GROUNDWATER GEOCHEMISTRY OF THE INDIAN WELLS VALLEY

by Barbara Dorst Houghton

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OF THE
INDIAN WELLS VALLEY

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DEDICATION AND ACKNOWLEDGEMENTS

This thesis is dedicated to my husband, Jim, who believed in me and stood by me through late nights and long weekends, without a single complaint, and to my parents, Tom and Barbara, who instilled in me the belief that I could do anything that I set my mind to do.

I would like to acknowledge Mike Stoner, who not only is a wonderful field partner, but has become a great friend. I would also like to acknowledge Bob Horton, who was always available to counsel and encourage me during the production of this thesis.

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GROUND WATER GEOCHEMISTRY
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ABSTRACT

Ground water in the shallow unconfined aquifer in the Indian Wells Valley can be divided geographically into three areas based on hydrogeochemistry. Ground water in the southwest and southern portions of the valley has low total dissolved solids (TDS) and a sodium-bicarbonate composition. Ground water in the west and northwest also has a sodium-bicarbonate composition, but tends to have higher TDS. Ground waters in the east and central portions of the valley are predominantly sodium-chloride in composition and have higher TDS than ground water in the other areas of the valley.

Ground water in the west and northwest does not appear to be hydraulically connected to ground water in the other areas of the valley. The ground water in this area may have several sources of recharge, whereas the ground water in the south and southwest may only have one major source. Southwest ground water may be hydraulically connected to the high TDS ground water in the central and eastern portions of the valley.

INTRODUCTION

Controversy exists regarding the source of ground water in the Indian Wells Valley, which is shown on Figure 1. Lee (1913), Thompson (1929), Kunkel and Chase (1969), Banta (1972), Dutcher and Moyle (1973), St. Amand (1986) and Berenbrock and Martin (1991) maintain that the valley is a fundamentally closed system and ground water comes from meteoric sources feeding ephemeral drainages, which would imply a limited supply of ground water. If this theory is true, ground water use must be carefully monitored to prevent over use of the ground water resource and to prevent contamination of ground water of good quality by ground water of poor quality from the playa on the east side of the valley.

Erskine (1989) and Whelan (1990) contend that the valley is an open system. Recharge is primarily derived from the Kern River recharge system and enters the valley through a system of faults and fractures in the Sierra Nevada. If this hypothesis is true, ground water recharge to the valley could be considerably greater than originally proposed by Lee (1913) and later workers.

Water is not imported from outside of the valley and the streams that run off from the surrounding mountains are intermittent. Consequently, ground water is the only source of water for the valley at this time. For this reason it is important to learn as much as possible about the origin of the ground water in the valley and how the quality and recharge could be affected by current use. Study of the hydrogeochemistry of the waters in and around the valley may make it possible to determine sources and estimate approximate quantities of water that enter the valley and recharge the aquifers.

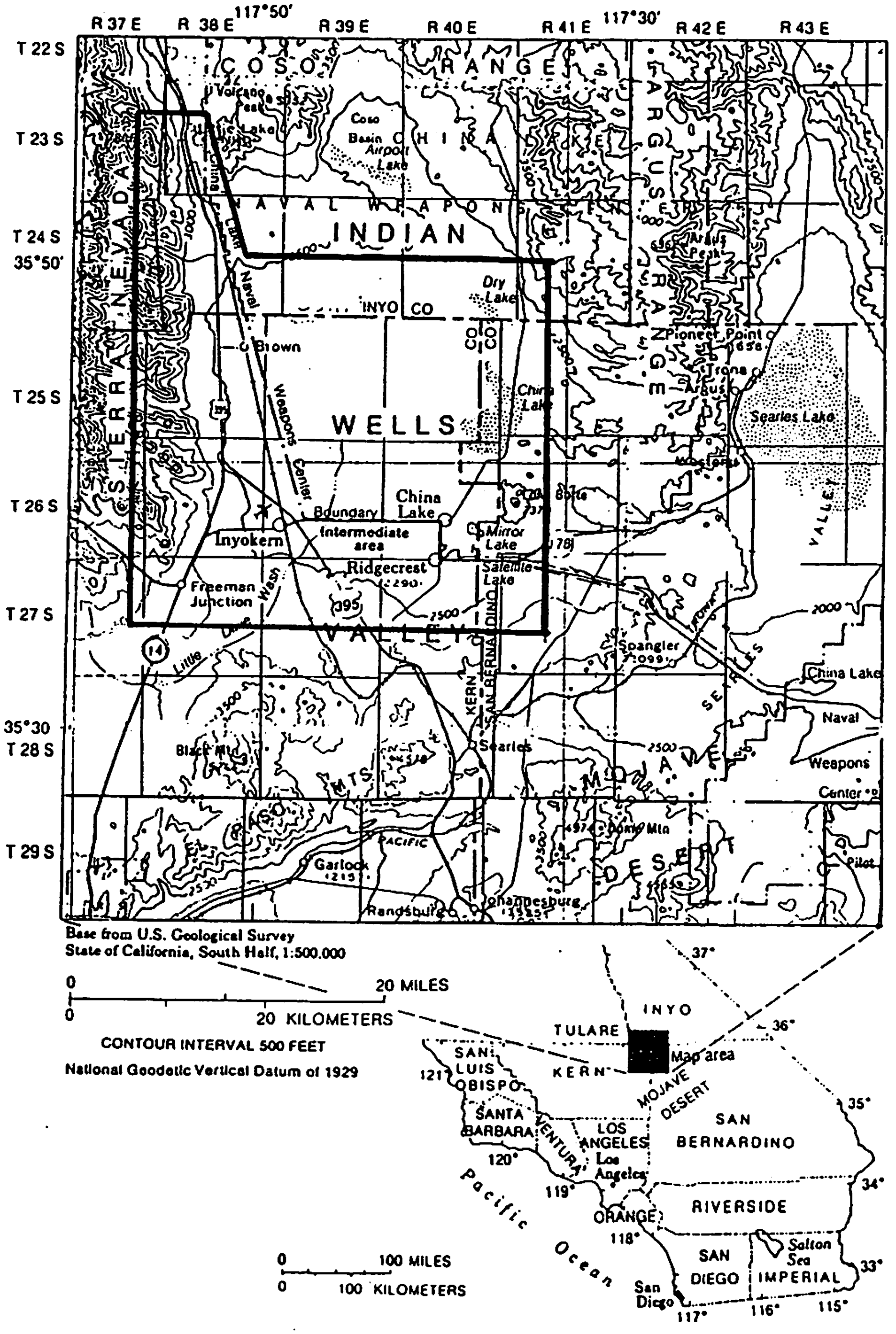

Figure 1. Location of Study Area. (Map from Berenbrock and Martin, 1991).

Most of the ground water used in the valley is taken from the Intermediate Well Field (located between Ridgecrest and Inyokern) and the Ridgecrest Well Field (located near Ridgecrest). In both of these well fields wells are clustered and their use has caused a large cone of depression in the shallow unconfined aquifer.

Another debate related to the issue of ground water recharge is whether the Sierra Nevada fault located on the west side of the valley is a thrust fault or a normal fault. Austin and Moore (1987) believe that the fault is a thrust fault, that the granite of the Sierra Nevada batholith has been thrust over sediments and meteoric water moves through a series of listric-type faults by geothermal convection. Erskine (1989) suggests that these faults may allow the transport of large amounts of ground water that originates from the Kern River recharge area.

The objective of this thesis is to analyze the hydrogeochemistry of the unconfined aquifer of the Indian Wells Valley, to add to ground water quality maps that were generated by past researchers and to investigate the main source or sources of ground water to this aquifer. Information collected for this thesis will be added to the existing database of hydrogeological and hydrogeochemical data so that it will be available for future studies.

LOCATION

The subject area of study is the Indian Wells Valley. The Indian Wells Valley is located approximately 110 miles east of Bakersfield and 125 miles north of Los Angeles, in the northern Mojave Desert in Kern, San Bernardino and Inyo counties (Figure 1). The valley is bordered on the west by the Sierra Nevada mountain range, on the north by the Coso Range, on the east by the Argus Range and on the south by the El Paso Mountains. The study area is approximately 300 square miles. Elevation of the valley is between 2,175 and 2,400 feet above sea level.

PREVIOUS WORK

Since the early 1900's much research has been conducted concerning the ground water and the geology of the Indian Wells Valley. Lee (1913) studied the geology of the valley along with ground water availability and future development. Thompson (1929) performed a general investigation of the Mojave Desert region, which included geology, climate and ground water geochemistry. Zbur (1963) conducted a geophysical study in the Indian Wells Valley using seismic and gravity data that yielded information on depth and types of sediments in the valley. Moyle (1963) studied perennial yield, ground water use, supply, storage, ground water levels and geochemistry, and mapped the local geology of the valley. Kunkel and Chase (1969) studied ground water levels, ground water quality and hydrogeology of the valley in order to establish values for perennial yield and ground water supply. Using previous United States Geological Survey (USGS) data, Bloyd and Robson (1971) developed a mathematical two-dimensional ground water model to predict ground water level changes based on the current and future pumping rates. Banta (1972) compiled data on ground water levels, volumes of ground water pumped and ground water quality for the valley for 1971. Dutcher and Moyle (1973) compiled data collected in previous studies of the valley in order to evaluate transmissivity, storage capacity, ground water flow and perennial yield. Warner (1975) used ground water quality and potentiometric surface elevation data to assess changes in the domestic aquifer due to natural barriers and use by humans. Mallory (1979) updated information concerning land use and ground water pumpage to use in the model developed by Bloyd and Robson (1971) in order to revise previous predictions made concerning future ground water level changes. Muir and Birman (1986) measured soil temperature in an attempt to determine the ground water flow divide between the valley and Red Rock Canyon. St. Amand (1986) assessed changes in elevation of the potentiometric surface, decrease in ground water quality, ground water recharge, perennial yield, storage and addressed the degradation of the ground water resource. Berenbrock (1987) compiled potentiometric surface elevations and ground water quality data collected from 1977 through 1984 in order to develop a ground water monitoring program for the valley. Austin and Moore (1987) evaluated geophysical data and structure of the valley. Bean (1989) and Erskine (1989) in separate publications evaluated the hydrogeology of the valley in order to suggest alternatives for future development of ground water resources. Whelan and Baskin (1989) used data collected by the USGS, University of Utah and the Naval Air Weapons Station. They evaluated and mapped ground water geochemistry in the valley. Berenbrock and Martin (1991) developed a three-dimensional ground water flow model that estimated vertical and horizontal movement of ground water. The Indian Wells Valley Technical Report (Watt, et al, 1992) was a compilation of data collected from ten wells installed jointly by the Naval Air Weapons Station, the Bureau of Reclamation, the Indian Wells Valley Water District and the North American Chemical Company. Data collected included transmissivity, ground water quality and storage capacities for shallow to deep ground water aquifers in different locations in the valley.

GEOLOGY

GENERAL DESCRIPTION

The Indian Wells Valley is surrounded by mountains composed of granodiorite and volcanics with low hydraulic conductivity. Consequently, there is little yield of ground water. The Indian Wells Valley is filled with approximately 6,200 feet of consolidated rocks and unconsolidated sediments (St. Amand, 1986). The Goler and Ricardo formations (which are exposed in the southern margin of the valley) are consolidated sedimentary and volcanic rocks. The unconsolidated sediments of the valley range from alluvial fans along the valley margins to playa deposits on the eastern margin. These sediments form the major fresh-water aquifer in the valley. The generalize geology of the Indian Wells Valley is shown on Figure 2.

STRATIGRAPHY

In the Indian Wells Valley a Paleozoic to Mesozoic basement complex underlies consolidated Tertiary continental deposits. On the southern and northern margins of the valley Tertiary/Quaternary volcanics rest above the continental deposits. Quaternary unconsolidated deposits lie above the continental deposits and the volcanics within the valley. A cross section and stratigraphic column for the Indian Wells Valley are shown on Figure 3.

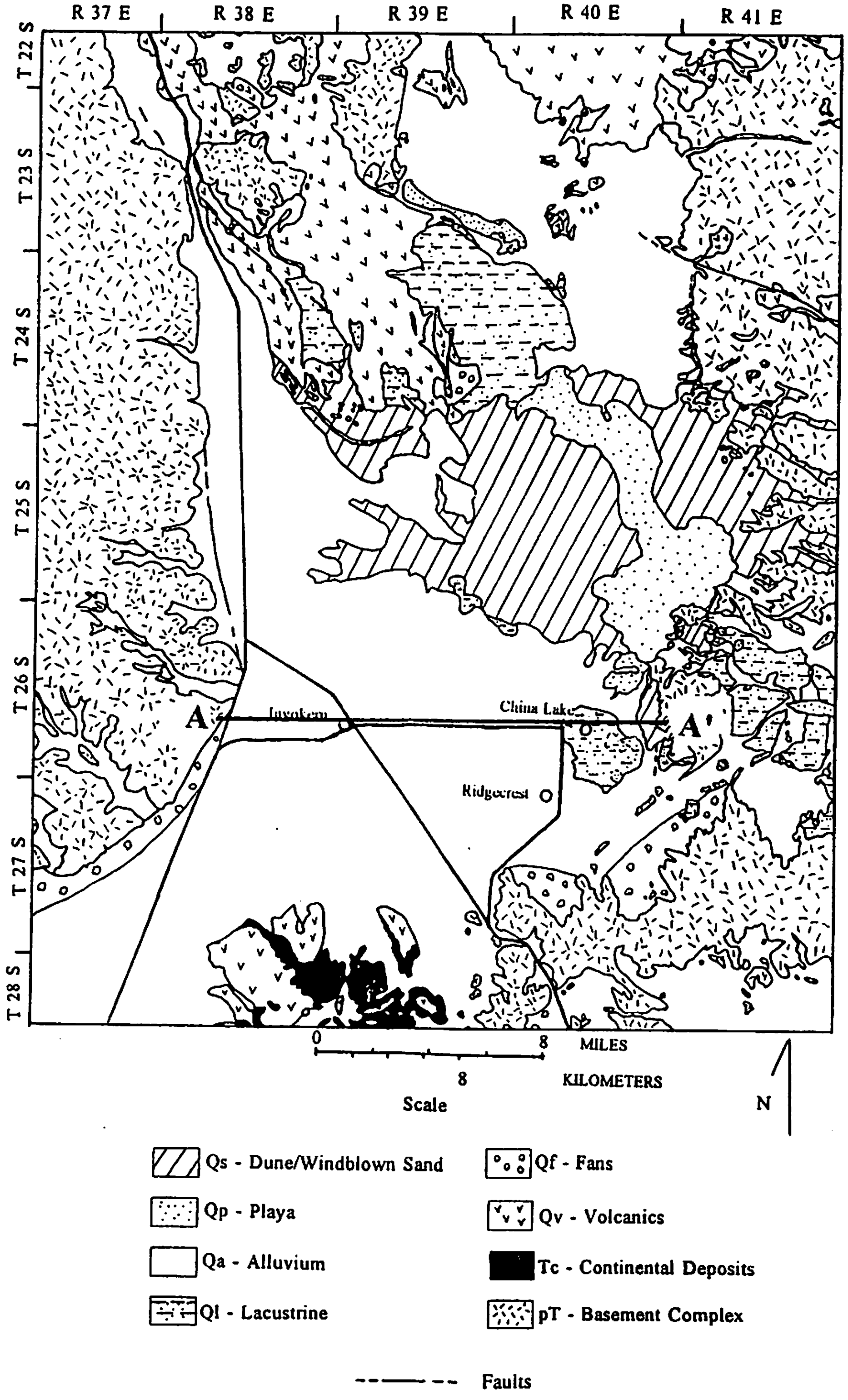

Figure 2. Generalized Geology of the Indian Wells Valley. (From Berenbrock and Martin, 1991 and Moyle, 1962).

