thermal water migration. Permeable units in the geothermal aquifer range in thickness from less than a foot to tens of feet and display high areal variablility. Low permeability units in the Moana area effectively confine the geothermal aquifer so that artesian conditions are present in most of the resource area. Confining units include, but are not limited to, the altered vitrophyre or "blue clay" of the Kate Peak Formation, the siltstones of the Sandstone of Hunter Creek, and clay layers in the Quaternary alluvium (Bateman and Scheibach, 1975).

Water level data compiled by Flynn and Ghusn (1984) show the piezometric surface of the thermal water dips towards the northeast and east as does the general topography. Ground-water flow direction of the thermal water is same as that in the regional, nonthermal water aquifers. Thermal water is believed to rise along the faults in the western and central portions of the resource area and subsequently flow to the northeast and east (Bateman and Scheibach, 1975). Temperature data supports this hypothesis. The highest temperatures, 90°C to 98°C, are found in the western and central portions of the resource area in close proximity to faults (Unpublished Drillers Logs). Geothermal aquifer temperatures decrease in the eastern portion of the resource area with maximum reported temperatures of 70°C or less.

GROUND-WATER CHEMISTRY

Chemical Composition

Ground-water samples collected in the Moana area can be broadly classified into two types; (1) nonthermal, bicarbonate dominated water and (2) thermal, sulfate dominated water. Mixing between nonthermal and thermal waters has been identified and can cause significant variation in the chemical composition of each water type (Scheibach, 1975).

The nonthermal waters of the area are of good quality and suitable for most uses. Table 1 contains historical single sample analyses of nonthermal waters from the eastern and southern boundaries of the Moana resource area. Sample locations are up gradient of the resource area and are thought to have little or no chemical contribution from thermal waters. Major chemical constituents are, in order of decreasing concentration, bicarbonate, silica , sulfate, calcium, sodium, magnesium, nitrate, chloride, and potassium.

Thermal waters are of poorer quality with concentrations of dissolved solids (estimated by ion summation) in the hottest waters of around 1000 milligrams per liter (mg/l). Table 2 contains analyses of waters from geothermal wells in the Moana resource area. These samples represent a broad cross section of thermal waters from the Moana area. The table includes both end member and mixed examples of thermal waters. Moana thermal waters contain, in order of decreasing concentration, sulfate, sodium, silica, bicarbonate, chloride, calcium, potassium as well as minor amounts of fluoride, magnesium, boron, lithium and arsenic.

Table 1. Chemical Analyses of Nonthermal Waters from the Southern and Eastern Boundaries of the Moana Geothermal Area

Address Location[1]	Date	Temp °C	pH	EC umhos/cm	SiO$_2$ mg/l	Na mg/l	K mg/l	Li mg/l	Ca mg/l	Mg mg/l	B mg/l	SO$_4$ mg/l	Cl mg/l	HCO$_3$ mg/l	CO$_3$ mg/l	F mg/l	As mg/l
4890 Piedmont T19N R19E 22	7-20-79	-	7.63	-	-	17	7	-	29	19	-	14	4	195	-	0.09	0.005
1705 Davis T19N R19E 34	1-24-85	-	7.48	399	66	30	4	-	34	15	0	25	5	217	0	0.17	0.005
8355 Lakeside T19N R19E 34	5-3-85	-	7.70	325	73	22	5	-	27	12	0	10	2	188	0	0.10	0.007
Lakeridge and Hash T19N R19E 35AA	1-21-75	19.4	7.80	-	-	24	3	-	24	7	-	27	4	124	-	0.06	0.01
6601 Lakeside T19N R19E 35	4-15-87	-	7.65	482	82	38	5	-	42	12	0.1	42	5	232	0	0.32	0.024
Lakeside and Evans Cr. T19N R19E 35	3-06-80	12.2	7.20	-	-	29	4	-	32	11	-	49	2	149	0	0.26	0
2770 Del Monte T19N R19E 35	9-08-81	-	7.69	-	68	32	4	-	48	22	0.1	19	4	303	0	0.30	0.005
SPPCO Lakeside Well T19N R19E 35AA	6-18-86	14.5	7.52	356	68	22	3	-	33	11	0.1	32	5	171	0	0.18	0.008

[1]: Based on Township, Range, and Section
Data Source: Laboratory Records from Nevada State Health Laboratory, Nevada Division of Health

Table 2. Chemical Analyses of Thermal Waters from the Moana Geothermal Area

Address	Date	Temp[1] °C	pH	EC umhos/cm	SiO₂ mg/l	Na mg/l	K mg/l	Li mg/l	Ca mg/l	Mg mg/l	B mg/l	SO₄ mg/l	Cl mg/l	HCO₃ mg/l	CO₃ mg/l	F mg/l	As mg/l
ᵃ2600 Eastshore1	9-27-89	56.0	8.28	971	93.7	189	9.42	0.14	20.3	0.98	1.2	281	30.1	180	-	3.01	0.09
ᵇ4520 Lakeside	3-1-74	63.1	8.05	1035	92.6	189.35	5.5	0.14	16.5	0.405	1.36	304.6	33.5	131.5	-	4.18	0.11
ᵇ1200 Manzanita	2-18-74	80.0	7.5	1070	103.7	248	7.1	0.22	20.5	0.32	1.74	419	53	95	-	4.95	0.09
ᵇ1140 W. Peckham	3-01-74	85.0	7.78	1430	92.3	258.7	7.17	0.18	22.1	0.79	2.08	478.2	53	99	-	4.8	0.11
ᵇ1160 W. Peckham	5-3-74	85.0	8.35	1423	111	243.2	7.71	0.19	14.23	0.19	1.87	448.8	54	97.55	-	5.1	0.006
ᵇ1150 Sweetwater	12-08-73	77.8	8.20	1320	103.2	293	8.1	-	25	0.26	1.77	465.5	53	100.6	-	6.3	0.20
ᵇ1204 Sweetwater	3-01-74	82.2	7.65	1185	134.7	203	7.37	0.16	28.98	0.786	1.80	348.3	42.0	146.0	-	4.8	0.04
ᵇ2201 S. Virginia	3-01-74	50.0	7.95	942	57.8	175	5.96	0.12	15.8	1.49	0.75	258.3	31	131.0	-	0.75	0.13
ᵇ1175 Yates	4-30-74	90.0	8.29	1367	102	243.19	7.36	0.19	23.4	0.205	1.99	457	50	86.2	-	4.83	0.10
ᵃ4220 Swanson	5-25-89	87.7	8.08	1360	97.2	248	7.83	-	27.2	0.24	-	485	48.2	86.1	-	-	0.11
ᶜ2707 S. Virginia1	10-1-86	52.0	8.30	1020	-	190	10.00	-	17.2	0.20	1.10	260.0	30	99.0	-	1.80	0.15
ᶜ2707 S. Virginia2	10-1-86	52.8	8.20	1040	-	190	10.00	-	18.5	0.20	1.30	280.0	32	99.0	-	2.10	0.16
ᵃ2135 Richter	9-13-89	97.2	8.39	1360	114	257	11.70	0.26	31.2	0.15	2.0	499	48.8	77.5	1.8	4.94	0.13
ᵃ1680 Manzanita	1-31-89	75.0	8.36	1060	78.5	213	6.05	-	18.6	0.18	-	244.0	27.2	276.0	2.3	-	0.09
ᵃ3915 Nuttree	1-31-89	49.7	8.18	1410	115.0	269	8.21	-	26.4	0.18	-	489.0	49.7	90.5	-	-	0.12
ᵈ1301 Manzanita1	2-1-83	90.0	8.37	-	120.0	259	11.20	0.26	24.6	0.21	2.25	449.0	48.0	106.0	-	5.57	-
ᵉ2600 Eastshore2	9-24-79	58.8	7.86	-	-	184	9.00	-	16.0	1.00	-	287.0	31.0	120.0	-	1.21	0.07
ᶜ380 Brinkby1	6-30-86	55.0	8.50	-	53.0	165	4.00	-	14.4	0.20	1.20	240.0	28.0	83.0	6.0	2.20	0.08
ᶜ380 Brinkby2	8-14-86	55.0	8.70	-	66.0	175	3.50	-	12.6	0.10	1.30	260.0	30.0	77.0	14.0	2.30	0.12
ᶜWarren1	1-4-88	97.0	8.10	-	78.0	215	9.00	-	23.0	0.10	3.10	410.0	45.0	62.0	-	4.20	0.12
ᶜWarren2	6-27-85	98.0	8.30	-	110.0	254	12.00	-	27.0	0.10	2.20	422.0	49.0	69.0	-	5.00	0.13
ᶜWarren3	7-29-85	93.3	8.70	-	110.0	310	9.50	-	24.0	1.20	2.70	540.0	58.0	90.0	14.0	5.10	0.10
ᵉ2820 Moana	9-15-83	82.2	7.60	-	91.0	320	7.50	-	26.0	0.50	-	500.0	56.0	116.0	-	3.40	0.07
ᵉ690 Starlight	2-11-80	54.4	8.09	-	-	159	6.00	-	13.0	-	-	193.0	25.0	154.0	-	3.50	0.14
ᵉ4095 Garlan	5-2-80	48.3	8.34	-	-	154	8.00	-	12.0	-	-	173.0	21.0	149.0	8.0	3.84	0.13
ᵉ4260 Warren	7-27-80	48.9	8.16	-	-	144	4.00	-	11.0	-	-	163.0	18.0	161.0	-	3.72	0.13
ᵉMoana Pool	2-5-85	56.1	8.17	792	92.0	153	7.00	-	15.0	-	0.90	212.0	24.0	144.0	-	2.52	0.09

Table 2. Chemical Analyses of Thermal Waters from the Moana Geothermal Area (continued)

Address	Date	Temp[1] °C	pH	EC umhos/cm	SiO$_2$ mg/l	Na mg/l	K mg/l	Li mg/l	Ca mg/l	Mg mg/l	B mg/l	SO$_4$ mg/l	Cl mg/l	HCO$_3$ mg/l	CO$_3$ mg/l	F mg/l	As mg/l
[e]4200 Garlan	3-7-80	43.3	8.12	-	-	134	6.00	-	10.0	1.00	-	129.0	10.0	188.0	-	3.87	0.15
[d]1100 Moana	2-1-83	47.2	8.16	-	81.0	235	8.40	0.22	20.9	0.14	1.80	386.0	39.5	184.0	-	4.06	-
[e]3705 Lakeside	6-04-86	75.6	8.27	1384	107	252	7.0	-	25.0	-	1.8	474	48.0	102.0	5.0	4.8	0.11
[e]3835 Lakeside	9-06-81	70.0	8.16	-	128	280	7.0	-	25.0	-	2.0	489	49.0	90.0	-	5.24	0.12
[d]2040 Manzanita	2-01-83	95.0	8.22	-	113	257	12.2	-	24.7	0.10	2.55	459	47.0	93.0	-	5.15	-
[d]4400 Plumas	2-01-83	92.2	8.29	-	110	241	11.6	-	25.2	0.07	2.24	459	46.5	114.0	-	5.36	-
[d]4000 Plumas	7-01-83	87.7	8.88	-	54.5	245	6.0	-	16.7	0.01	2.10	445	30.0	133	-	4.4	-
[e]3850 Plumas	9-6-80	71.3	7.94	-	-	263	7.0	-	28	2.0	-	494	47.0	98	-	4.94	0.165
[f]Old Moana Pool	6-14-79	51.7	7.96	813	77.5	153	6.8	-	17.5	1.20	-	232	25.0	140	-	-	-

[1]: Temperatures obtained from well logs or literature

Sources: [a] Jacobson and Johnston, 1991

[b] Scheibach, 1975

[c] Sierra Environmental Monitoring

[d] Flynn and Ghusn, 1984

[e] Nevada Division of Health

[f] William E. Nork, Inc.