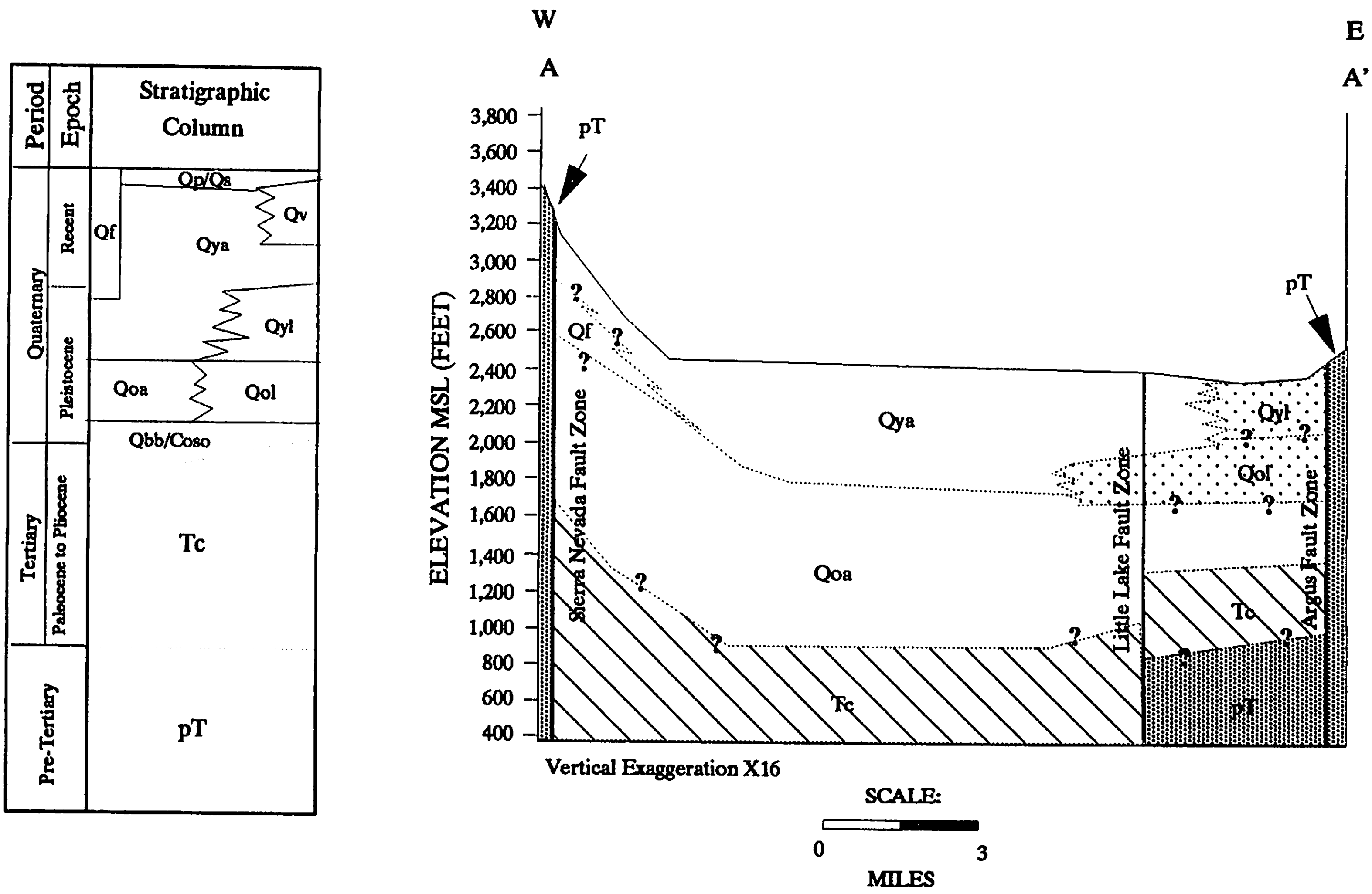

Figure 3. Stratigraphic Column and Cross Section (modified from Berenbrock and Martin, 1991) along line A - A' from Figure 2.

BASEMENT COMPLEX (pT)

The Indian Wells Valley is underlain by a basement complex which consists of Paleozoic to Mesozoic crystalline rocks of plutonic, hypabyssal and metamorphic origin. The basement complex is exposed in the mountain ranges surrounding the basin (Kunkel and Chase, 1969) (Figure 2). The basement complex rocks have limited to non-existent yields of ground water.

CONTINENTAL DEPOSITS (Tc)

Continental deposits of Paleocene to Pliocene age lie unconformably above the basement complex. The continental deposits include consolidated fluvial and lacustrine sediments, and extrusive and intrusive volcanics. It is not known how far the continental deposits extend laterally into the valley.

Continental deposits include the Goler and Ricardo Formations. The Goler Formation is exposed on the northeast side of the El Paso Mountains (Figure 2). It is composed of consolidated arkose, clay, shale and conglomerate (Moyle, 1963). The Goler Formation contains no pyroclastics; it is mostly composed of granitic-derived sediments. This formation has low ground water yield, although ground water flows along the contact between it and the overlying Ricardo Formation (Moyle, 1963).

The Ricardo Formation, which is well-exposed in Red Rock Canyon State Park, lies unconformably above the Goler Formation. The Ricardo Formation is composed of silt, sand, gravel, clay, limestone, opal chert, conglomerate, tuff, basalt flows, andesite, breccia flows and granitic cobbles (Moyle, 1963). The Ricardo Formation has low permeability and low yields of poor quality ground water. The Ricardo and Goler

Formations and the underlying basement complex were uplifted and tilted to the north and northwest during the early Pleistocene (Zbur, 1963).

BLACK MOUNTAIN BASALT (Qbb)

The Black Mountain Basalt exposed in the El Paso Mountains is Tertiary or Quaternary in age. Originally the flow covered at least 50 square miles.

The Black Mountain Basalt is approximately 100 feet thick and unconformably overlies the Ricardo Formation (Kunkel and Chase, 1969). These basalts are vesicular, dense, mostly impermeable and lie above the ground water table.

COSO FORMATION

The Coso Formation is located in the northern portion of the Indian Wells Valley. The Coso Formation is exposed in the Coso Range and is approximately 500 feet thick. It is Late Pliocene to early Pleistocene in age. It consists of white pumice and may also contain silt, sand and gravel interbedded with the pumice (Moyle, 1963). This formation has high permeability, but lies above the water table.

OLDER ALLUVIUM (Qoa)

Older alluvium lies above the Coso Formation and the Black Mountain Basalts in most of the valley. It is exposed south of Little Lake and west of US 395. The older alluvium is Early to mid-Pleistocene age (Kunkel and Chase, 1969).

Older alluvium was deposited during or before glacial periods and is an average of 800 feet thick. It is made up of unconsolidated weathered gravel, sand, silt and clay.

According to Moyle (1963) the older alluvium has high yields and is probably the main source of ground water for the Indian Wells Valley. Kunkel and Chase (1969) and St. Amand (1986) dispute this stating that this unit has low yield.

In the southwestern most part of the valley, a thin veneer of older alluvium overlies the Ricardo Formation. Moyle (1963) agrees that the older alluvium has low yield in this area.

OLD LACUSTRINE DEPOSITS (Qol)

Lacustrine deposits of Quaternary age were deposited before and during the glacial periods. They are exposed on the northern margin of the valley south of Coso Lake (Figure 2). This deposit is divided into two sub-units. The sub-units are separated by tufa deposits that precipitated along an ancient shoreline. The old lacustrine deposits are composed of silt, sand, clay and freshwater marl, all of which are cemented with calcite and tuff. The old lacustrine deposits are contemporaneous with older fan deposits that are part of the older alluvium. The old lacustrine deposits contain poor quality ground water (St. Amand, 1986).

UNNAMED VOLCANIC ROCKS (Qv)

Unnamed volcanic rocks are Quaternary age and originate from extrusive basalt flows. These rocks are situated at the northern end of Indian Wells Valley, north of Coso Basin and lie above the water table (Figure 2). They are made up of basalt flows with interbedded scoria, pumice, obsidian and andesite. They are locally covered by a veneer of windblown sand. The southern margin may be interbedded with the younger alluvium.

It is believed that the unnamed volcanics are younger than the Black Mountain Basalts because they are less weathered and are interbedded with the younger alluvium (Kunkel and Chase, 1969). Volcanic vents and fissures that occur at the northern end of the valley are the probably the source of these volcanic rocks.

FAN DEPOSITS (Qf)

Fan depositions along the valley margins began in the Late-Pleistocene and continues to the present. These deposits are unconsolidated, poorly to moderately sorted and composed of gravel, sand, silt and some mud flow materials. The source of the fan deposits are the nearby mountains bordering the valley. East of the Sierra Nevada fault zone the thickness of the fans is 1,000 feet or greater. West of the fault zone the they may be 0 feet to 300 feet in thickness (Kunkel and Chase, 1969). The majority of the fan deposits are above the water table. Where the fans lie below the water table low yields of poor quality ground water can be obtained (Kunkel and Chase, 1969).

YOUNGER ALLUVIUM (Qya)

Younger alluvium is mid- to Late-Pleistocene to Recent in age, unconsolidated, moderately to well sorted, and composed of sand, clay and gravel (Kunkel and Chase, 1969). The younger alluvium was deposited during the current climate (St. Amand, 1986) and is approximately the same age as the younger fan deposits. The younger alluvium overlies the older alluvium.

The slopes of the younger alluvium range from 100 feet per mile to less than 50 feet per mile. These deposits have high porosity and permeability. Kunkel and Chase (1969) and St. Amand (1986) state that these deposits compose the main aquifer for ground water in the Indian Wells Valley, although Moyle (1963) suggests that they lie above the water table.

The younger alluvium deposits lie east of the alluvial fans of the Sierra Nevada. They are exposed on the valley floor except where they are replaced by playa deposits or where they are covered by windblown sand (Figure 2).

YOUNGER LACUSTRINE DEPOSITS (Qyl)

Younger lacustrine deposits are composed of lenticular beds of silty clay and silt. Younger lacustrine deposits generally occur at an altitude of 2,256 feet or less and are associated with ancient Lakes China and Searles. These deposits also occur as tufas in both the Indian Wells Valley and the Salt Wells Valley at an altitude of 2,240 or less. They are believed to have been deposited during the Pleistocene when Lake Searles and Lake China were a single water body. The younger lacustrine deposits are overlain by windblown sand and interdune playas.

Wells completed in the younger lacustrine deposits may produce a small amount of saline water, however, the bulk of the lacustrine deposits are above the water table.

PLAYA DEPOSITS (Qp)

Playa deposits are Recent in age and are found in the lowest elevations of the valley. The playa deposits are generally fine-grained deposits composed of silt and clay, with some sand lenses and have low permeability. Ground water stored in the playa deposits has high total dissolved solids (TDS). These deposits occur beneath the surface of China[1], Mirror, Satellite and Coso Lakes (Kunkel and Chase, 1969) (Figure 2). The playa deposits interfinger with the younger alluvium and are locally covered by windblown sand.

Kunkel and Chase (1969) estimate that the thicknesses of the playa deposits are several tens of feet in the middle part of China Lake. The playa deposits grade into and are indistinguishable from the younger and older lacustrine deposits that lie beneath.

WINDBLOWN SAND AND INTERDUNE PLAYA DEPOSITS (Qs)

Interdune playa deposits are Recent age and composed of windblown sand that has been deposited in the vicinity of China Lake. These deposits overlie the playa deposits. They cover areas that are hundreds of square feet to many acres in size. Interdune playa deposits are only partially below the water table. These deposits have low yield of poor quality ground water.

Windblown sand is the youngest deposit in the valley. It occurs as a thin veneer over all of the older formations. Windblown sand is not considered a source of ground water as it occurs above the water table.

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[1] Lake China was the name of the fresh water lake that was a part of a chain of lakes formed during the interglacial period. The lakes were formed when the climate in the valley was temperate rather than arid as it is today. China Lake is the name of the playa lake that is currently located on the eastern margin of the valley. The water in China Lake is saline water.

Windblown sand fills a channel that was once the outlet from China Lake to Searles Lake. Test wells indicate that this channel is filled with windblown sand down to bedrock at a depth of 41 feet below ground surface (Kunkel and Chase, 1969).

FAULTING

The Indian Wells Valley is commonly believed to be a typical half-graben associated with the Basin and Range Province (Kunkel and Chase, 1969). There are large faults along the base of the Sierra Nevada and smaller faults bordering the Argus Range (Figure 2). The valley itself contains many faults that may act as ground water barriers (Bloyd and Robson, 1971; Dutcher and Moyle, 1973). Most of the faults strike northwest.

The Sierra Nevada fault zone separates the Sierra Nevada Range from the Indian Wells Valley and forms the eastern escarpment of the Sierras. The Sierra Nevada has been uplifted along this fault relative to the valley. The vertical displacement along this fault is at least several thousand feet. Movement on the Sierra Nevada fault zone began at the end of the Miocene. The last major movement on this fault took place during the middle Pleistocene (Kunkel and Chase, 1969).

Austin and Moore (1987), Erskine (1989) and Whelan and Baskin (1989) dispute the typical Basin-and-Range extensional basin model for the Indian Wells Valley. These researchers believe that the Sierra Nevada and Argus ranges thrust eastward over the adjacent basins. Austin and Moore (1987) suggest that the Sierra Nevada range is not as deeply rooted as commonly believed and that marine sediments may exist beneath the thrust sheet. They base their theory on fracture patterns, carbonate mounds, geochemical, geothermal, seismic data and models of similar basins.

More research in this area should be performed to evaluate on these opposing structural models for the valley. Recently, an extensive seismic study was undertaken in the Indian Wells Valley, however, the data from that study has not yet been released for public interpretation. This data may reveal the true structural nature of the Indian Wells Valley.

The Garlock fault zone occurs on the south side of the El Paso Mountains and trends in a northeasterly direction towards Death Valley. Movement along this fault is predominantly left-lateral strike-slip. This fault has probably been active since the Oligocene (Mayer, 1987).

The Argus fault zone lies along the west side of the Argus Range. The Argus Range has been uplifted along this fault relative to the valley floor. The northern end of this fault may be truncated by the Wilson Canyon fault zone. The southern end of this fault may be truncated by the Garlock fault. Vertical displacement is believed to be several thousand feet (Kunkel and Chase, 1969).

The Wilson Canyon fault is part of a group of northwest trending faults in the Argus Range. Kunkel and Chase (1969) speculate that the Wilson Canyon fault extends to Little Lake and that the volcanic vents from which the unnamed volcanic rocks extruded, developed along this zone of weakness.

HYDROGEOLOGY

MOVEMENT AND RECHARGE OF GROUND WATER

In their flow model Bloyd and Robson (1971) demonstrate that ground water moves from west to east and that there are many barriers that impede flow. These barriers are shown on Figure 4. Dutcher and Moyle (1973) suggest that there is flow from the west to the east and that ground water barriers in the form of faults exist throughout the valley. The soil temperature probe study conducted by Muir and Birman (1986) suggests the presence of a ground water barrier south of Inyokern between Bowman Road and Freeman Wash and a ground water divide south of Freeman Junction near Sage Canyon. The ground water flow model developed by Berenbrock and Martin (1991) also shows movement from west to east. However, they did not include any ground water flow barriers in their model. Lee (1913), Kunkel and Chase (1969), Dutcher and Moyle (1973) and Berenbrock and Martin (1991) maintain that ground water moves eastward toward the playa and water is lost by evapotranspiration from the playa surface.

General ground water movement was evaluated for this thesis using the 1992 ground water elevation contour map from the Kern County Water Agency (1993) and a 1985 ground water elevation contour map from Berenbrock and Martin (1991). Figure 5 shows that in 1992 a cone of depression had developed due to pumping agricultural wells on the western margin of the valley. Figure 6 shows that in 1985 there was a ground water mound at this location. The mounding may indicate a flow barrier to the east. The barrier may be a thick clay layer that is located in the central portion of the

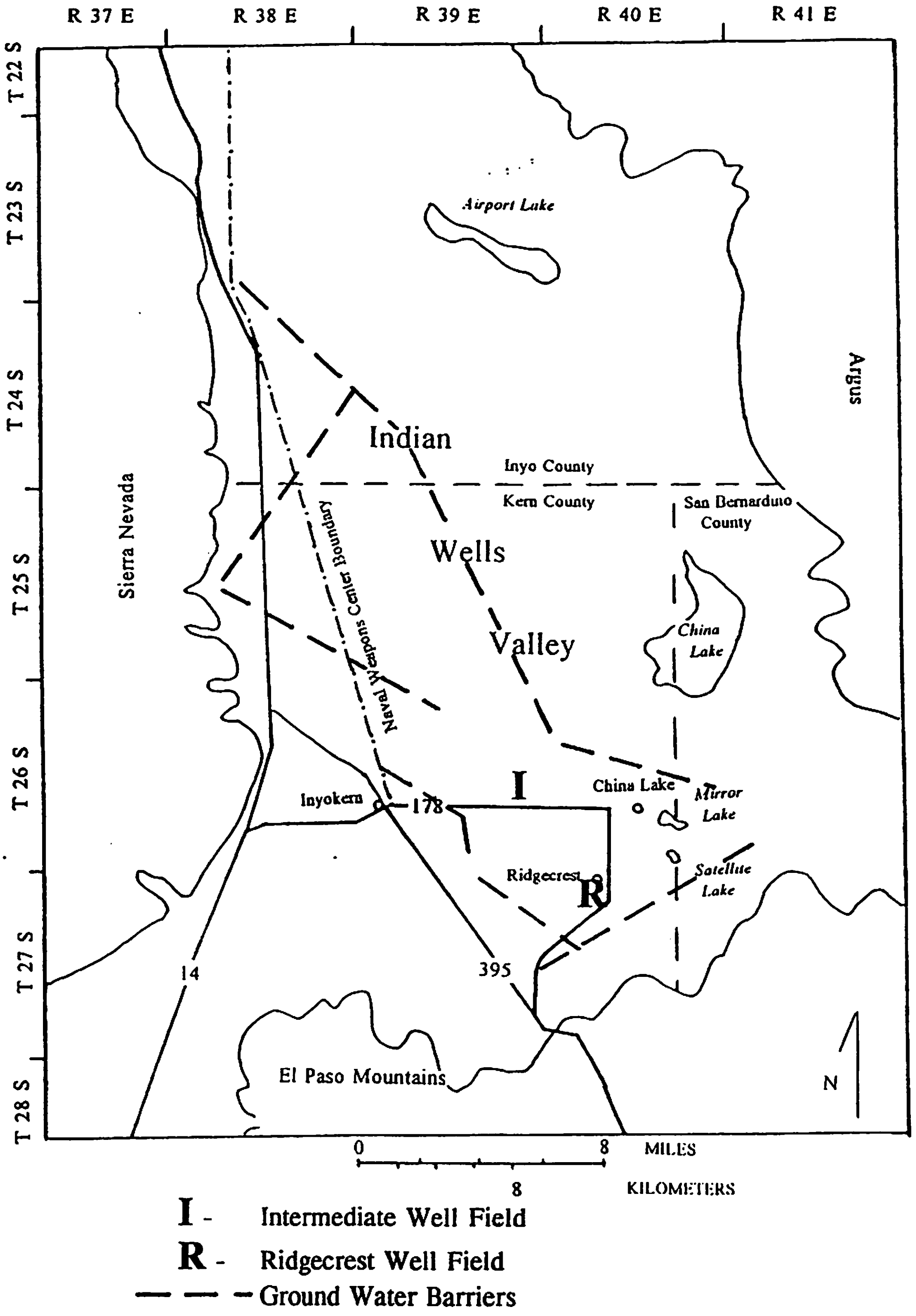

Figure 4. Location of Wells Fields and Possible Ground Water Barriers in the Indian Wells Valley.

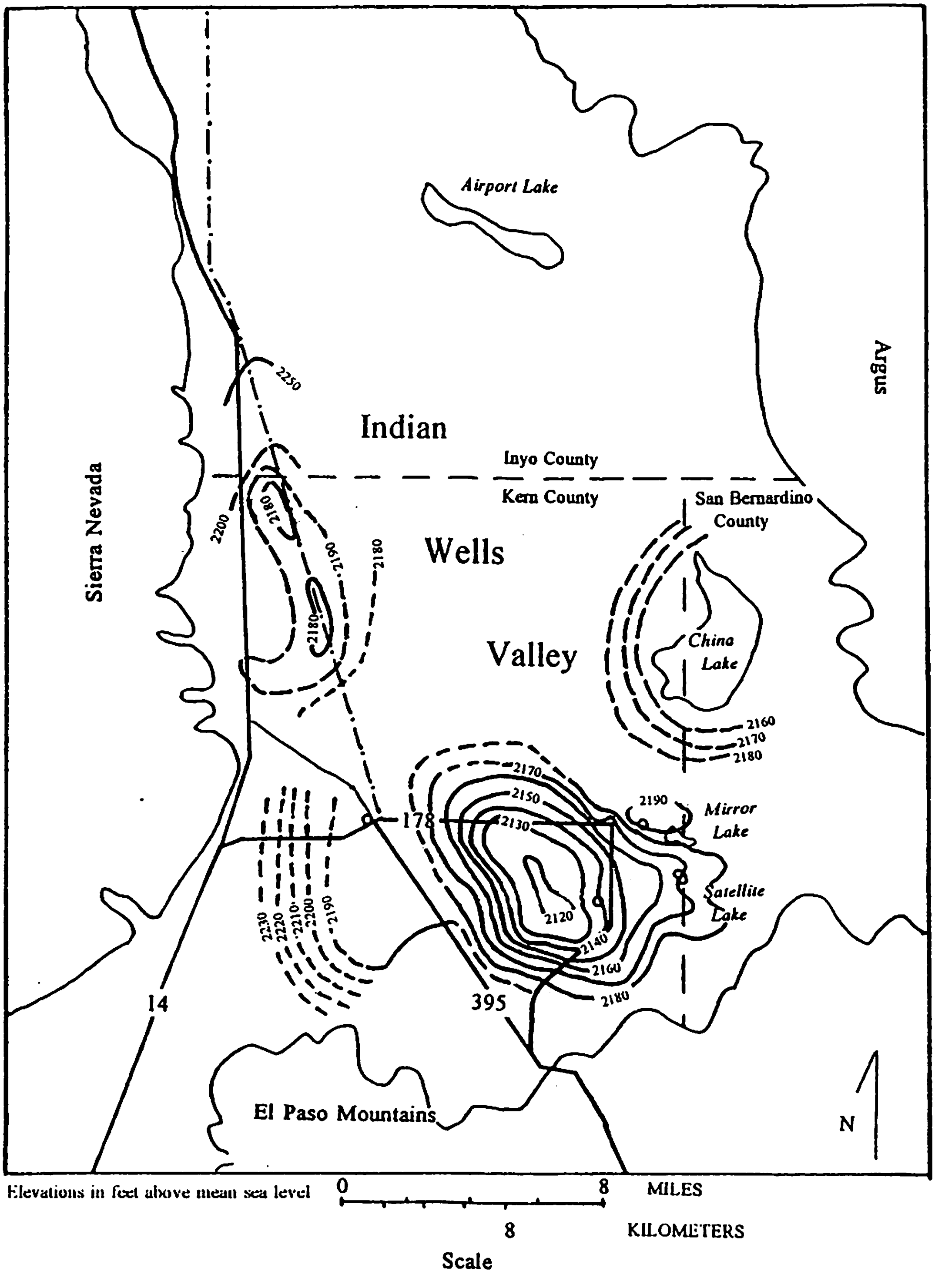

Figure 5. 1992 Ground Water Elevations in the Indian Wells Valley. (Modified from Kern County Water Agency's 1992 Water Supply Report).

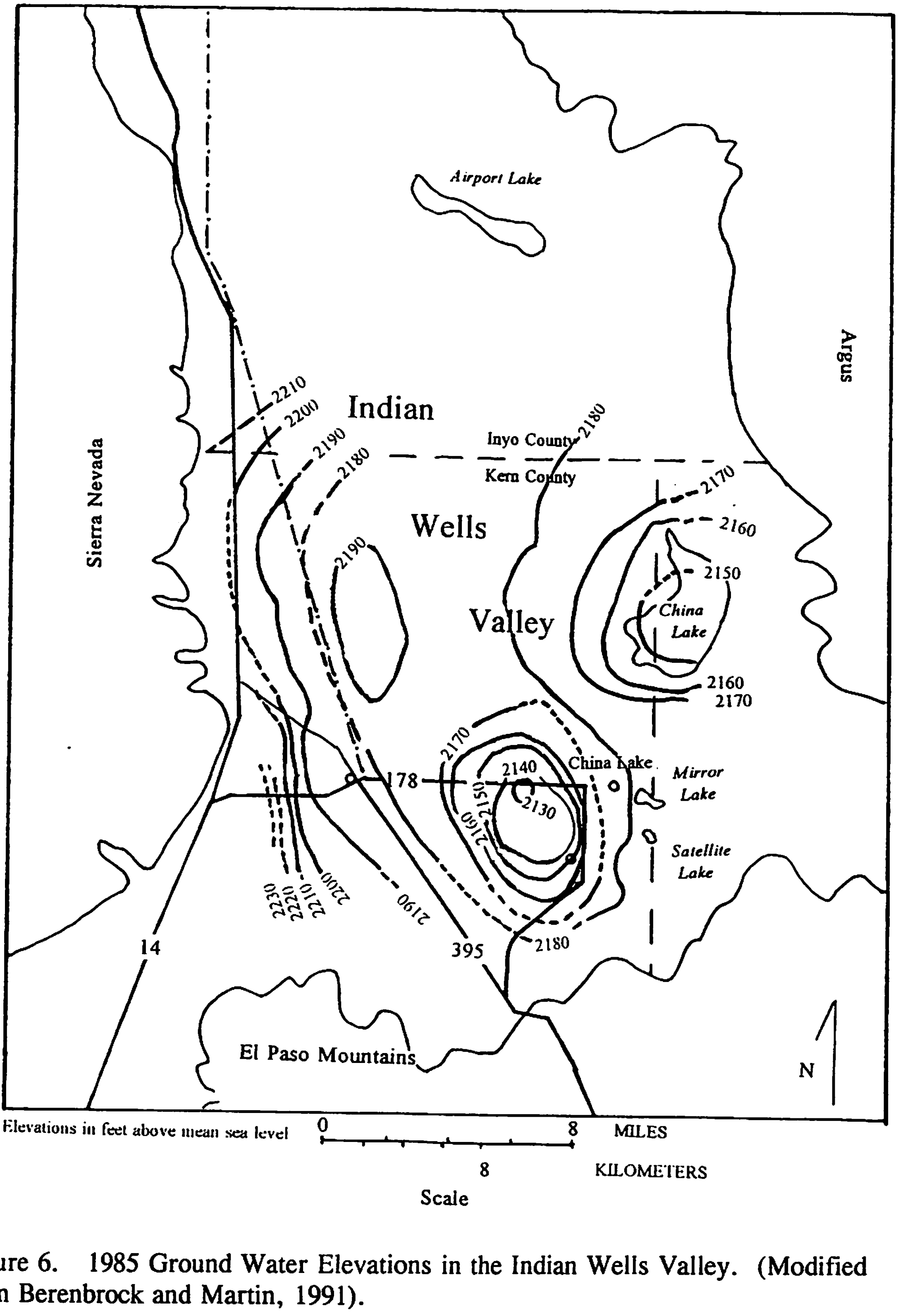

Figure 6. 1985 Ground Water Elevations in the Indian Wells Valley. (Modified from Berenbrock and Martin, 1991).

valley at a depth of 440 feet to 1,480 feet below ground surface (approximately 1,000 feet thick) (Watt, et al, 1992).