Mixing

The chemical constituents present in thermal waters are often controlled by temperature and pressure dependent water-rock reactions. The exceptions are chloride, bromine, boron and cesium which act as soluble elements in most situations and to a limited extent fluoride, lithium, and arsenic in waters at deep levels (Ellis, 1970). These elements tend to concentrate in solution once liberated from rock and do not readily enter into secondary mineral structures. Examination of the behavior of these elements can provide insight into processes such as mixing, boiling and conductive cooling, which may affect the geothermal aquifer. Mixing of thermal and nonthermal waters is believed to be an important aquifer process which controls temperature in the Moana resource area.

Thermal waters of the Moana area are enriched in chloride, boron, fluoride, lithium and arsenic in comparison to the nonthermal waters. The concentrations of these elements are not affected by temperature and pressure dependent water-rock reactions within the geothermal aquifer and are considered a signature of the thermal waters. Since this signature is unaffected by temperature, decreasing concentrations of these elements along with a simultaneous decrease in temperature indicate mixing with cooler waters of a different origin. The relative degree of mixing in the geothermal aquifer can be identified because of the different chemical makeup of the thermal and nonthermal waters of the area.

The relationship between temperature and concentration was examined for the soluble elements: chloride, boron, fluoride, lithium, arsenic and for bicarbonate, the most abundant constituent in nonthermal waters of the area. Figures 2 through 7 show the relationship between maximum observed temperature and the concentration of these chemical constituents in geothermal wells of the resource area.

Boron Concentration versus Temperature
R = 0.84
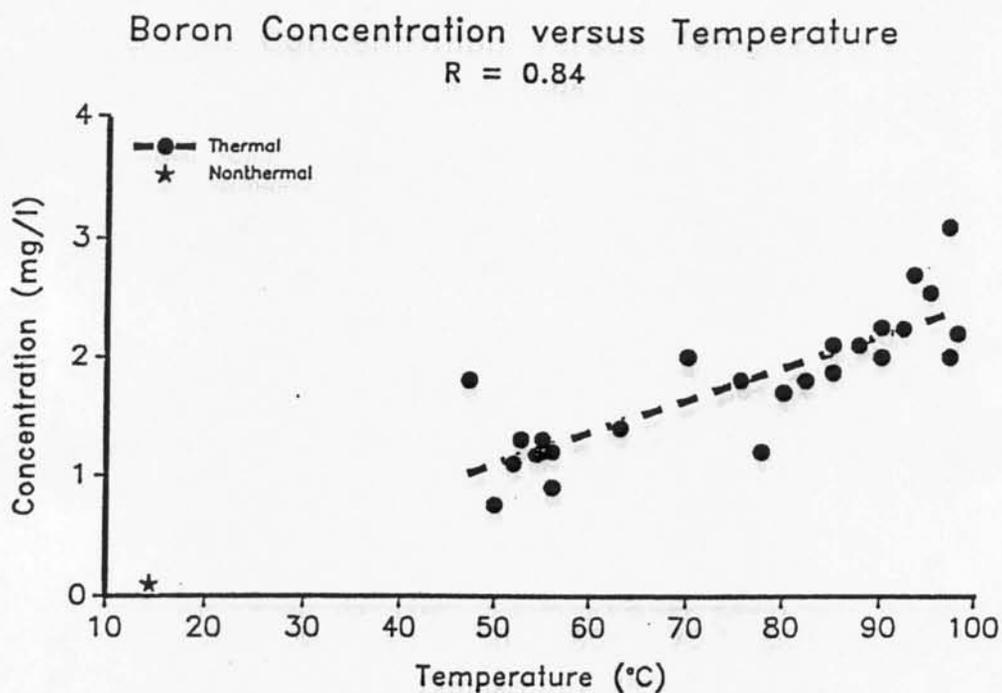
Figure 2.   Boron Concentration versus Temperature in Moana Thermal Waters