Another cone of depression can be seen on both maps in the area east of Ridgecrest where the domestic well fields are located (Figures 5 and 6). According to St. Amand (1986) the well fields are situated between two sub-parallel ground water barriers that trend to the southwest. These barriers may limit recharge and the depression has been created due to pumping of the wells. The overall decline in water level may decrease the storage capacity of the aquifer. Such a decrease is caused by the compression or collapse of the sediments (especially clays) due to overburden pressure because the pore spaces are no longer supported by fluid. This compression of pore spaces can be irreversible and reduces the holding capacity of the aquifer.

Pumping or overdraft of the aquifer may also cause a decrease in ground water quality. Before pumping of ground water, the natural flow was probably from the southwest toward the playas on the east. Ions dissolved in the ground water were then precipitated as salts in the playas due to evapotranspiration of the ground water (Dutcher and Moyle, 1973; Berenbrock and Martin, 1991). The cone of depression caused by pumping in the well fields near Ridgecrest has changed the natural gradient in the vicinity of the playas which may cause saline water to flow from the playas toward the well fields.

The clay layer located in the center of the valley is a barrier that may prohibit the eastward movement of ground water on the west side of the valley. The ground water that is found in the clay layer has very high salinity and TDS. Current pumping on the west side of the valley has caused drawdown of ground water, rather than mounding, as was indicated on the 1985 ground water elevation contour map (Figure 6). The drawdown may also permit low quality water that is found in the clay layer to influence the better quality ground water that is located in the western portion of the valley.

Many estimates have been made concerning recharge of ground water in the valley. However, none of the estimates are based on measurements of actual recharge. Kunkel and Chase (1969) believe the main source of recharge is from the west and southwest from the Sierra Nevada watershed. The second most important source is from the fans and escarpment northwest of Inyokern and the third most important source of recharge is from Rose Valley (Little Lake). They state that a small amount of recharge occurs from the Argus, Coso and El Paso Ranges. They estimate a perennial yield of approximately 12,000 ac-ft/year available for pumping. Their estimate is shown on Table 1.

St. Amand (1986) believes that the total recharge for the valley is approximately 11,000 ac-ft/yr and that the perennial yield is 10,000 ac-ft/yr with 1000 ac-ft/yr evapotranspiration from the playas. He estimates that 68 percent of the recharge to the domestic aquifer is from runoff from the Sierra Nevada, and 32 percent is from Coso and Argus Ranges (Table 1).

Muir and Birman (1986) estimated that 50 percent of recharge to the valley is from the Sierra Nevada in the southwest. Their figure is based on data collected in their soil temperature probe study conducted to determine the ground water divide in the southwest (Table 1).

Bean (1989) used data from many researchers including Lee (1913), Thompson (1929), Bloyd and Robson (1971) and Berenbrock (1987) as well as unpublished studies not available for this thesis. According to Bean's report, the greatest source of recharge is from the Sierran streams (41 percent). The second highest source of recharge is from the Sierran granitics (16 percent) due to deep recharge along listric faults. The total calculated recharge into the valley was approximately 15,100 ac-ft/yr.

In addition to natural sources of recharge, treated waste water has been released into sewage ponds in the vicinity of the China Lake playa prior to 1921 (Dutcher and Moyle, 1973). St Amand (1986) estimates that the ponds have leaked approximately 1,500 acre-feet of water each year since 1985.

TABLE 1. THE MAIN SOURCES FOR GROUND WATER RECHARGE BY RESEARCHER

SOURCE	**KUNKEL & CHASE (1969)**	**ST.AMAND (1986)**	**MUIR & BIRMAN (1986)**	**BEAN (1989)**
SIERRA (WEST + SOUTHWEST)	No. 1 source	68%	50%	41%
COSO & ARGUS	small	32%	--	--
GRANITICS (FRACTURES)	--	--	--	16%
ROSE VALLEY (LITTLE LAKE)	No. 2 source	--	--	
PERENNIAL YIELD	12,000 ac-ft/yr	10,000 ac-ft/yr		
TOTAL RECHARGE	--	11,000 ac-ft/yr	--	15,100 ac-ft/yr

According to Berenbrock and Martin (1991) an average of approximately 22,000 ac-ft/yr. of ground water was pumped from the shallow unconfined aquifer in the Indian

Wells Valley between 1980 and 1985. This amount is greater than estimated recharge into the valley indicating possible overdraft of the shallow aquifer.

TRANSMISSIVITY AND STORAGE COEFFICIENTS

There is a large discrepancy between the transmissivity data obtained for the Indian Wells Valley Technical Report (Watt, et al, 1992) and the data presented by Kunkel and Chase (1969) and Dutcher and Moyle (1973). Watt, et al (1992) found transmissivities of the sediments in the unconfined aquifer to be 2.32×10^{-2} m^2/min. (0.25 ft^2/min.) in the south and southwest (average), 2.14×10^{-2} m^2/min. (0.23 ft^2/min.) in the west, 1.77×10^{-2} m^2/min. (0.19 ft^2/min.) in the northwest and 4.46×10^{-2} m^2/min. (0.48 ft^2/min.) in west-central portion of the valley. These values, which are shown on Table 2, were based on slug tests conducted in 1991 during the installation of Bureau of Reclamation wells.

Dutcher and Moyle (1973) calculated coefficients of transmissivity from pump tests and driller's logs. From their calculations they obtained coefficients of transmissivity ranging from zero at the margins of the valley to approximately 2.59 m^2/min. (27.85 $feet^2$/min.) in the central part of the valley.[2] Dutcher and Moyle (1973) indicated that the highest transmissivity values were in the west-central portion of the valley and maintained that the lowest area of transmissivity was in the south, southwest and eastern margins of the valley. Their assumption disagrees with the Watt, et al

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[2] Berenbrock and Martin (1991) used transmissivities of 2.38 m^2/min. (25.60 $feet^2$/min.) to less than 9.01×10^{-2} m^2/min. (0.97 $feet^2$/min.) from data obtained by Dutcher and Moyle (1973) for their ground water model.

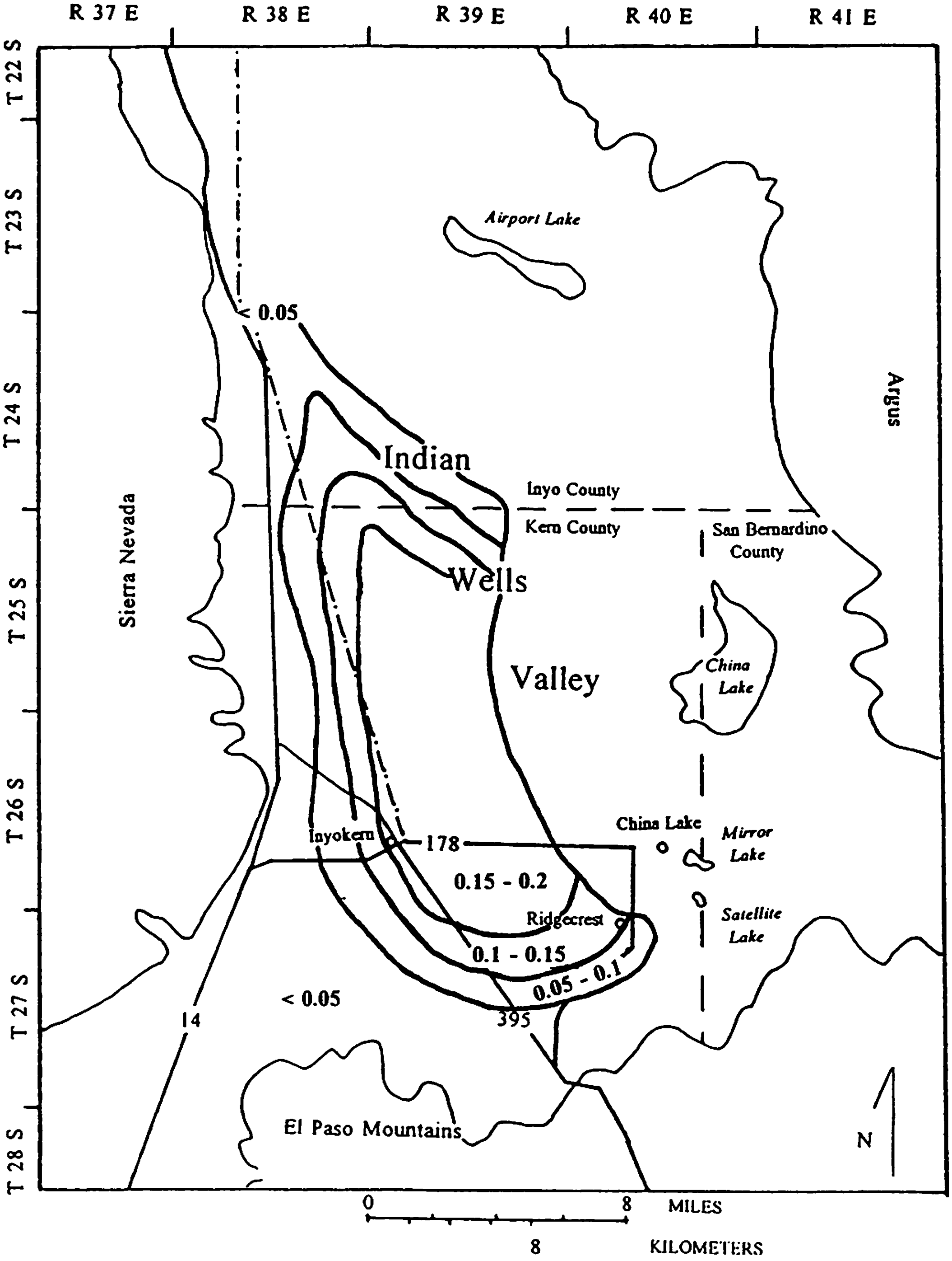
(1992) which showed the lowest transmissivity to be in the west-central portion of the valley (Table 2).

From pump test data, Kunkel and Chase (1969) obtained transmissivity values that ranged from 1.31 m^2/min. (14.11 ft^2/min.) to 2.71 m^2/min. (29.15 ft^2/min.). The overall average for all locations was 1.73 m^2/min. (18.57 ft^2/min.) (Table 2).

TABLE 2. COMPARISON OF PUBLISHED TRANSMISSIVITIES VALUES (UNITS = m^2/min.)

LOCATION	**WATT, ET AL (1992)**	**DUTCHER & MOYLE (1973)**	**KUNKEL & CHASE (1969)**
South/southwest	2.32×10^{-2}	0.86 to 1.73	--
West	2.14×10^{-2}	0.86 to 1.72	--
Northwest	1.77×10^{-2}	0.84 to 2.58	2.10
West central	4.46×10^{-2}	2.16 to 2.58	--
East central	--	8.64×10^{-2} to 0.86	--
Central	--	8.64×10^{-2} to 1.73	22.09
North central	--	0.21 to 1.73	1.31

Dutcher and Moyle (1973) calculated storage coefficients for the unconfined aquifer for three area of the valley which are shown in Figure 7. Storage Unit 1 runs from north to south on the western margin and along the southern margin of the valley. Unit 1 has coefficients of storage between 0.05 and 0.1. Storage Unit 2 lies inside Unit 1 and covers the same pattern. The coefficients of storage for Unit 2 are between 0.1 and 0.15. Storage Unit 3 encompasses the central portion of the valley from Inyokern to western Ridgecrest and from the Inyo-Kern county line to approximately three miles



Storage Unit 1 = 0.05 to 0.1
Storage Unit 2 = 0.1 to 0.15
Storage Unit 3 = 0.15 to 0.2

Figure 7. Storage Coefficients for the Indian Wells Valley According to Dutcher and Moyle (1973).

south of Inyokern. Unit 3 has coefficients of storage between 0.15 and 0.2. The valley margins have coefficients of storage that are less than 0.05.

CHANGES IN GROUND WATER LEVEL

According to Dutcher and Moyle (1973) ground water level changes from 1953 to 1965 were negative in the unconfined aquifer. During a twelve year period ground water levels dropped more than 20 feet northwest of Ridgecrest, eight feet near Inyokern and seven feet south of Satellite Lake. On the valley margins there was little change in ground water levels. In the very shallow ground water areas near the playa, recorded ground water levels increased due to irrigation and sewage pond infiltration.

Berenbrock (1987) documented that ground water levels dropped in several wells since 1950. Some of these changes are shown on Figure 8 and Berenbrock's (1987) data from selected wells is summarized in Table 3.