Chloride Concentration versus Temperature
R = 0.76
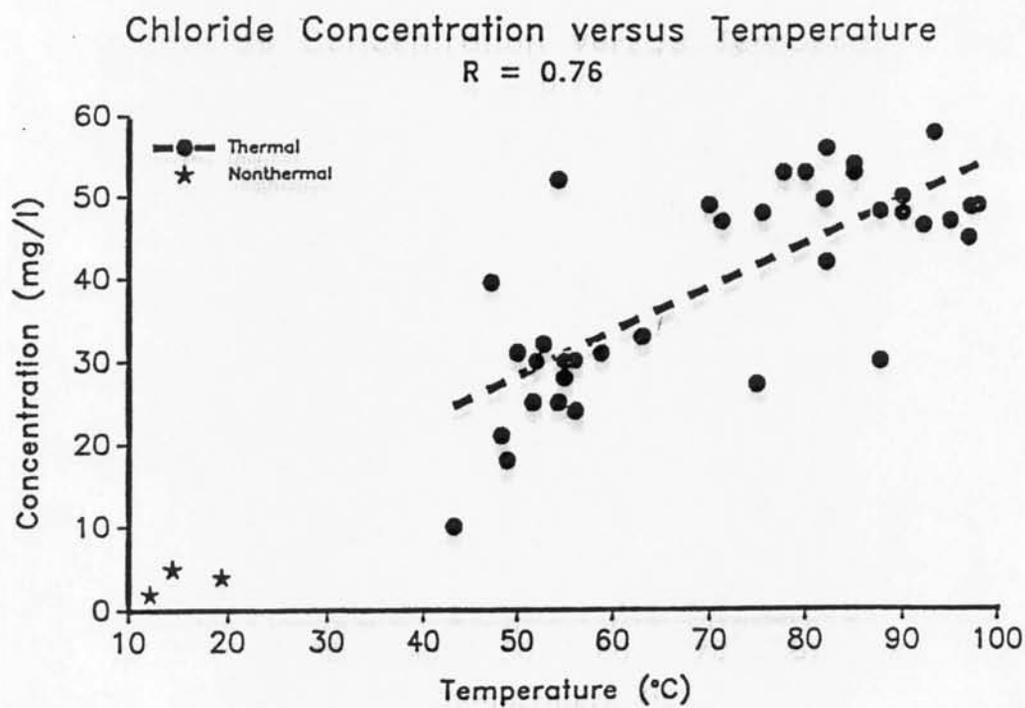
Figure 3.   Chloride Concentration versus Temperature in Moana Thermal Waters
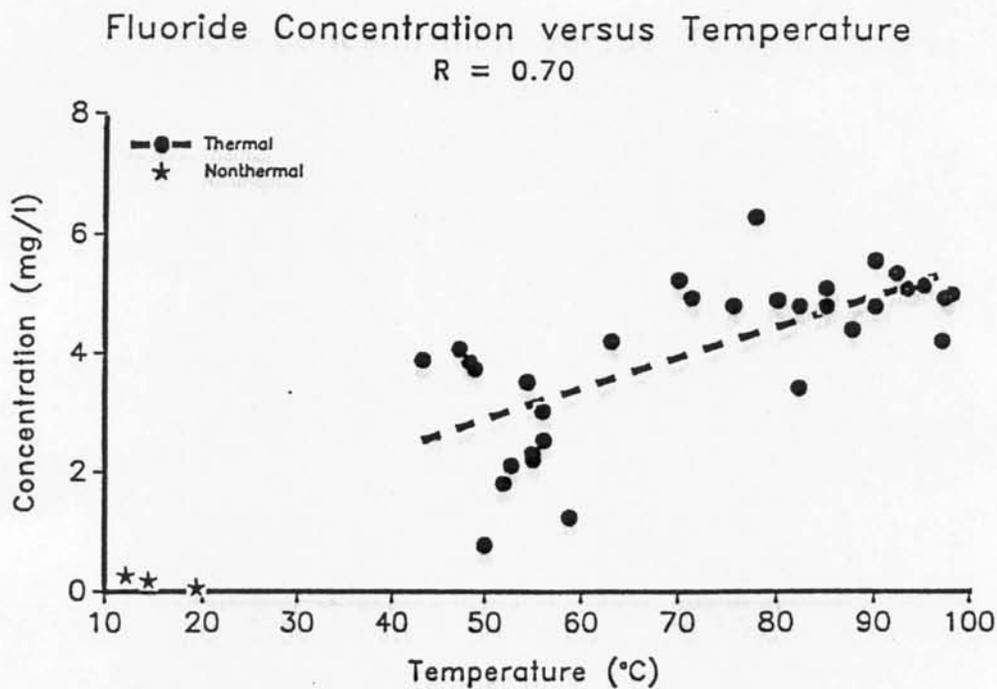
Figure 4.   Fluoride Concentration versus Temperature in Moana Thermal Waters
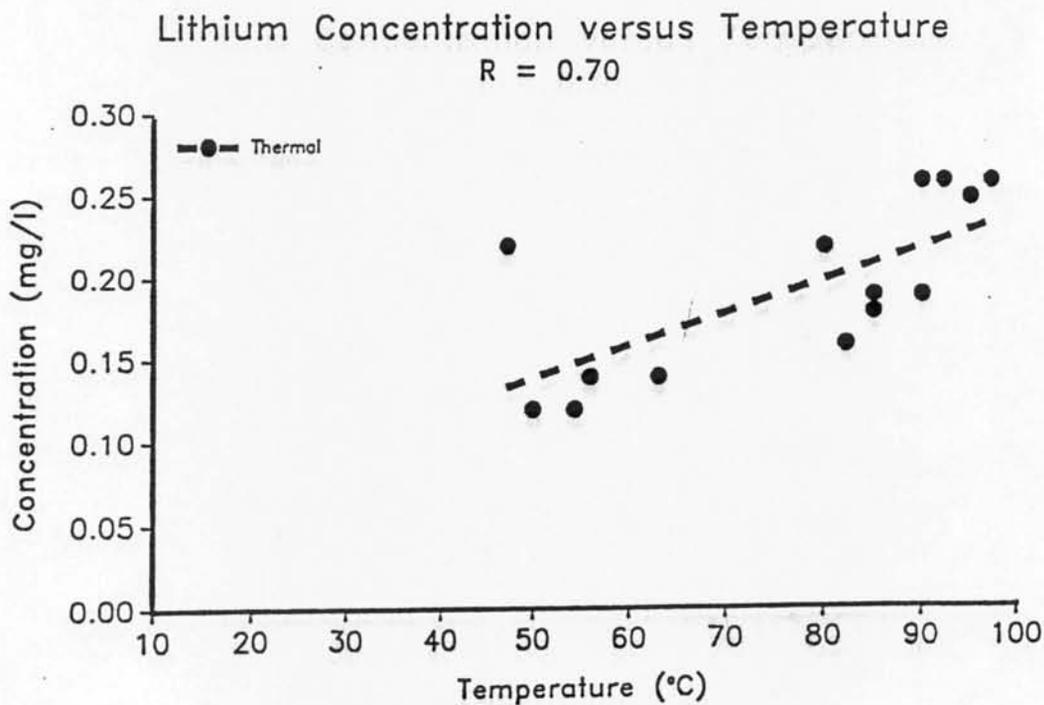
Figure 5.   Lithium Concentration versus Temperature in Moana Thermal Waters
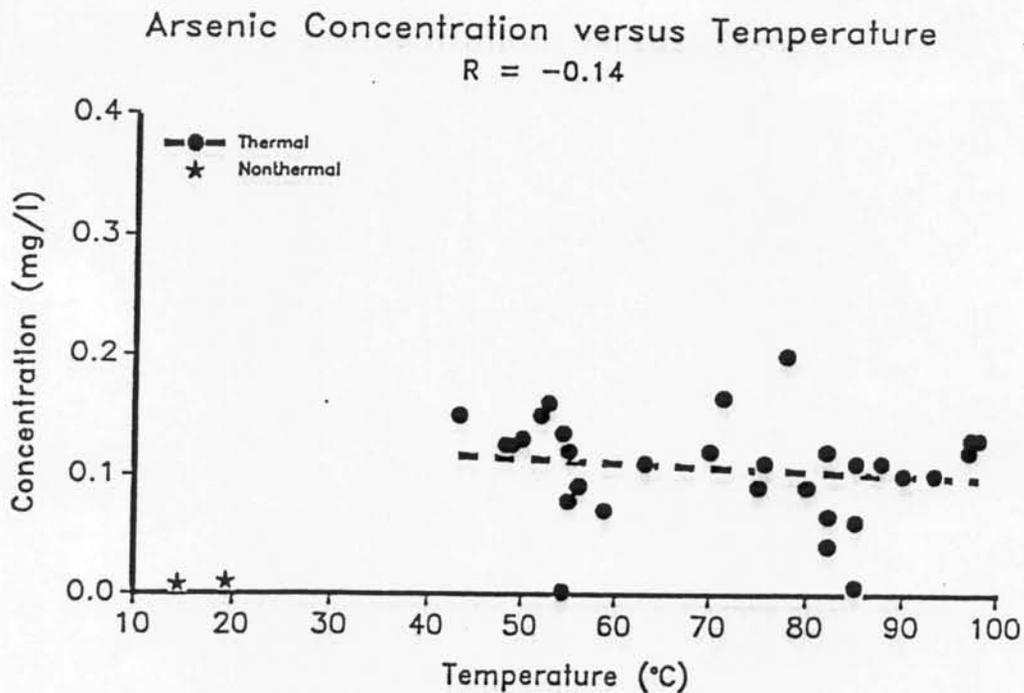
Figure 6.   Arsenic Concentration versus Temperature in Moana Thermal Waters
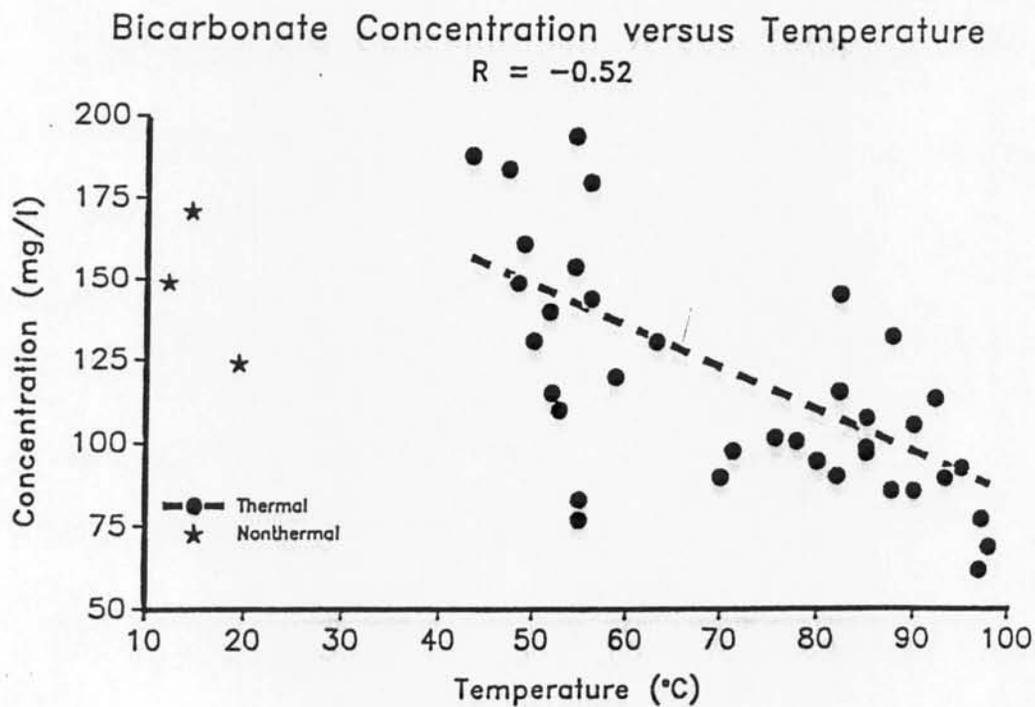
Figure 7.   Bicarbonate Concentration versus Temperature in Moana Thermal Waters

Examples of nonthermal waters from the southern boundary of the Moana area are included in the plots for comparison. A linear least squares fit of each data set illustrates the general trend of the data. The least squares fit line is considered an approximate mixing trend in most of the plots.

The chemical constituents boron, chloride, fluoride and lithium, figures 2 through 5, all show a positive correlation between concentration and temperature. Generally, the higher the temperature the higher the concentration of each constituent. The best correlation coefficient values, R, of temperature and concentration are for the elements boron and chloride. The nonthermal water data are consistent with the mixing trend line.

The trend between arsenic concentration and temperature, figure 6, is relatively flat. The scatter of the data and poor correlation coefficient suggests that arsenic may not be conservative and/or a poor quality data set.

The concentration of bicarbonate in Moana area waters is inversely proportional to temperature (Figure 7). Generally, higher temperature wells have lower concentrations of bicarbonate. The nonthermal water samples are not consistent with the least squares fit line. This suggests that the increase in bicarbonate content as the water temperature decreases may not be entirely a function of mixing with nonthermal waters. The nonconservative behavior of bicarbonate makes alternative methods of analysis necessary.

Several geochemical modeling simulations were run using WATEQDR (Bohm and Jacobson, 1981). Simulations were run for eleven different water samples with temperatures ranging from 50 to 98 °C. Although this model has only been verified for temperatures less than 75 °C, it is still useful for understanding the general chemical equilibria of the thermal waters.

The simulations show that the thermal waters are at saturation with respect to calcite. The solubility of calcite increases with decreasing temperature. However, the thermal waters remain at saturation even in the lower temperature waters of the resource area. Calcite solubility is a control on the bicarbonate content of the thermal waters. This suggests that bicarbonate concentration is sensitive to any change in temperature independent of cause.

An alternative source of the bicarbonate is the reaction of dissolved carbon dioxide with feldspars to produce clays within the geothermal aquifer. Several pieces of evidence support this mechanism as a source of bicarbonate. The andesites and dacites of the Kate Peak Formation (host rock of the geothermal aquifer) are chiefly plagioclase feldspars (Bonham, 1969). Smectite clays compose a large portion of the geothermal aquifer materials (Flynn and Ghusn, 1984). The activities calculated by WATEQ DR for the sodium-hydrogen ratio and silica fall near the stability field boundary for albite (a plagioclase feldspar) and smectite (Drever, 1982). Finally, partial pressures of carbon dioxide decline as temperatures of the thermal waters decline. This suggests that the dissolved carbon dioxide is consumed in some type of reaction. The increase in bicarbonate concentration is probably a function of both mixing and water-rock reactions within the geothermal aquifer. The two sources of bicarbonate cannot be separated without better chemical characterization of the shallow, nonthermal water. Whatever the mechanisms, bicarbonate content increases with decreasing temperature in the thermal waters.

The expression of ion ratios is also useful in identifying changes in the geothermal aquifer (Ellis, 1977). Figure 8 examines the relationship between the bicarbonate-chloride ratio and temperature.

Figure 8.   Bicarbonate-Chloride Ratio versus Temperature in Moana Thermal Waters

The ratio has a negative correlation with temperature, the higher the ratio the lower the temperature. The bicarbonate-chloride ratio is particularly useful in identifying thermal changes in the geothermal aquifer. Bicarbonate and chloride concentrations have contradictory relationships with temperature. Changes in temperature will be reflected as a decrease in one constituent and an increase in the other. Therefore, meaningful changes in the concentration of each constituent are amplified when examining the ratio.

It is important to keep in mind that these chemistry data were assembled from many different sources. This is believed to contribute to the scatter of the data and the low correlation coefficients in some of the plots. As a test, the bicarbonate and chloride data from 11 wells included in the 1989 DRI investigation were plotted against the maximum observed temperatures in the wells (Jacobson and Johnston, 1991). Figures 9 and 10 present these data and correlation coefficients. There is a significant increase in the correlation coefficient.

Figures 2 through 10 illustrate the thermal effect of mixing between; (1) dilute, bicarbonate dominated, nonthermal water and (2) chloride, boron, fluoride, and lithium enriched thermal water in the Moana geothermal aquifer. Now that the general relationships between these chemical constituents and temperature have been defined, they can be used to explore changing thermal conditions in the geothermal aquifer.

Bicarbonate Concentration versus Temperature
R = −0.86
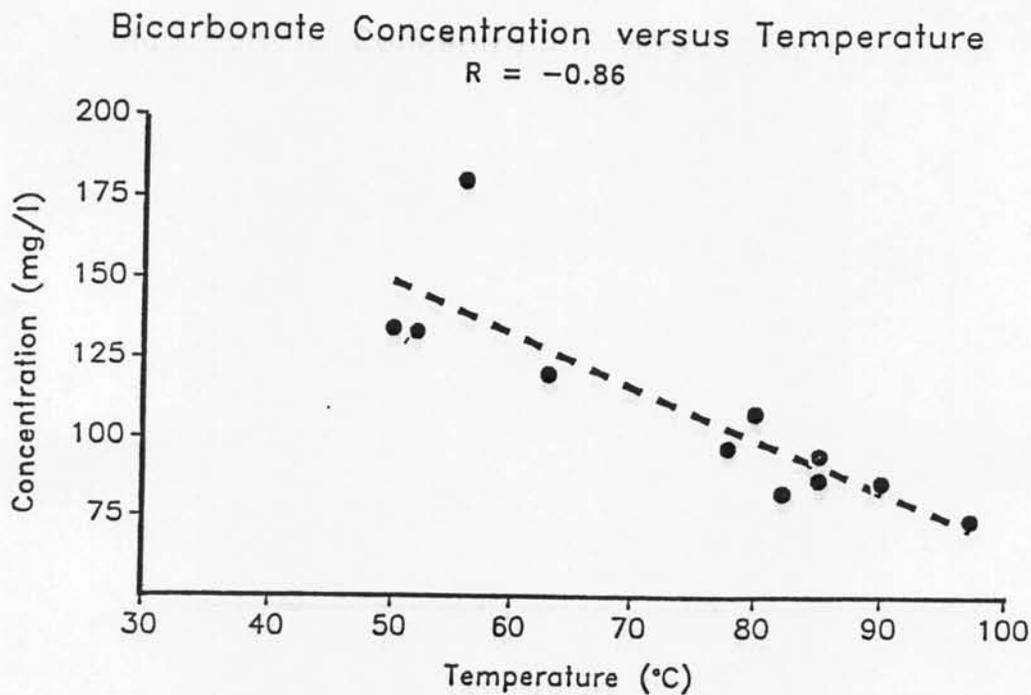
Figure 9.   Bicarbonate Concentration versus Temperature in Moana Thermal Waters Using 1989 DRI Analyses

Chloride Concentration versus Temperature
R = 0.95
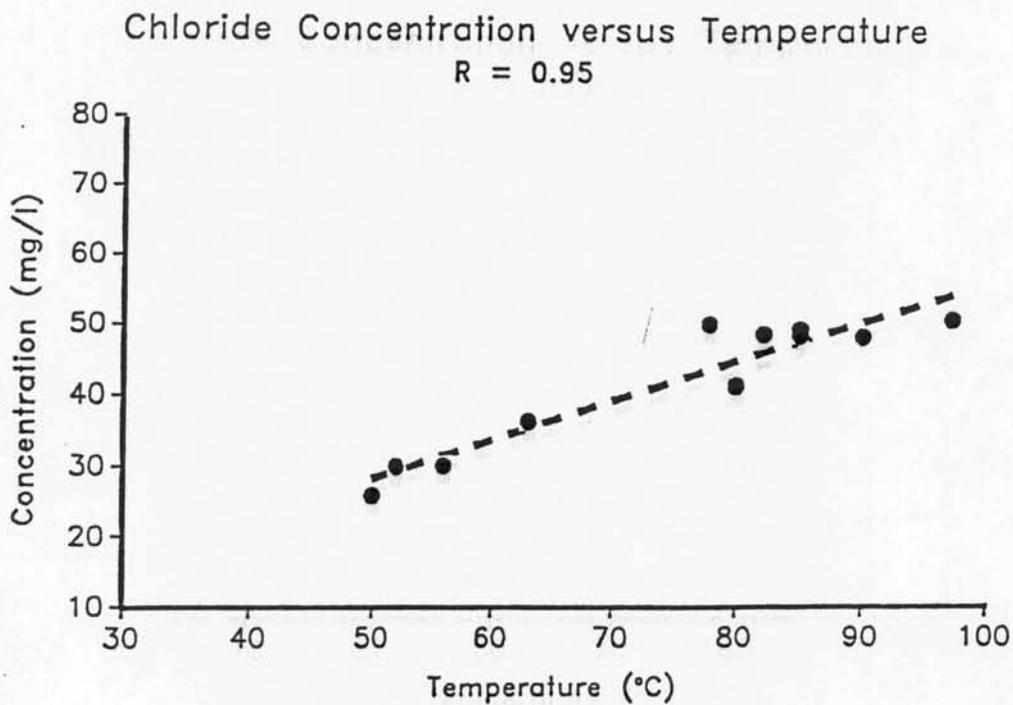
Figure 10.   Chloride Concentration versus Temperature in Moana Thermal Waters Using 1989 DRI Analyses

Temporal Variation

Assuming steady-state aquifer conditions, the concentration of soluble elements in geothermal waters should be constant at any given location. Variations in the concentration of these elements at a given location indicate a change in the rate of mixing between nonthermal and thermal waters. Temperature in the Moana geothermal aquifer is a function of the degree of mixing. Therefore, variations in the concentration of these elements can be used as a qualitative measure of temperature change.

The soluble elements boron and chloride have the best correlation with temperature. An increase or decrease in the concentration of these elements should correspond to an increase or decrease in temperature. The relationship of bicarbonate to temperature is the opposite of chloride to temperature. Examination of the bicarbonate-chloride ratio emphasizes opposite changes in the concentration of each constituent. Similar changes, i.e. both increase or decrease, in the concentration of each constituent will be canceled out by examining the ratio. Increases in the ratio correspond to decreasing temperatures and decreases in the ratio correspond to increasing temperatures. Boron, chloride, and the bicarbonate-chloride ratio are considered qualitative temperature analogs and are used examine thermal changes in the geothermal aquifer.

Seasonal and long term variations of water chemistry were investigated in the Moana geothermal area. Seasonal variations were examined to determine if pumping rate has an effect on the mixing process and therefore temperature in the aquifer. Long term variations were examined to investigate the thermal response to decreasing aquifer pressures in the resource area.

Seasonal Variation

Seasonal variation was examined for two commercial wells in the Moana resource area. The wells were the Virginia Lake Townhouses production well at 2600

Eastshore Drive and the Sierra Geothermal production well at 2135 Richter Circle. The wells were sampled approximately monthly between January, 1989 and September, 1989. The sampling program intent was to determine if changes in the rate of pumpage between heating and nonheating seasons have an effect on temperature. The Virginia Lake Townhouse and Sierra Geothermal wells have peak heating season discharges of 300 and 50 gallons per minute (gpm), respectively (NDEP, 1989, personal communication). The nonheating period discharge is unknown but is probably on the order of 10 gpm at both locations. Table 3 presents the chemical analyses for the water samples collected at these sites.

Figures 11 through 14 graphically examine chloride concentration versus time and bicarbonate-chloride ratios versus time for both locations. A linear least squares fit is applied to each dataset. The figures show that chloride concentrations and bicarbonate-chloride ratios are constant, at least within the analytical error, during the sampling period. These data suggest that the rate of mixing between thermal and nonthermal waters is seasonally constant and independent of discharge rate at the two sample locations. Therefore, changes in the rate of pumpage do not produce mixing induced temperature changes during the study period.

Table 3. Comparison of Seasonal Chemical Analyses in Geothermal Waters

Address Location[2]	Date	Temp[1] °C	pII	EC umhos/cm	SiO₂ mg/l	Na mg/l	K mg/l	Li mg/l	Ca mg/l	Mg mg/l	B mg/l	SO₄ mg/l	Cl mg/l	IICO₃ mg/l	CO₃ mg/l	F mg/l	As mg/l
2600 Eastshore1	1-05-89	-	8.25	1030	94.8	194	9.32	-	21.8	1.20	-	293	31.1	173	-	-	0.11
T19N R19E 24DCD	2-13-89	-	8.28	1030	93.6	191	9.78	-	20.8	1.01	-	293	31.4	174	-	-	0.09
	3-28-89	-	8.27	1020	92.6	191	9.64	-	20.8	0.98	-	277	30.5	175	-	-	0.11
	4-27-89	-	8.34	1020	92.8	190	9.93	-	19.6	1.31	-	294	31.1	171	-	-	0.11
	5-25-89	-	8.29	1040	93.3	190	9.77	-	20.5	0.94	-	309	31.0	173	-	-	0.11
	6-29-89	54.0	8.36	1010	93	189	9.30	-	20.3	0.98	-	279	30.3	174	2.5	-	0.10
	9-27-89	54.0	8.28	971	93.7	189	9.42	0.14	20.3	0.98	1.2	281	30.1	180	-	3.01	0.09
2135 Richter	1-05-89	-	8.34	1390	112	250	11.3	-	30.8	0.49	-	489	49.1	78.2	1.1	-	0.15
T19N R19E 27A	2-13-89	-	8.42	1410	113	258	12.0	-	30.3	0.15	-	496	49.2	77.4	2.1	-	0.15
	3-30-89	-	8.35	1410	113	262	11.0	-	30.3	0.14	-	497	49.2	78.9	1.0	-	0.13
	4-27-89	-	8.27	1410	113	260	11.6	-	30.3	0.16	-	500	49.3	81.0	-	-	0.15
	6-29-89	95.0	8.40	1410	111	261	11.8	-	31.2	0.13	-	493	50.2	75.7	2.8	-	0.12
	7-26-89	97.0	8.42	1390	112	260	11.8	-	31.2	0.14	-	483	50.7	73.9	3.2	-	0.12
	9-13-89	98.0	8.39	1360	114	257	11.7	0.26	31.2	0.15	2.0	499	48.8	77.5	1.8	4.94	0.13