TABLE 3. GROUND WATER LEVEL CHANGES - BERENBROCK (1987)

25/38-25L1	20 foot drop since 1950 10 foot drop since 1977
26/39-19Q1 Inyokern	20 foot drop since 1950 6 foot drop since 1977
26/40-19P1 Intermediate	40 foot drop since 1950 10 foot drop since 1977
26/40-4A Ridgecrest	20 foot drop since 1960 10 foot drop since 1977

Banta (1972) studied ground water level changes from October 1970 to October 1971. For that period he showed average decline in ground water level of three feet in

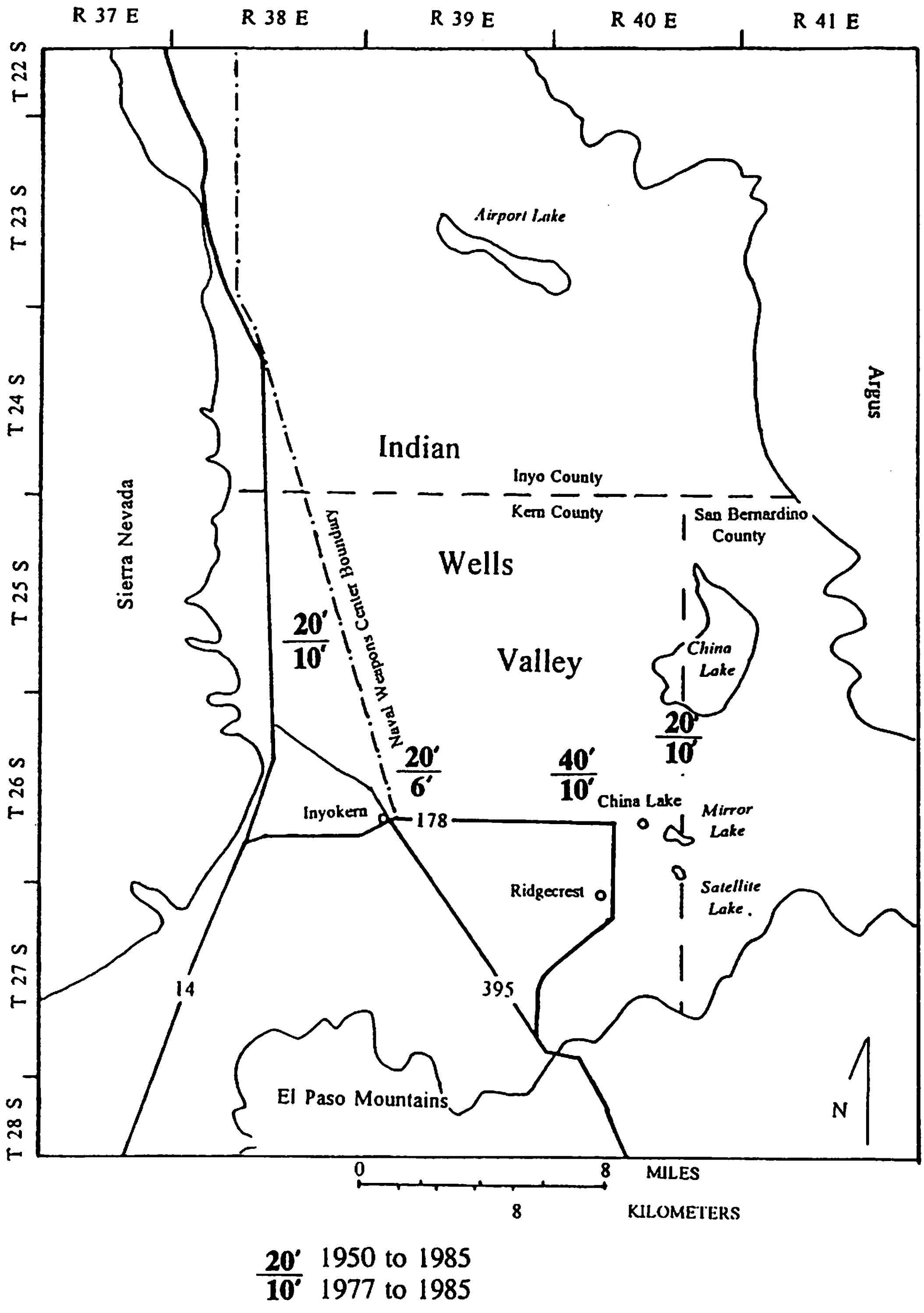


Figure 8. Water level changes in the unconfined aquifer in the Indian Wells Valley from 1950 to 1985 and 1977 to 1985 (Berenbrock, 1987).

the Intermediate area, of 0.5 foot in the Inyokern area and of 0.1 foot in the Ridgecrest area. Overall Banta's (1972) data indicated a drop in ground water levels throughout the valley. However, in the vicinity of the sewage ponds near the Naval Air Weapons Station ground water levels increased from previous measurements.

Mallory (1979), using the ground water model developed by Bloyd and Robson (1991) with updated information, predicted ground water level changes for the years 1986, 1998 and 2020. His model indicated that the gradient may be reversed across the suspected ground water barrier near China Lake (Figure 4) by 1984, allowing poor quality water from the playa to negatively impact the good quality ground water stored in the domestic aquifer.

By the year 2020, Mallory's (1979) model indicated a 125 foot drop in ground water levels from the 1921 levels (pre-pumping). This number is approximately 84 feet lower than what models predicted in 1976.

St. Amand (1986) agreed that continued pumping would cause a shift in ground water gradient from west to east to east to west. He based his assumption on current and proposed domestic water needs and the theoretical recharge, which will be less than the amount needed in the future.

GROUND WATER QUALITY

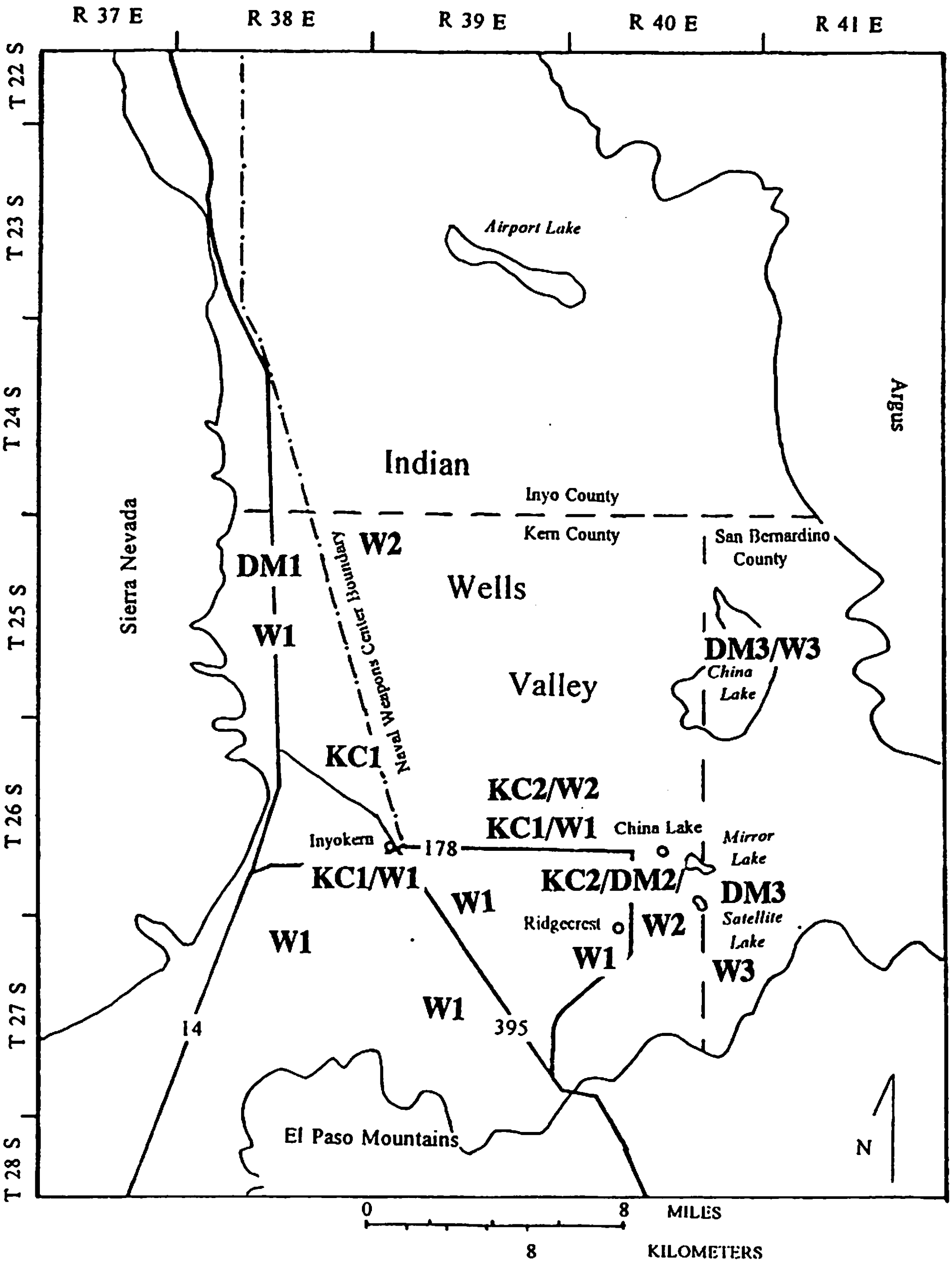
Kunkel and Chase (1969) separated ground water types into three groups which are shown on Table 4. In Group I the dominant ions were Na^+ and HCO_3^-. Group I had a chemical quality similar to the springs and surface water located along the east side of the Sierra Nevada. Group I ground waters, shown in Figure 9, were found in the Inyokern and Intermediate well fields and also to the north of these well fields.

Group II ground water was relatively soft with low levels of Mg^{2+} and Ca^{2+}, otherwise it was similar to Group I ground waters. Group II ground water was found in the deeper zones near the Naval Weapons Center main gate and continued several miles west to approximately one mile north of the Intermediate Well field (Figure 9).

Group III ground water was a sodium chloride water that was located in the region at and around China Lake (Figure 9). Kunkel and Chase (1969) stated that Group III ground water was similar to Group II but had a higher chloride level. They believed that the deeper water near the China Lake playa and east of Ridgecrest may actually be Group II ground water as it had a lower TDS than Group III or that it may be residual saline water from a past lake. Kunkel and Chase (1969) suggested that a thick clay zone east of the Naval Air Weapons Station main gate may form a barrier to the westward migration of poor quality ground water.

TABLE 4. GROUND WATER QUALITY DATA (KUNKEL AND CHASE, 1969)

CATEGORY	**Na^++ K^+ % OF TOTAL CATIONS**	**TDS ppm (mg/l)**	**TOTAL HARDNESS ppm (mg/l)**	**Cl^- ppm (mg/l)**	**B ppm (mg/l)**	**Fl^- ppm (mg/l)**
GROUP I	30-65	<600	100-200	<100	<1.0	<1
GROUP II	65-99	<600	30-100	<100	3 ->10	0.8 - 4
GROUP III	65-99	HIGH	--	250-3000	--	--



KC#- Kunkel and Chase DM# - Dutcher and Moyle W#- Warner

1- Low TDS 2- Low TDS/Low Mg^{+2} and Ca^{+2} 3- High Salinity

Figure 9. Ground Water Quality in Indian Wells Valley according to Kunkel and Chase (1969), Dutcher and Moyle (1973) and Warner (1975).

Dutcher and Moyle (1973) also separated the ground water quality into three types, which are shown on Table 5. Type I ground water was the best quality. Sodium and bicarbonate ions were dominant however, Dutcher and Moyle (1973) found that measurements of dominant ions varied from sample to sample. Type II ground water was also good quality ground water and was very similar in composition to Type I. Sodium and bicarbonate ions were dominant, but there were less calcium and magnesium ions in Type II ground water, which made it less hard than Type I ground water. Some of the Type II ground water had a high fluoride content. Type I ground water was found in the alluvial deposits of shallow to medium thickness, in the western and north-western part of the valley. Type II ground water was found between the Naval Air Weapons Station main gate and westward towards Ridgecrest (Figure 9).

Type III ground water had Na^+ and Cl^- as the dominant ions. This ground water was found at and around the China Lake playa, in the south east portion of the valley and east of Ridgecrest (Satellite Lake) in the shallow playa deposits (Figure 9). Dutcher and Moyle (1973) suggested that poor quality ground water was separated from good quality ground water by a thick clay barrier that is believed to be located east of the main gate of the Naval Air Weapons Station.

TABLE 5. GROUND WATER QUALITY DATA (DUTCHER AND MOYLE, 1973)

CATEGORY	$Na^+ + K^+$ % OF TOTAL CATIONS	TDS mg/l	TOTAL HARDNESS mg/l	Cl^- mg/l	B mg/l	Fl^- mg/l
TYPE I	36-60	>600	100-200	<100	<1	<1
TYPE II	65-99	<600-<1000	30-100	>100	3->10	<1 - >1
TYPE III	65-99	>1000	>100	>250->3000	3-10	1 - >1

Warner (1975) also divided the ground water into three groups, which are shown on Table 6. Groups 1 and 2 were good quality ground water with sodium and bicarbonate ions dominant. Group 2 ground water had lower values for magnesium and calcium than Group 1. Group 3 was a sodium chloride water. Group 1 was located in the central-western portion of the valley, in the Intermediate well field, in Inyokern and in Ridgecrest. Group 2 ground water was located in a small strip between Inyokern and Armitage Field, south of the Naval Air Weapons Station main gate and in the north-central portion of the valley. Group 3 ground water was located in the northeast portion of the valley in the area of the China Lake Playa and on the southeastern margins of the valley (Figure 9).

TABLE 6. GROUND WATER QUALITY DATA (WARNER, 1975)

CATEGORY	TDS mg/l	Cl^- mg/l	B mg/l	Fl^- mg/l
GROUP 1	<600	<100	<1	<1
GROUP 2	<600	>150	<3	1 - 3
GROUP 3	>1000 - >50,000	0 - >250	>2 - >10	1 - 6

Whelan and Baskin (1989) divided ground water quality types into greater detail than the previous researchers. Whelan and Baskin (1989) counted 55 water types, eight of which they mapped. Their data was a compilation of USGS data and samples they collected. Some of the USGS data was from wells where the construction and depth was unknown therefore, there could be mixing of ground water from deeper aquifers.

Berenbrock and Martin (1991) stated that better quality ground water existed at depth below the playa, below confining clays that were deposited during a fluvial period. They suggested that the better quality ground water moved upward through the clay layers and evaporated.

Watt, et al (1992) concluded that more ground water of good quality exists at depth than previously believed and that a clay layer in the central-north and northwest portions of the valley contains poor quality water. Temperature profiles conducted by Watt, et al (1992) indicated that there may be geothermal influences on the deeper ground water aquifers.