[1]: Temperatures obtained at sample port.
[2]: Based on Township, Range, and Section

2600 Eastshore1 Chloride Concentration vs Time
1/89 to 9/89
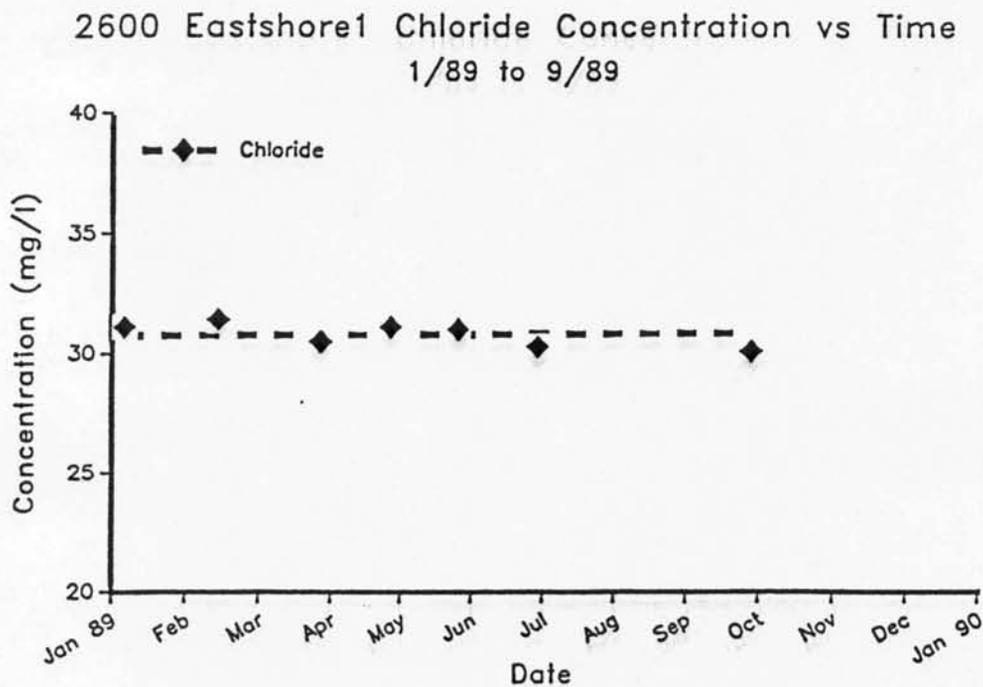
Figure 11.   Seasonal Variation of Chloride Concentration at 2600 Eastshore Drive

2600 Eastshore1 Bicarbonate—Chloride Ratio vs Time
1/89 to 9/89
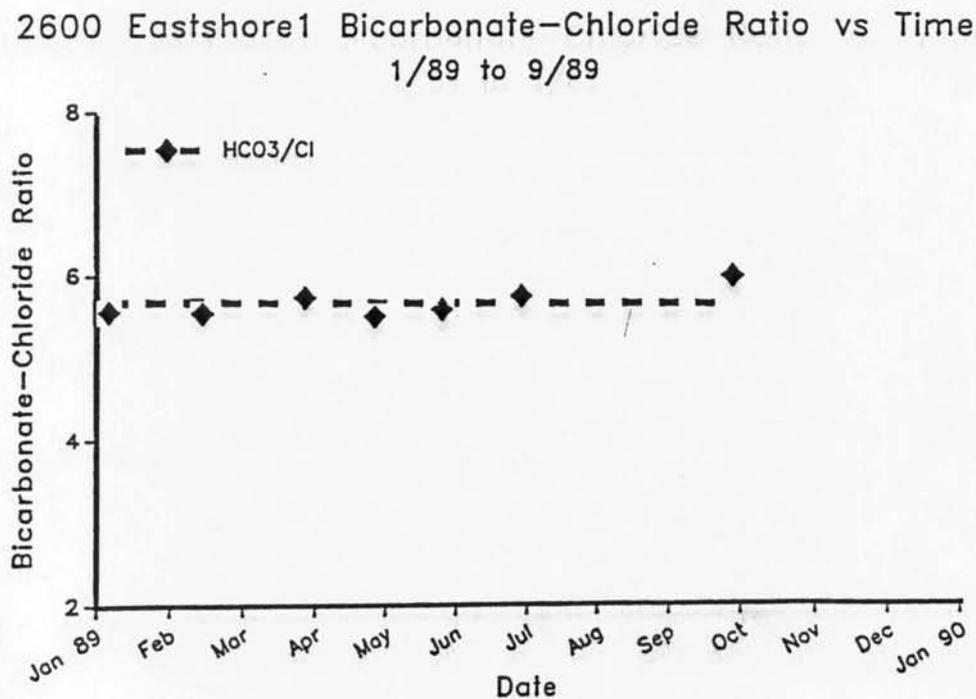
Figure 12.   Seasonal Variation of Bicarbonate-Chloride Ratio at 2600 Eastshore Drive

2135 Richter Chloride Concentration vs Time
1/89 to 9/89
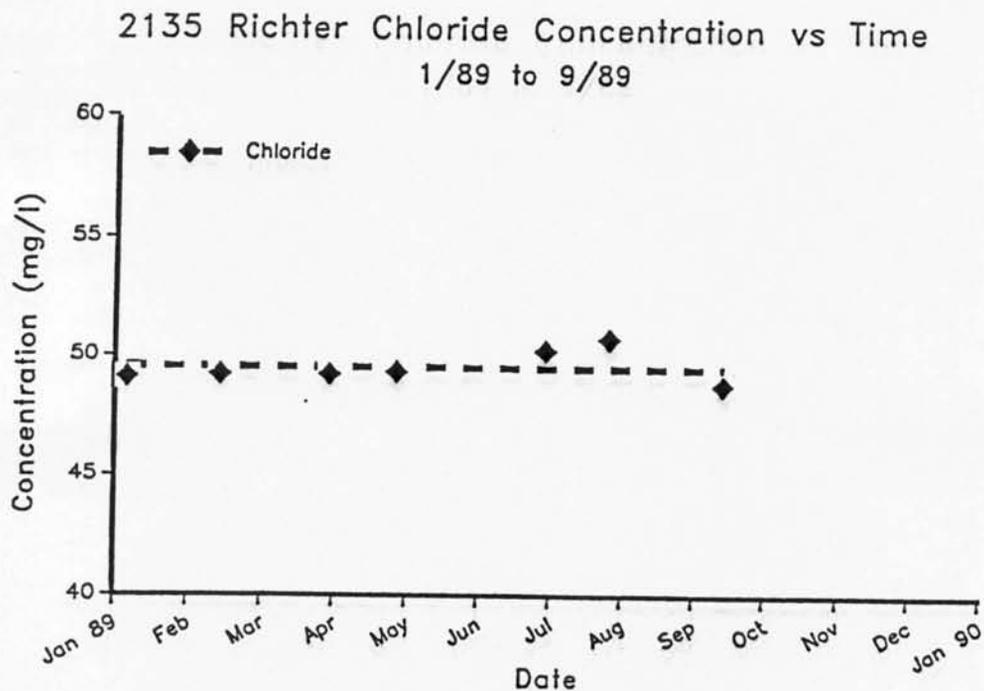
Figure 13.   Seasonal Variation of Chloride Concentration at 2135 Richter Circle

2135 Richter Bicarbonate—Chloride Ratio vs Time
1/89 to 9/89
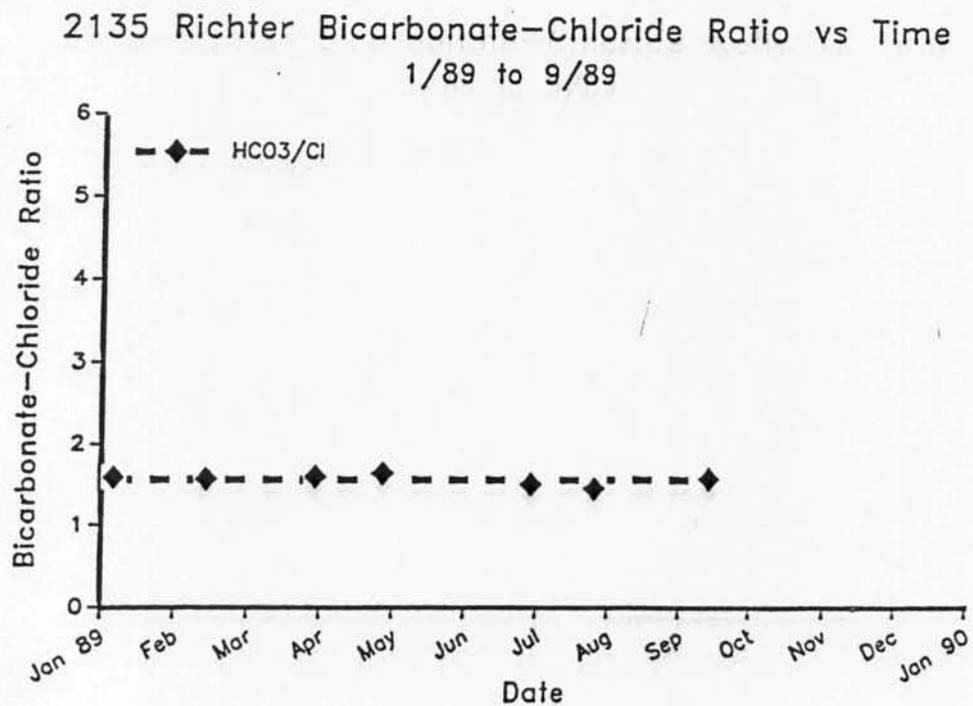
Figure 14.   Seasonal Variation of Bicarbonate-Chloride Ratio at 2135 Richter Circle

Long Term Variation

Long term variations in geothermal waters of the Moana resource area were examined by resampling ten of twelve locations sampled by Scheibach (1975) during his 1974 study. Scheibachs chemistry data is believed to represent aquifer geochemical conditions in a pre or low stress environment. The 1989 Desert Research Institute sample data is believed to be representative of the current stressed conditions (lowered aquifer pressures) in the geothermal aquifer (Jacobson and Johnston, 1991). Table 4 presents the 1974 and 1989 chemical analyses for the ten wells.

The data is graphically examined by plotting boron and chloride concentrations versus the bicarbonate-chloride ratios. Changes in the composition of the waters are considered significant when both variables in the plot exhibit a change.

Figures 15 and 16 present the boron, chloride, and bicarbonate relationships for wells at 4520 Lakeside, the Peppermill Hotel-Casino, 1200 Manzanita, and 1204 Sweetwater. These four wells all exhibit significant changes in composition since the 1974 sampling event.

Three of the wells; 4520 Lakeside, Peppermill, and 1204 Sweetwater, show an increase in thermal water components in the samples. This is expressed as an increase in chloride and boron content and a corresponding decrease in the bicarbonate-chloride ratio. These data indicate that the nonthermal water contribution to the geothermal aquifer has decreased in the vicintiy of these wells. The results suggest that well temperatures were hotter during the 1989 sampling event than during the 1974 sampling event.

Table 4. Comparison of 1974 and 1989 Chemical Analyses of Geothermal Waters

Address Location[2]	Date	Temp[1] °C	pH	EC umhos/cm	SiO$_2$ mg/l	Na mg/l	K mg/l	Li mg/l	Ca mg/l	Mg mg/l	B mg/l	SO$_4$ mg/l	Cl. mg/l	HCO$_3$ mg/l	CO$_3$ mg/l	F mg/l	As mg/l
2600 Eastshore1	4-23-74	59.0	7.76	886	85.8	154.7	6.55	0.18	5.68	0.40	0.6	226.7	26	143.6	-	0.5	0.01
T19N R19E 24BCD	9-27-89	54.0	8.28	971	93.7	189	9.42	0.14	20.3	0.98	1.2	281	30.1	180	-	3.01	0.09
4520 Lakeside	3-1-74	63.1	8.05	1035	92.6	189.35	5.5	0.14	16.5	0.405	1.36	304.6	33.5	131.5	-	4.18	0.11
T19N R19E 25CBB	8-10-89	53.0	8.26	1110	99	211	6.10	0.19	21.5	0.60	1.5	350	36.3	120	-	3.94	0.13
1200 Manzanita	2-18-74	80.0	7.5	1070	103.7	248	7.1	0.22	20.5	0.32	1.74	419	53	95	-	4.95	0.09
T19N R19E 26DABA	12-02-89	37.0	7.94	1160	86.7	217	6.21	0.207	24.7	0.74	1.70	392	41.3	108	-	4.3	0.07
1140 W. Peckham	3-01-74	85.0	7.78	1430	92.3	258.7	7.17	0.18	22.1	0.79	2.08	478.2	53	99	-	4.8	0.11
T19N R19E 26ADA	12-14-89	-	8.13	1360	116	257	8.62	0.24	27.8	0.15	2.4	486	48.4	94.6	-	5.1	0.14
1160 W. Peckham	5-3-74	85.0	8.35	1423	111	243.2	7.71	0.19	14.23	0.19	1.87	448.8	54	97.55	-	5.1	0.006
T19N R19E 26ADAB	10-01-89	70.0	8.05	1350	118	265	8.42	0.24	27.4	0.17	2.2	479	49.2	86.9	-	4.83	0.11
1150 Sweetwater	12-08-73	78.0	8.20	1320	103.2	293	8.1	-	25	0.26	1.77	465.5	53	100.6	-	6.3	0.20
T19N R19E 26ADDA	12-08-89	49.0	8.19	1390	113	272	8.30	0.244	28.3	0.20	2.5	490	50.0	97.0	-	5.1	0.15
1204 Sweetwater	3-01-74	90.0	7.65	1185	134.7	203	7.37	0.16	28.98	0.786	1.80	348.3	42.0	146.0	-	4.8	0.04
T19N R19E 26ADCC	9-28-89	55.0	8.05	1330	99.1	260	7.64	0.25	27.8	0.26	2.1	475	48.5	82.7	-	4.90	0.11
2201 S. Virginia	3-01-74	42.0	7.95	942	57.8	175	5.96	0.12	15.8	1.49	0.75	258.3	31	131.0	-	0.75	0.13
T19N R19E 24BBA	9-28-89	42.0	8.39	854	60.8	164	5.20	0.12	15.9	1.08	0.9	249	25.8	134	2.2	1.25	0.13
2707 S. Virginia1	2-05-74	47.2	8.06	724	85.4	139	7.38	0.17	5.20	0.30	0.76	170.6	20.2	135.9	-	0.81	0.10
T19N R19E 24CABA	10-19-89	52.0	8.30	965	91.7	181	8.85	0.145	19.3	0.38	1.4	295	29.9	133	-	2.1	0.14
1175 Yates	4-30-74	89.9	8.29	1367	102	243.19	7.36	0.19	23.4	0.205	1.99	457	50	86.2	-	4.83	0.10
T19N R19E 26ADDD	11-29-89	76.0	8.09	1330	112	254	8.54	0.247	27.8	0.17	2.2	474	48.2	85.9	-	5.0	0.13

[1]: Temperatures obtained during sampling.

[2]: Based on Township, Range, Section.
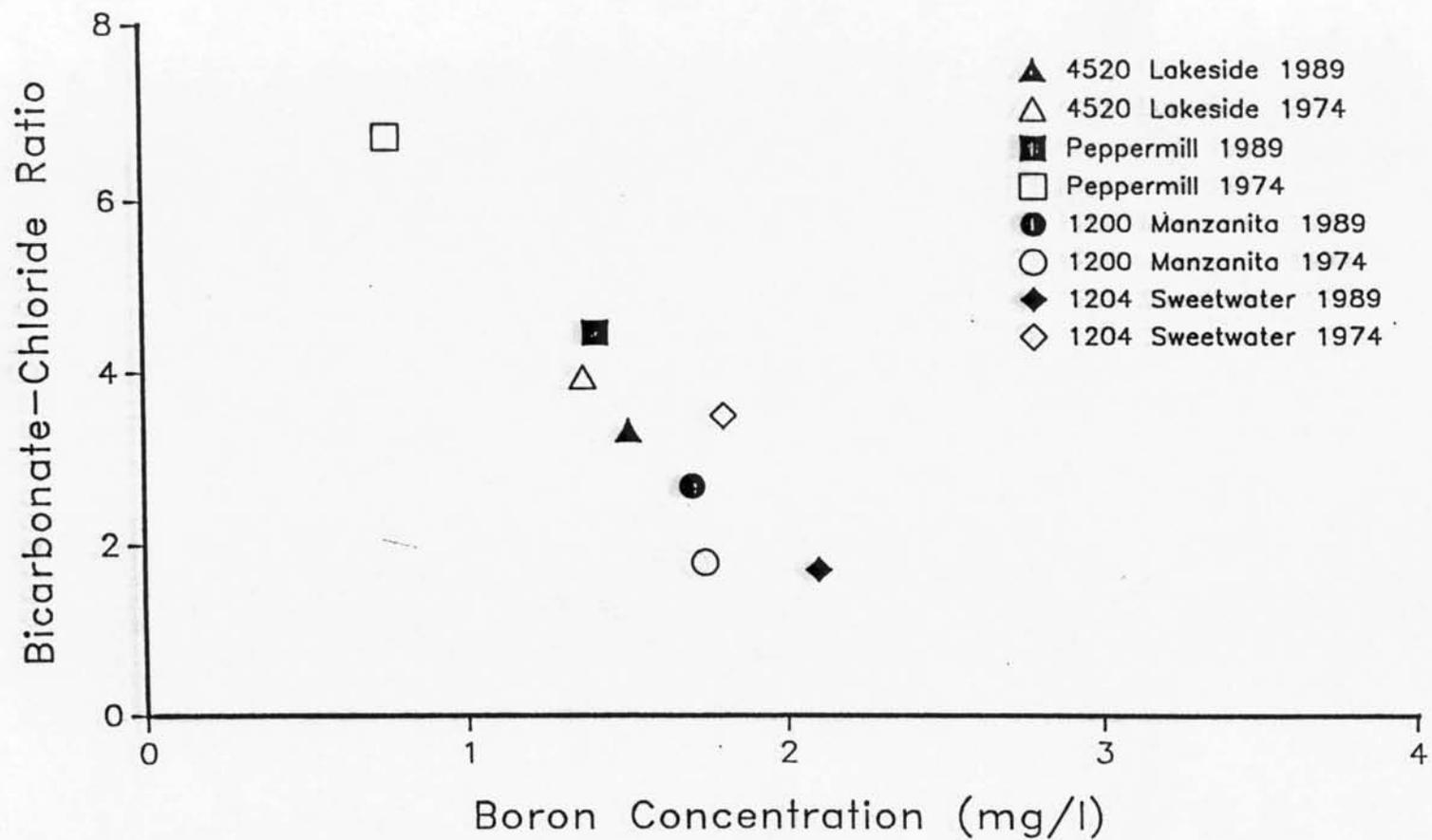
Figure 15. Long Term Variation of Bicarbonate-Chloride Ratio versus Boron Concentration