METHODS

WELL LOCATIONS AND SAMPLE COLLECTION

Samples were collected of from 31 wells and 12 surface water sites. Sample locations are shown on Figures 10 and 11 and listed on Table A1 in Appendix A. Ground water sampling locations within the valley were determined by using transects designed to systematically cover as much of the valley as possible. Transects were laid out from south to north, east to west, northwest to southeast and northeast to southwest. The majority of the wells were located on China Lake Naval Air Weapons Station.

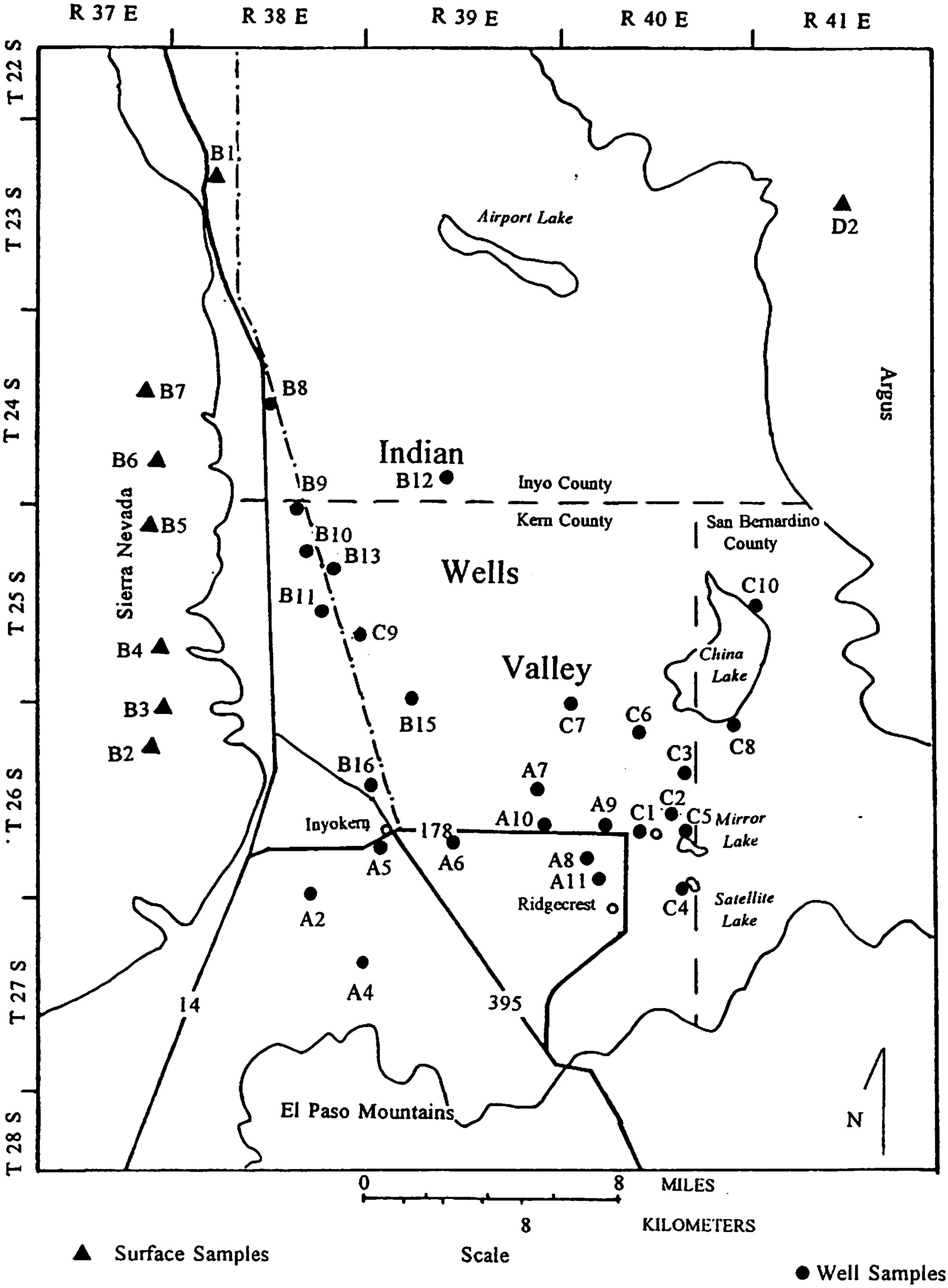


Figure 10. Location of Ground Water and Surface Samples within the Indian Wells Valley.

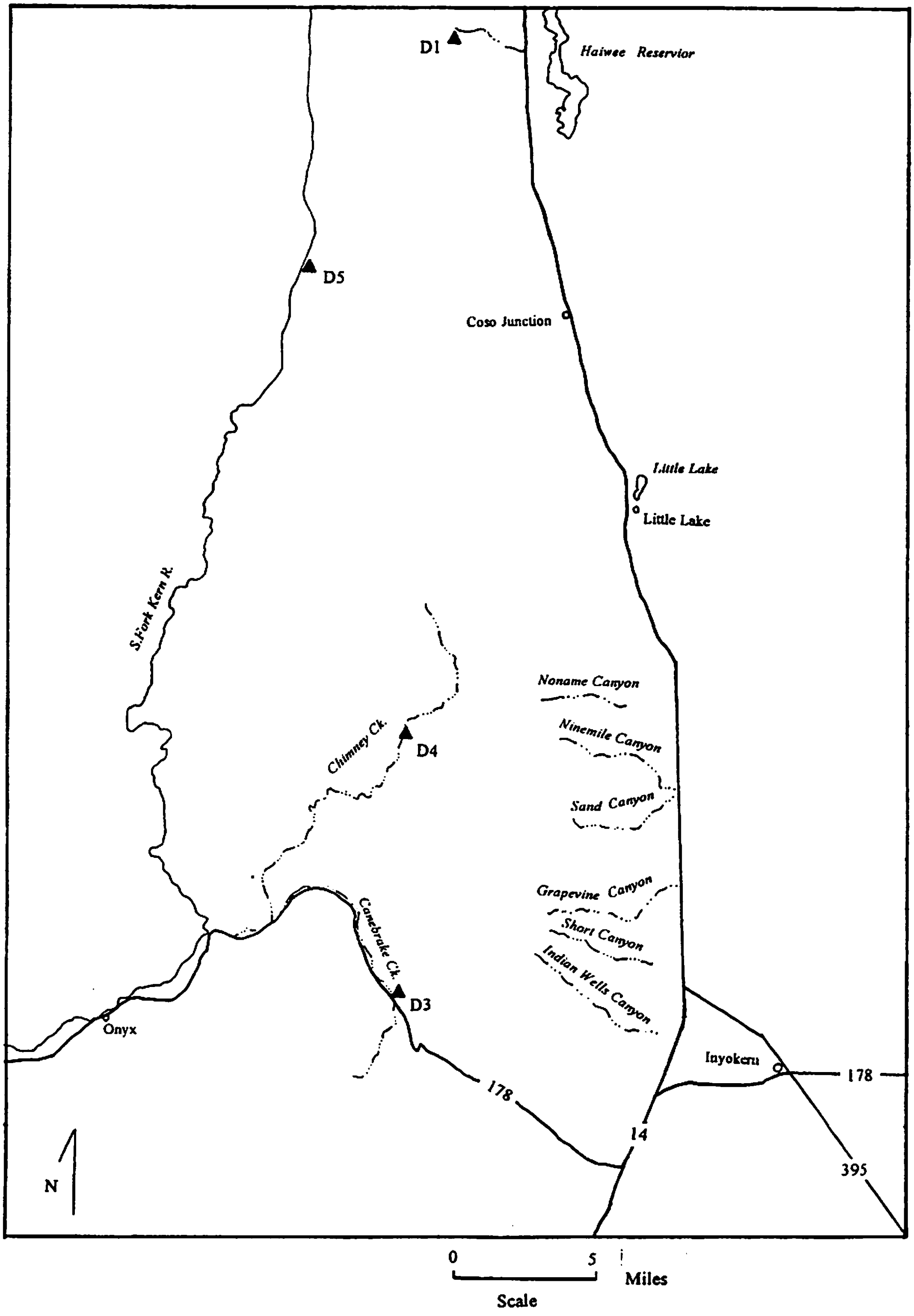


Figure 11. Location of Water Samples outside of the Indian Wells Valley.

Some wells were privately owned and the owner's permission has been obtained before including information on data from their wells in this project.

Surface samples were taken of many of the ephemeral streams that drain into the valley from the Sierra Nevada. Because isotopic analysis may be affected by altitude, care was taken to sample each stream at approximately the same elevation. Other surface samples were taken from outside the valley at locations northwest, southwest and west of the valley for comparison.

Before samples were collected from non-pumping wells, the wells were purged until the conductivity of the ground water stabilized. Wells were sampled by means of a Teflon® bailer. The bailer was triple rinsed with deionized water before being lowered into a well. Pumping wells were sampled at the well head.

Samples that were to be analyzed for cations (sodium, potassium, calcium and magnesium) were collected in 16 ounce high density polyethylene (HDPE) bottles containing nitric acid as a preservative. Nitrate samples were collecting in 16 ounce HDPE bottles containing sulfuric acid as a preservative. All other analysis methods required no preservation, therefore samples were collected in 16 ounce HDPE bottles for the rest of the dissolved constituents to be analyzed and in 40 milliliter (ml) volatile organic analysis (VOA) bottles for isotopic analysis. All samples were collected such that no head space existed in the sample container. Isotopic sample containers were sealed with Teflon® tape. All samples were labeled and listed on a Chain-of-Custody form before shipment to the laboratory.

After collection, samples were placed in an ice chest with blue ice and kept at a temperature of approximately four degrees Centigrade. Samples were shipped to the laboratory within three days of collection. Samples were stored in a refrigerator at four degrees Centigrade or less until they were shipped. All samples were filtered by the laboratory before beginning analysis.

FIELD ANALYSIS

Samples were measured in the field for temperature, conductivity and pH with a Hydac® meter, provided by Naval Air Weapons Station, Environmental Division. The meter was calibrated each day before sampling. Temperature measurements on the meter were calibrated by comparing with another thermometer. The pH was calibrated by using standard solutions with a pH of 4, 7 and 10, respectively. The conductivity of the meter was calibrated at the factory. Alkalinity was determined in the field by titrating with sulfuric acid.

LAB ANALYSIS

Samples were analyzed by Diversified Laboratories in Inglewood, California using the following methods:

- EPA Method 120.1 for Specific Conductance.
- EPA Method 150.1 for pH.
- EPA Method 160.1 for Total Dissolved Solids (TDS).
- EPA Method 200.7 for Boron, Calcium, Iron, Magnesium, Potassium, Silica and Sodium.
- EPA Method 300.0 for Chloride, Nitrate, Phosphate and Sulfate.
- EPA Method 310.1 for Total Alkalinity and Bicarbonate.

•EPA Method 340.2 for Fluoride.

•The Calculation Method was used to determine Sodium Adsorption Ratios and Total Hardness.

•Twenty samples (eight well samples, twelve surface samples) were analyzed for isotopes $\delta^{18}O$ and δD using a Gas Chromatograph and Mass Spectrometer (GC/MS).

Laboratory analysis results were checked for errors. The analysis results were given by the laboratory in units of milligrams per liter (mg/l). All analysis results for dissolved ions were converted to meq/l. The number of cations and anions from each sample were added together in order to obtain the Total Dissolved Ions (TDI) for the sample. A reaction error calculation (Mazor, 1991) was performed to determine the valence charge imbalance for each sample using the following equation:

$$100 \times (\text{cations} - \text{anions})/(\text{cations} + \text{anions})$$

If the charge imbalance was greater than ±11 percent then the laboratory analysis results for that sample were thrown out of the data evaluation process that involved dissolved ions. Samples A4, C7 and C9 (Figure 10) had charge imbalances greater than the 11 percent cutoff, however, C7 and C9 were used for the study because of unique physical characteristics observed in the field and A4 was used only in the isotopic evaluation.

DATA EVALUATION METHODS

Collected data was evaluated by graphical means which included fingerprint diagrams and compositional diagrams (Mazor, 1991) using the chemical parameters obtained by the laboratory. Saturation indices calculated by MINTEQA (Brown and Allison, 1987) were also used to evaluate the data. The diagrams and saturation indices were used to identify trends or similarities in the data.

Originally, all data collected in the valley was compiled together under the assumption that all ground water in the valley had similar sources and evolution. From the compiled data it was possible to deduce similarities and differences in ground water types. Ground waters were separated into three groups based on the similarities and differences. A fourth group was also included in the analysis. This group was composed of surface water samples that were collected from outside the area of study for comparison purposes.

Fingerprint Diagrams

Fingerprint diagrams, as developed by Mazor (1991), were used to see relationships between samples based on the cation-anion ratios by using pattern recognition. The diagrams were constructed using the major cations and anions versus the log of their concentrations.

A fingerprint diagram has an X axis on which the major ions are shown and a Y axis which has the ionic concentration in meq/l. The cations are placed on the left side of the diagram closest to the Y axis and it is preferable to list them with the cation of lowest concentration closest to the Y axis (the cation with the second lowest concentration is placed to the right of the cation with the lowest concentration and so on). The anions are placed on the right side of the diagram on the X axis with the anion of the lowest concentration farthest from the Y axis (the anion with the second lowest concentration is placed to the left of the anion with the lowest concentration and so on). The placement of the ion species label is determined by the data set. This method of positioning the ion labels makes the diagram easier to interpret. The Y axis has a logarithmic scale rather than a linear scale. A logarithmic scale allows the plotting of data of low TDI with data that has high TDI. By combining data in this manner it is possible to see evolutionary changes in water type as the water reacts with the aquifer sediments or mixes with other water types thereby allowing families of ground water to be seen if they exist.