Bicarbonate–Chloride Ratio vs Chloride Concentration
1974 and 1989 Data
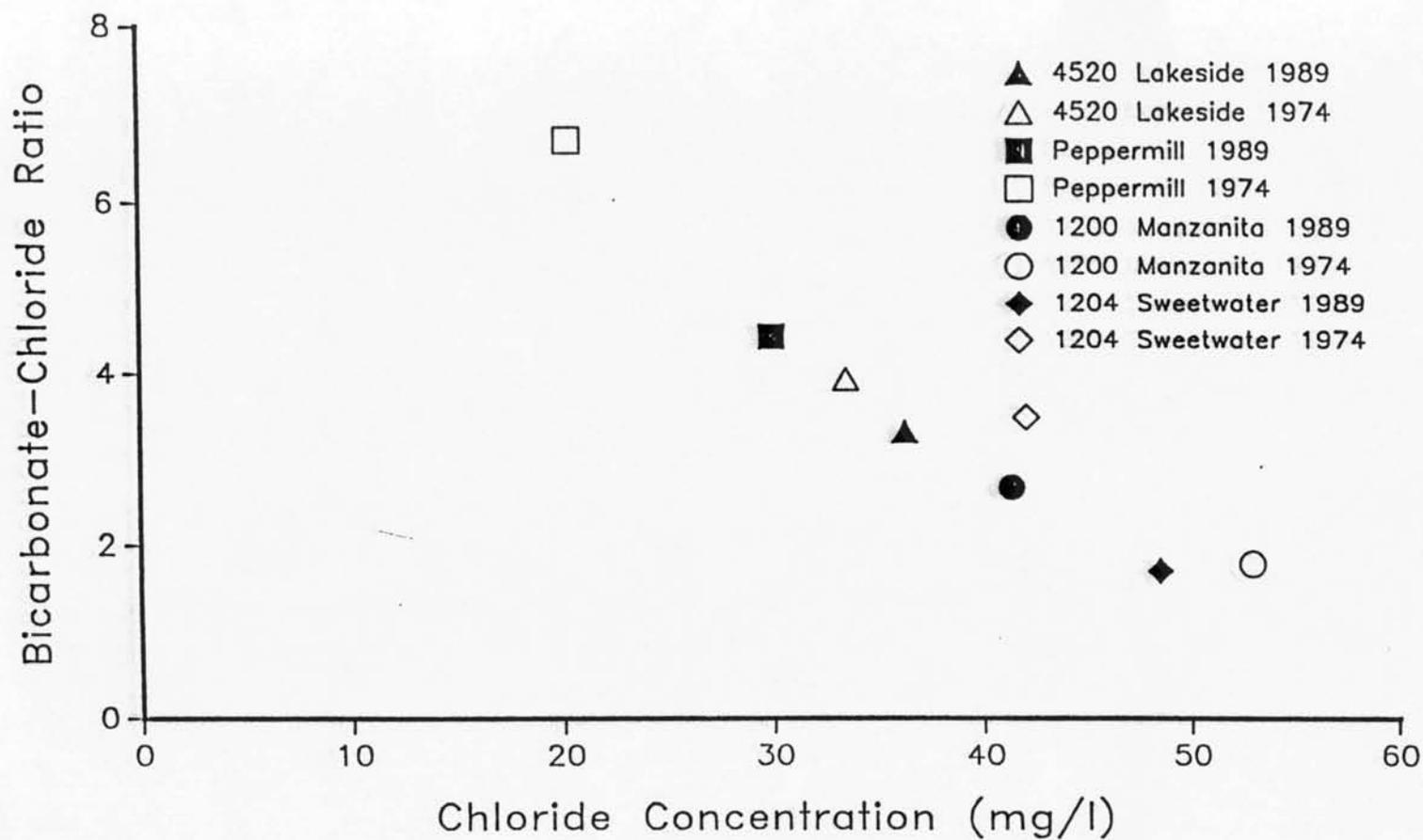
Figure 16. Long Term Variation of Bicarbonate-Chloride Ratio versus Chloride Concentration

The well at 1200 Manzanita shows a decrease in thermal water components since the 1974 sampling event. This change is expressed by a decrease in chloride and boron content and a corresponding increase in the bicarbonate-chloride ratio. The owner of this well has complained of decreasing heat output (Richard Moore, Personal Communication, 1989). The water chemistry data supports his complaints and suggests that temperatures are declining in the well.

Figures 17 and 18 illustrate the boron, chloride and bicarbonate relationships for wells at 2201 South Virginia, 1150 Sweetwater, and 1175 Yates. The well at 2201 South Virginia was the only one of the three to show significant chemical changes. Chloride concentration decreased, boron concentration was approximately the same, showing a slight increase, and the bicarbonate-chloride ratio increased. The chloride data and bicarbonate-chloride ratio suggest decreasing aquifer temperatures in the vicinity of this well.

Figures 19 and 20 present the boron, chloride, and bicarbonate relationships for wells at the Virginia Lake Townhouses, 1140 West Peckham and 1160 West Peckham. The water chemistry of these wells has either remained constant or the changes observed are inconclusive with respect to temperature variation.

Five of the ten wells resampled showed significant water chemistry variations. Three wells, 4520 Lakeside, Peppermill, and 1204 Sweetwater, had an increase in thermal water constituents suggesting an increase in water temperatures at these locations. Two locations, 1200 Manzanita and 2201 South Virginia, had a decrease in thermal water constituents which suggests declining temperatures in the wells.

Bicarbonate–Chloride Ratio vs Boron Concentration
1974 and 1989 Data

Legend:
- ▲ 2201 S.Virginia 1989
- △ 2201 S.Virginia 1974
- ▣ 1150 Sweetwater 1989
- ☐ 1150 Sweetwater 1974
- ● 1175 Yates 1989
- ○ 1175 Yates 1974

Y-axis: Bicarbonate–Chloride Ratio

X-axis: Boron Concentration (mg/l)
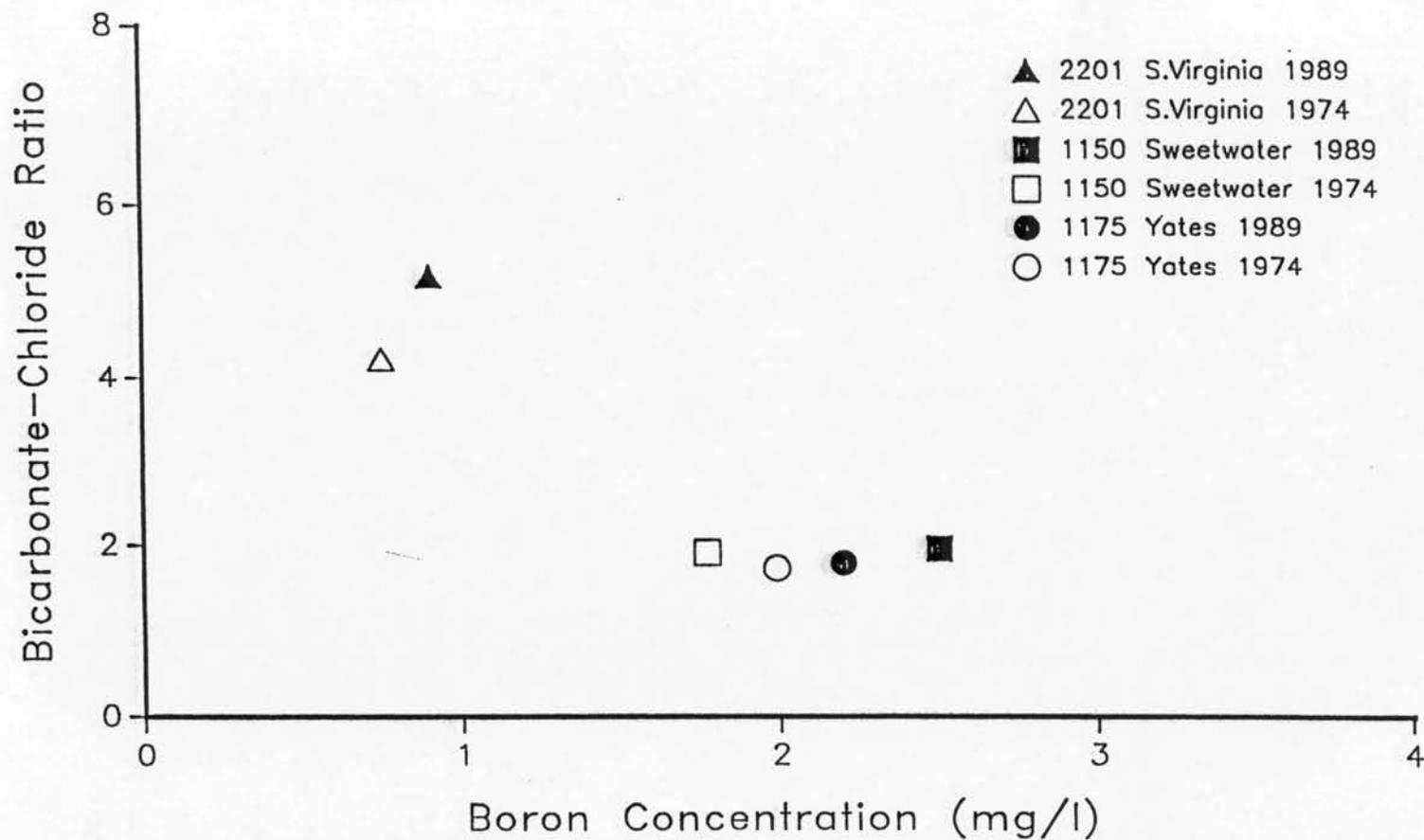
Figure 17. Long Term Variation of Bicarbonate-Chloride Ratio versus Boron Con-
centration

Bicarbonate–Chloride Ratio vs Chloride Concentration
1974 and 1989 Data

Legend:
- ▲ 2201 S.Virginia 1989
- △ 2201 S.Virginia 1974
- ■ 1150 Sweetwater 1989
- □ 1150 Sweetwater 1974
- ● 1175 Yates 1989
- ○ 1175 Yates 1974

Y-axis: Bicarbonate–Chloride Ratio

X-axis: Chloride Concentration (mg/l)
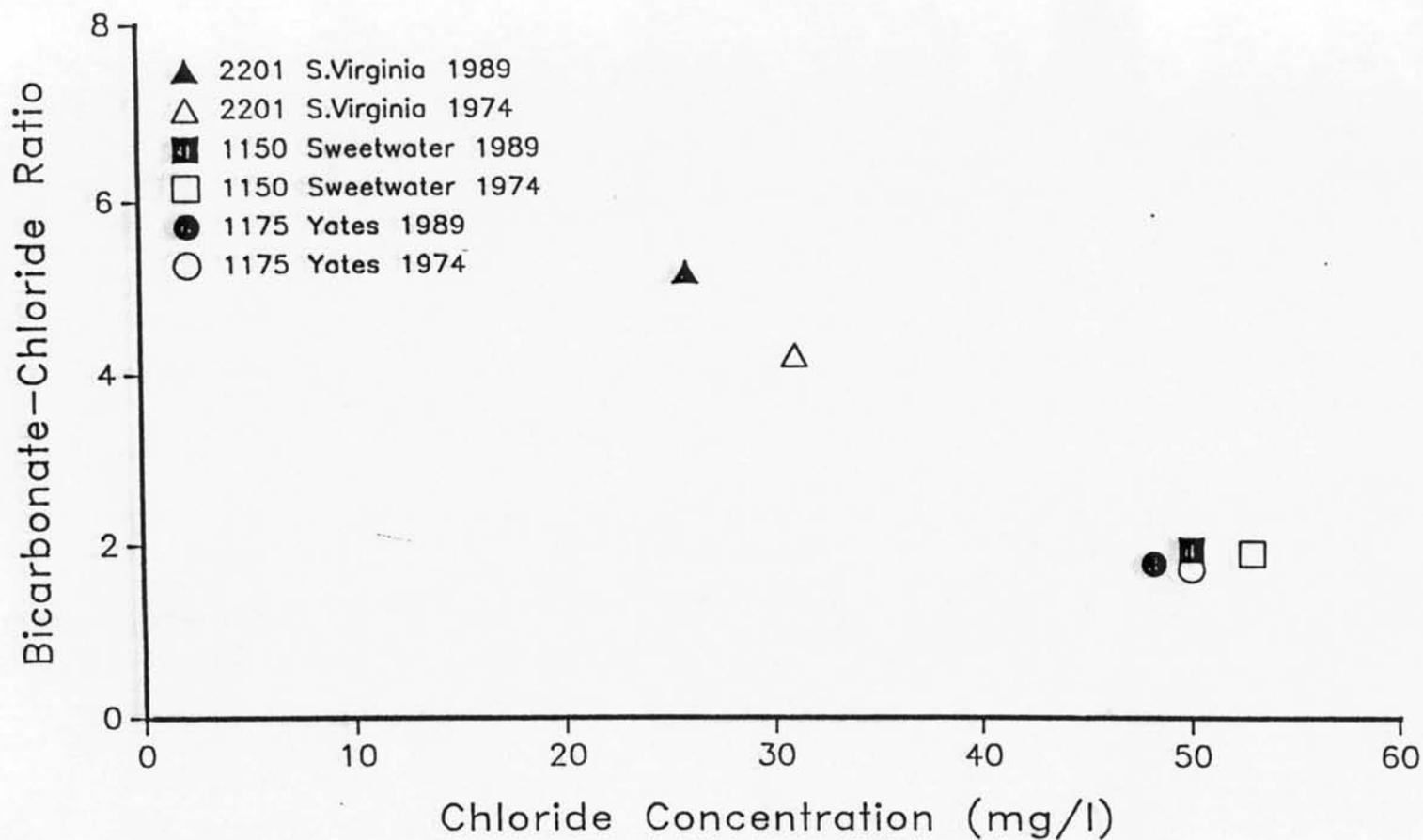
Figure 18. Long Term Variation of Bicarbonate-Chloride Ratio versus Chloride Concentration

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Figure 19. Long Term Variation of Bicarbonate-Chloride Ratio versus Boron Concentration

Bicarbonate–Chloride Ratio vs Chloride Concentration
1974 and 1989 Data

Legend:
- ▲ VLT 1989
- △ VLT 1974
- ▣ 1140 W.Peckham 1989
- ☐ 1140 W.Peckham 1974
- ● 1160 W.Peckham 1989
- ○ 1160 W.Peckham 1974
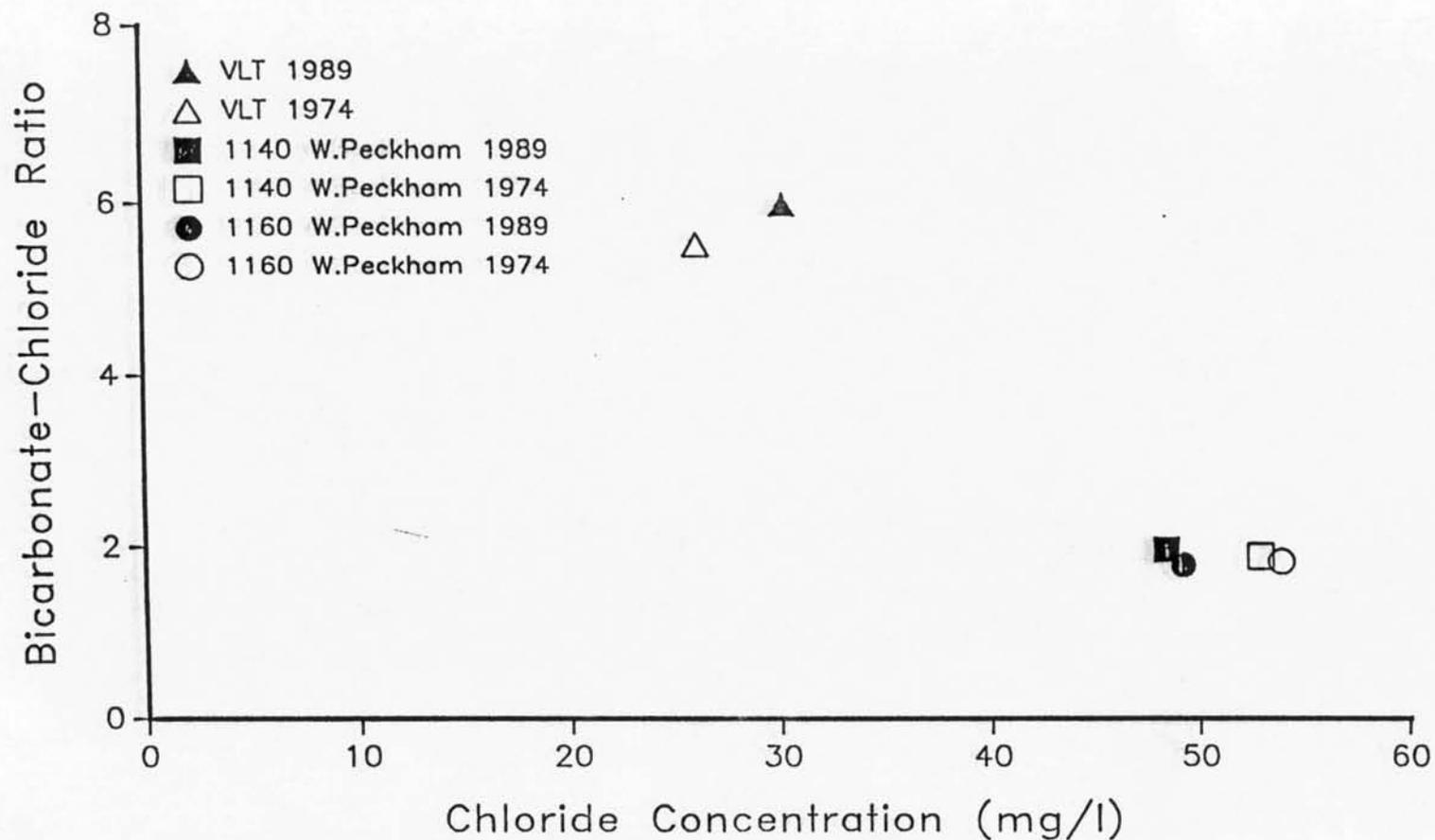
Figure 20. Long Term Variation of Bicarbonate-Chloride Ratio versus Chloride Concentration

Unfortunately, no clear pattern of water chemistry variation is apparent based on the location of the wells. The two wells which exhibited a decline in thermal water constituents are in different parts of the geothermal area. The well at 1200 Manzanita is in the central portion of the resource area (the area which has experienced the greatest decline in aquifer pressures) and the well at 2201 South Virginia is on the northeast boundary of the resource area. The other water chemistry data do not confirm that aquifer conditions are changing in the vicinity of these well locations. Two wells approximately 500 feet from 1200 Manzanita either exhibited no change in water chemistry (1175 Yates) or showed an increase thermal water constituents (1204 Sweetwater). Similar inconclusive behavior was observed in the vicinity of the well at 2201 South Virginia. The closest sampling location to this well is approximately 1500 feet away at the Virginia Lake Townhouses. The Virginia Lake Townhouse well exhibited ambiguous changes in water chemistry which do not confirm decreasing aquifer temperatures on the northeast boundary of the geothermal area.

The three wells which exhibited an increase in thermal water constituents are also in different locations. The well at 1204 Sweetwater is in the central part, the 4520 Lakeside well is in the eastern part, and the Peppermill Hotel well is the northeastern part of the resource area, respectively. The mechanism for the increase in thermal water constituents in these wells is not clearly understood. The data suggests that the quanitity of nonthermal water mixing in the geothermal aquifer has declined at these locations. A possible reason for the decrease in nonthermal water quantity is a reduction in recharge rate to the nonthermal water aquifers of the area. Changes in land use patterns and four years of drought may account for a reduction in recharge rate to the nonthermal water aquifers.

Although the data are limited, they suggest that thermal conditions are changing in portions of the geothermal aquifer. Additional sampling events are needed before

any conclusions can be made about long term chemical and thermal changes taking place in the Moana geothermal area.

SUMMARY AND CONCLUSIONS

The thermal waters of the Moana geothermal area are enriched in the soluble elements: boron, chloride, fluoride, and lithium in comparison to the nonthermal waters of the area. The relationship between temperature and concentration of these soluble elements indicates mixing of thermal and nonthermal waters in the geothermal aquifer. The concentration of these elements has a positive correlation with temperature, generally, the higher the temperature the higher the concentration. This indicates that mixing of thermal and nonthermal waters in the Moana geothermal aquifer is an important control on temperature in the resource area.

The concentration of bicarbonate in the thermal waters has a negative correlation with temperature, generally, the higher the temperature the lower the concentration. Geochemical modeling of the thermal waters suggests that bicarbonate concentration is a function of both: (1) mixing with bicarbonate enriched nonthermal waters and (2) temperature and pressure dependent water-rock reactions in the geothermal aquifer.

The concentration of the soluble elements: boron, chloride, fluoride and lithium and the chemical constituent bicarbonate can be considered qualitative temperature analogs at individual well locations. Chemical analyses of monthly sampling events at two commercial production wells in the Moana geothermal area exhibited constant chloride concentrations and bicarbonate-chloride ratios. These data suggest that aquifer temperatures are seasonally constant and independent of pumping stress during the study period.

Long term (fifteen years) variations in thermal water chemistry indicate changing thermal conditions in the resource area. The limited data suggest that temperatures have increased at three locations and decreased at two locations. No pattern of thermal change is apparent from the sample locations. Portions of the resource area

experiencing development stress, i.e. reduced aquifer pressures, are not readily corre-
lated to well locations exhibiting thermal changes. Additional sampling events are
needed before any definite conclusions can be made about hydrochemical and thermal
changes taking place in the Moana geothermal area.

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