Several samples are plotted on each diagram. The pattern that each sample forms is it's fingerprint. If two or more of the samples have a similar pattern or fingerprint then those samples probably have the same genesis or source. The water from these samples has reacted with similar sediments along the ground water flow path and the samples were probably collected from an aquifer that is hydraulically interconnected (Mazor, 1991). Fingerprint patterns that have a fan shape suggests mixing of two different water types in the same aquifer (Mazor, 1991). Dissimilar fingerprints indicate that the samples were collected from aquifers that are not hydraulically connected, that there may be several sources or that the ground waters are reacting with different lithologies that may be included in the aquifer sediments indicating differences in the flow path for those samples (Mazor, 1991).

Fingerprint diagrams are more specific than Piper diagrams (Piper, 1944). Piper diagrams plot data based on cation-anion ratios, but neglect concentrations. Fingerprint diagrams are also preferred to Stiff diagrams (Stiff, 1951) which also use a pattern recognition to define water types but each diagram only shows one sample, the data is plotted on a linear scale so the pattern is affected by concentration, and units of mg/l are used which do not take into account ionic charge.

Compositional Diagrams

Compositional diagrams or X-Y diagrams allow the examination of major patterns that may be indicated by similarities or differences between data points. Clusters, linear relationships, triangular patterns and even random distribution patterns may yield information useful for interpreting the data set. Clusters of data may indicate that samples, in this case ground water samples, are being influenced by one source. Data that plots in a straight line can indicate mixing of two or more different sources or water types. Linear patterns may also indicate evolutionary changes as ground water reacts with the aquifer sediments as it moves along the flow path. Triangular distribution of data can indicate mixing of three water types. Random patterns can indicate that data is unrelated, that there are several sources or that the analytical quality is poor (Mazor, 1991).

For this study the milliequivalent values for sodium, calcium, magnesium, bicarbonate and sulfate were plotted versus chloride and TDI. Chloride is normally a conservative parameter that is not affected by reaction with rocks or sediments. TDI is a parameter that is the total of all constituents present. TDI is not conservative but can be used to indicate relationships between samples.

Isotopic sample analysis results were shown on a compositional diagram by plotting δD per mil (o/oo) Standard Mean Ocean Water (SMOW) versus $\delta^{18}O$ o/oo SMOW. Samples with increasing values for both δD and $\delta^{18}O$ with respect to a calculated meteoric water line indicate evaporation has affected the water (the evaporated samples will plot diagonally upward and to the right of the meteoric water line). Samples elevated with respect to $\delta^{18}O$, but not with respect to δD (to the right of the meteoric water line) indicate hydrothermal alteration.

Saturation Indices

Saturation indices were used to determine if the ground water was in equilibrium with some of the minerals that may be present in the valley sediments. To calculate the saturation index MINTEQA (Brown and Allison, 1987) uses to following equation:

$$SI = \log (IAP/K_{sp})$$

where:
SI = Saturation Index
IAP = Ionic Activity Product
K_{sp} = Solubility Product Constant

A saturation index equal to one indicates equilibrium, greater than one indicates super-saturation and less than one indicates under-saturation.

RESULTS OF LABORATORY ANALYSIS

Ground waters collected for this thesis have been labeled A, B and C based on aqueous chemistry, geographic location and proposed recharge source. A fourth group of waters labeled D were collected from outside the study area for comparison purposes. Table A-1 (Appendix A) summarizes the isotopic analysis. Table A-2 (Appendix A) summarizes the dissolved ion and field analysis results. Graphical evidence supporting the classification into groups A, B and C is included in the section on Data Interpretation.

Dissolved ion laboratory analysis results have shown that the unconfined aquifer can be separated into at least three primary ground water groups with differing chemistries. Group A ground waters are located in the south and southwest portion of the valley. Group B ground waters are located in the west-central and north-western portion of the valley. Group C ground waters are found at shallow depths near the playas and in the center of the valley. The location of these groups are shown on Figure 12. Results of field and laboratory analysis are detailed below.

ISOTOPE HYDROCHEMISTRY

The δD values for group A ground water samples range from -89.0 to -97.0 o/oo Standard Mean Ocean Water (SMOW) and $\delta^{18}O$ values range from -11.9 to -12.5 o/oo SMOW. δD values for group B surface water samples range from -82.0 to -91.0 o/oo SMOW and $\delta^{18}O$ values range from -10.1 to -11.7 o/oo SMOW. Ground water samples collected from group B have δD values of -90.0 and -96.0 o/oo SMOW and $\delta^{18}O$ values of -11.7 and -12.0 o/oo SMOW. Ground water samples from group C have δD values of -98.0 and -96.0 o/oo SMOW and $\delta^{18}O$ values of -12.3 and -12.5 o/oo SMOW (Table A-1, Appendix A). Isotopic sample results have been plotted on a X-Y diagram with $\delta^{18}O$ on the X axis and δD on the Y axis as shown on Figure 13. The meteoric water line was calculated using an equation developed for the continental northern hemisphere (Dansgaard, 1964).

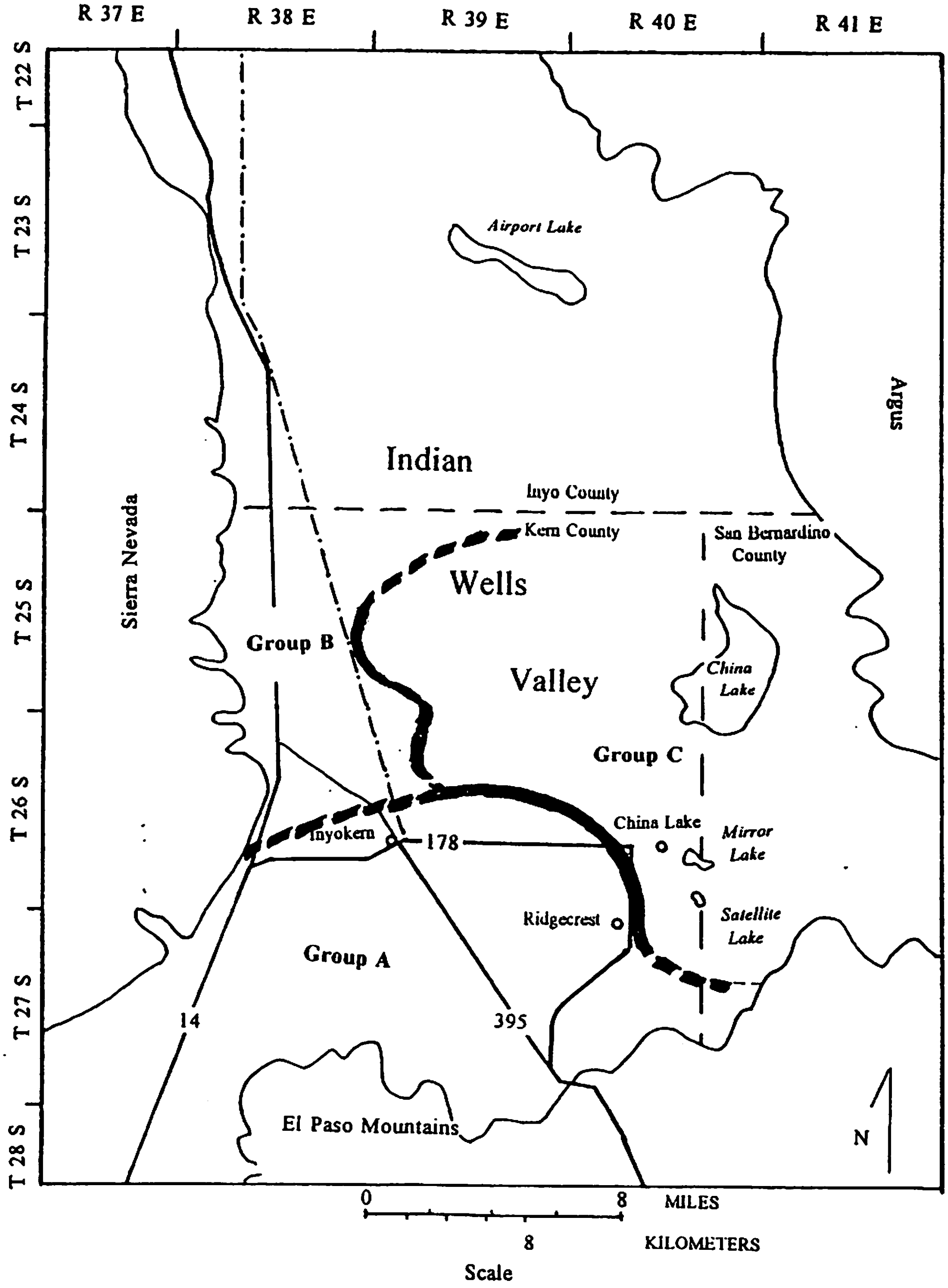


Figure 12. Location of Ground Water Groups A, B and C.

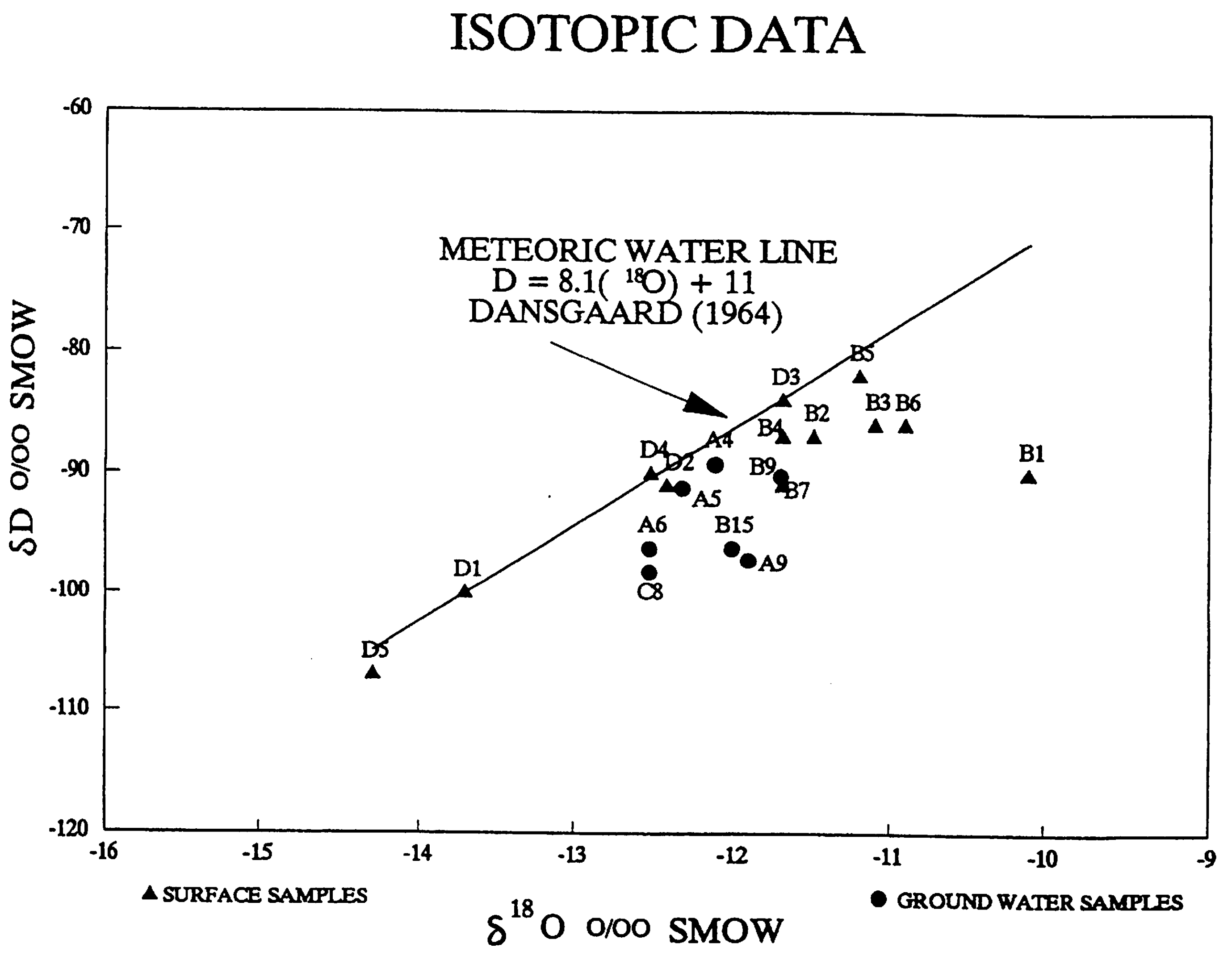


Figure 13. Isotopic Analysis.

Most of the ground water samples have similar values to each other with respect to $\delta^{18}O$ but varied values with respect to δD. Ground water samples are generally lighter with respect to $\delta^{18}O$ and δD than the surface water samples collected from streams flowing into the valley. Many of the ground water samples are also lighter with respect to δD than some of the group D samples (Figure 13).

From the southwest towards the playa δD values for group A ground water decrease becoming isotopically lighter with respect to δD. Group C ground water samples have the lowest δD values of all samples collected within the valley. The surface water samples collected from streams draining into the valley generally have the highest δD and $\delta^{18}O$ values of all samples collected. The Little Lake sample has a higher value with respect to $\delta^{18}O$ than any of the other samples collected.

DISSOLVED ION HYDROCHEMISTRY

GROUP A - SOUTHWEST

Group A ground waters are predominately located south of Inyokern in the south and southwestern portion of the valley (Figure 12). Typically ground water samples collected in this area have TDS values less than 400 mg/l (TDI less than 9.09 meq/l). These samples have field pH values that range from 7.5 to 10.3, field alkalinities as $CaCO_3$ ranging from 22 mg/l (0.04 meq/l) to 125 mg/l (2.5 meq/l) and temperatures ranging from 20.3°C (68.5°F) to 28.9°C (84.0°F).

Most of the samples in this group are sodium bicarbonate ground waters. One exception is sample A2 which has chloride ions dominant making this sample a sodium chloride ground water. However, the difference in value between the chloride and bicarbonate ions in the sample are minor when compared to the other ground waters in this group.

GROUP B - CENTRAL-WEST AND NORTHWEST

Little Lake

Surface water that originates from Little Lake located in the northern portion of the valley, flows south and then disappears underground. It is possible that some subsurface flow may be entering the valley at this point (Kunkel and Chase, 1969).

Little Lake water (sample number B1) is a sodium bicarbonate water with a TDS of 1240 mg/l (TDI of 43.33 meq/l). TDS for Little Lake is somewhat higher than all of the other surface water samples collected of water entering the valley. The Little Lake sample has a pH of 8.3, an alkalinity as $CaCO_3$ obtained from the lab of 615 mg/l (12.3 meq/l) and a field temperature of 16.7°C (62.0° F).

Sierran Streams

The Sierran streams (sample numbers B2 through B7) that drain into the valley on the west typically have a calcium-bicarbonate composition (most samples have a calcium-sodium-bicarbonate composition). The exceptions are the samples from the stream in Noname Canyon (B6) which is a magnesium-calcium-bicarbonate-sulfate water and the Nine-mile Canyon stream (B7) which is a calcium-magnesium-bicarbonate water.

The samples from the Sierran streams have TDS values that range from 360 to 1060 mg/l (TDI ranging from 10.33 to 36.97 meq/l). The stream in Noname Canyon

(B6) has the highest TDS value and the stream in Short Canyon (B3) has the lowest TDS value. The Sierran streams have pH values that range from 8 to 8.4. Alkalinities as $CaCO_3$ as reported by the laboratory ranging from 156 mg/l (3.12 meq/l) to 559 mg/l (6.76 meq/l). Temperatures for the streams range from 15.0°C (59.0°F) to 18.3°C (65.0°F).

Ground water

Group B ground water extends from just south of Little Lake to north of Inyokern (Figure 12). Most of the ground water samples from this group are similar in composition to the waters in the Sierran streams. Ground water samples from this area are predominately sodium-bicarbonate ground waters. The exceptions are sample numbers B8 and B15, which are sodium-sulfate ground water and sample B16, which is a calcium-chloride ground water. TDS values range from 330 mg/l to 960 mg/l (TDI ranging from 10.0 to 34.93 meq/l), pH values range from 7.0 to 9.7, field alkalinities as $CaCO_3$ range from 130 mg/l (2.6 meq/l) to 430 mg/l (8.6 meq/l) and temperatures range from 19.4°C (67.0°F) to 25.6°C (78.0°F).

GROUP C - PLAYA

Group C ground water is located in the eastern portion of the valley where there are playa lakes and in the central portion of the valley (Figure 12). The aqueous chemistry of the group C ground water collected in the vicinity of the playa lakes is predominantly sodium-chloride or sodium-sulfate. These ground water samples have high TDS and salinity which is typical of playa waters. TDS values for group C ground water in this area range from 670 mg/l to 7,780 mg/l (TDI ranging from 19.4 meq/l to 242.91 meq/l), pH values range from 7.4 to 9.0, field alkalinity as $CaCO_3$ ranges from 85 mg/l (1.7 meq/l) to 790 mg/l (15.8 meq/l) and temperature values range from 21.1°C (70.0°F) to 24.3°C (75.8°F).

The ground water from the north-central portion of the valley where a thick clay layer is known to exist (Watt, et al 1992) has also been included in group C based on TDS of the ground water sampled there and the aqueous chemistry, which is predominantly sodium-chloride. Although these samples do not correlate well when TDS versus conductivity are plotted and the ionic charge imbalance is large, the samples have been used for this study because they are so unique compared to the other ground water samples collected. When sampled the ground water from this area had bright yellow color, was foamy and had a strong odor. These samples have extremely high TDS values of 24,300 mg/l (TDI of 613.70 meq/l) for sample C7 and 91,500 mg/l (1,179.48 meq/l) for sample C9. Alkalinity titrations performed in the field on the C9 sample could not be completed; several milliliters of 0.5 molar sulfuric acid were titrated into the sample without any change in pH. pH values are 9.7 for sample C7 and 9.6 for sample C9, the field alkalinity as $CaCO_3$ for C7 is 9,800 mg/l (196.0 meq/l) and temperature values are 22.2°C (72.0°F) for C7 and 22.7 °C (73.0°F) for C9.

GROUP D WATER - OUTSIDE OF VALLEY

Surface water was collected from outside the study area in order to obtain data on dissolved ions and isotopes of water from outside the valley (Figure 11). This data was used to determine if there was a correlation between water from outside the valley and ground water in the valley in hopes of shedding some light on the concept of ground water recharge from outside the valley.

The hydrogeochemistry of the group D water is typically calcium-bicarbonate with one exception, the sample collected from the Kern River at Kennedy Meadows campground. This sample is a sodium-bicarbonate water. Isotopic analysis results indicate that most of the waters collected outside the valley are close to meteoric water (Figure 13). These waters have TDS values that range from 110 to 440 mg/l (TDI from 2.31 to 13.7 meq/l), pH values that range from 7.0 to 8.1, alkalinities as $CaCO_3$ obtained by the laboratory ranging from 42 mg/l (0.84 meq/l) to 252 mg/l (5.04 meq/l) and temperatures ranging from 8.3°C (47.0°F) to 17.8°C (64.0°F).

INTERPRETATION OF DATA

By graphing data collected for this thesis using the fingerprint and compositional diagrams, separate ground water groups emerged. Patterns in each group indicate that ground water in the Indian Wells Valley can be divided geographically. Hydrochemical data, diagrams and flow data suggest that some of the groups have different sources, flow paths and evolution than previous models have shown. To describe the differences in ground waters in the valley the samples have been divided into the geographic groups.

GROUP A

The fingerprint diagram shown on Figure 14 is composed of group A samples with similar patterns.[3] This similarity in patterns suggests that samples collected in the group A area are from a hydraulically connected aquifer, that they may have one source and that the ground water from these samples are reacting with similar sediments. Although the fingerprints constructed for group A ground waters show similar compositions between samples they do not show any trends (such as changes in TDI) that suggest a flow path direction.

Figure 15 is composed of compositional diagrams where major ions are plotted versus chloride. These diagrams show a clustering of the group A samples. This clustering is indicative of ground water that has the same origin or source and similar sediment reaction history. Figure 16 shows compositional diagrams where the major ions are plotted versus TDI. These diagrams are not as definitive as the ion versus chloride diagrams (Figure 15). The compositional diagrams for group A like the fingerprints, did not show any trends that would suggest a direction of flow.

Saturation index calculations for the group A ground waters, which are shown on Table 7, suggest a flow path for ground water movement from the southwest towards the playas. These calculations show that group A ground water is coming into

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[3] Samples A2, A6 and A10 are not shown on the fingerprint diagram. These samples have low concentrations of some ions (magnesium and sulfate) that affect the appearance of the diagram. On a log scale the low concentrations are highly emphasized even though the differences in concentrations between the samples are less than 1.

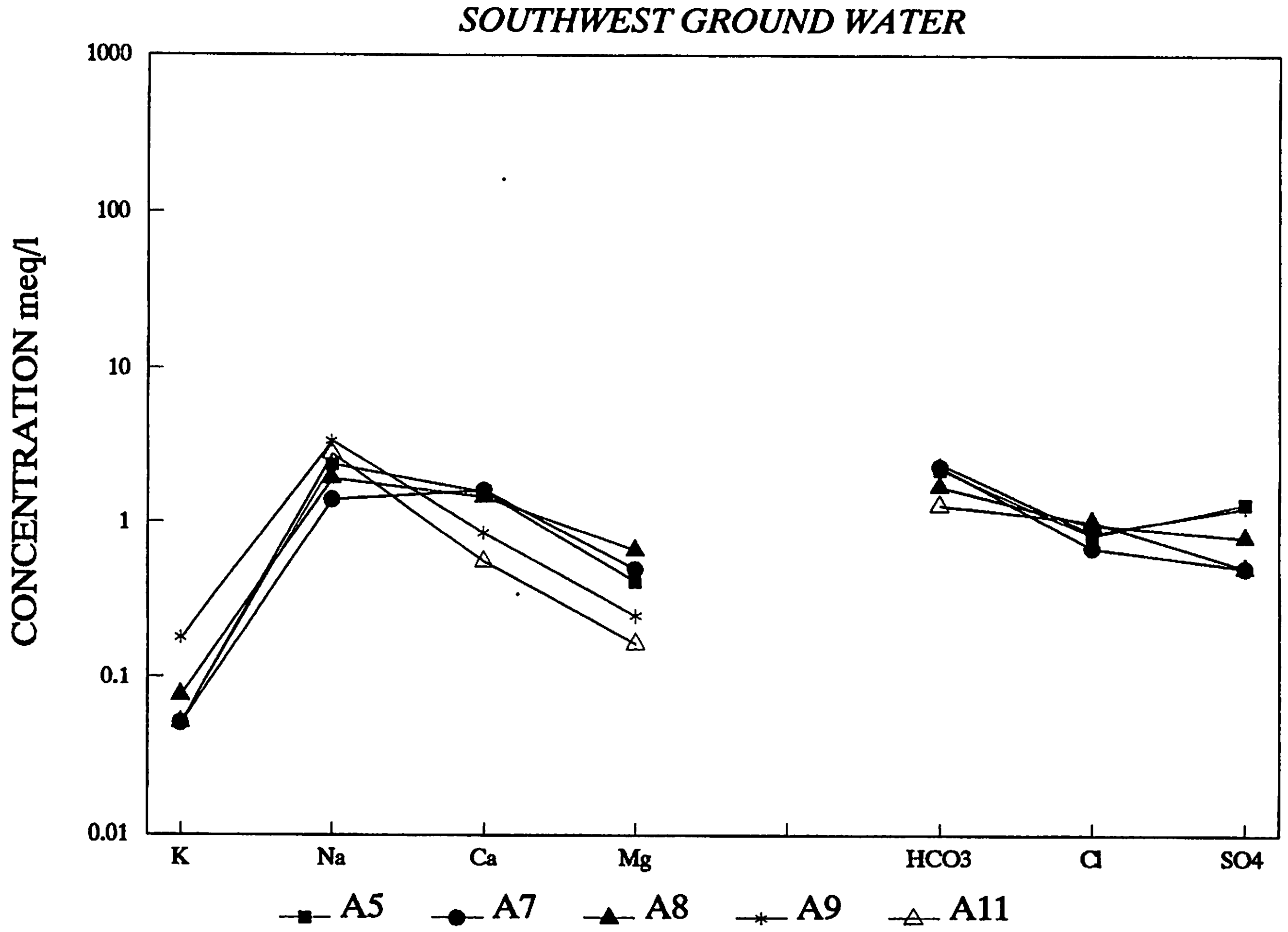


Figure 14. Fingerprint Diagram for Group A Samples.

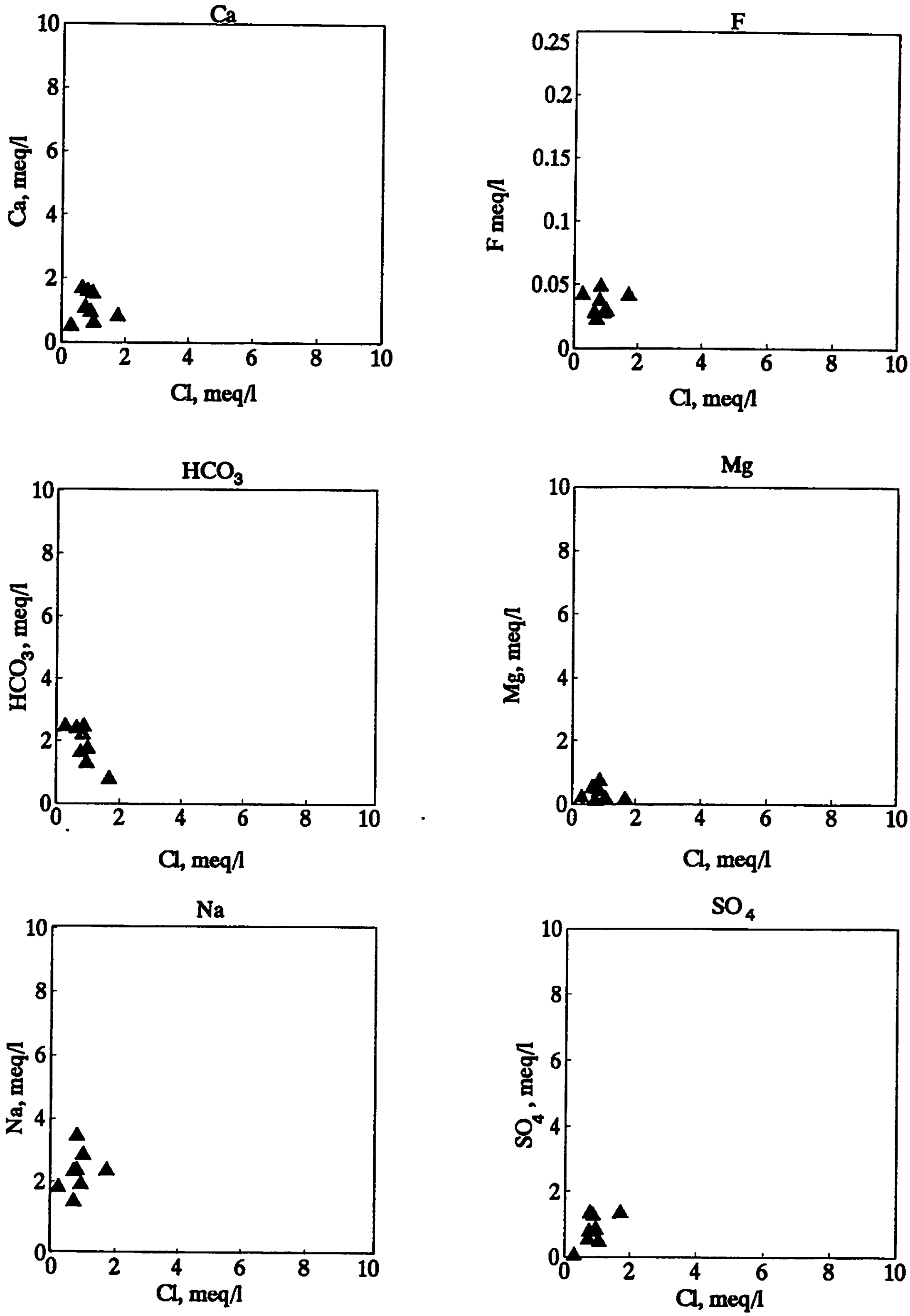


Figure 15. Compositional Diagrams for Group A Samples: Chloride vs Ions.

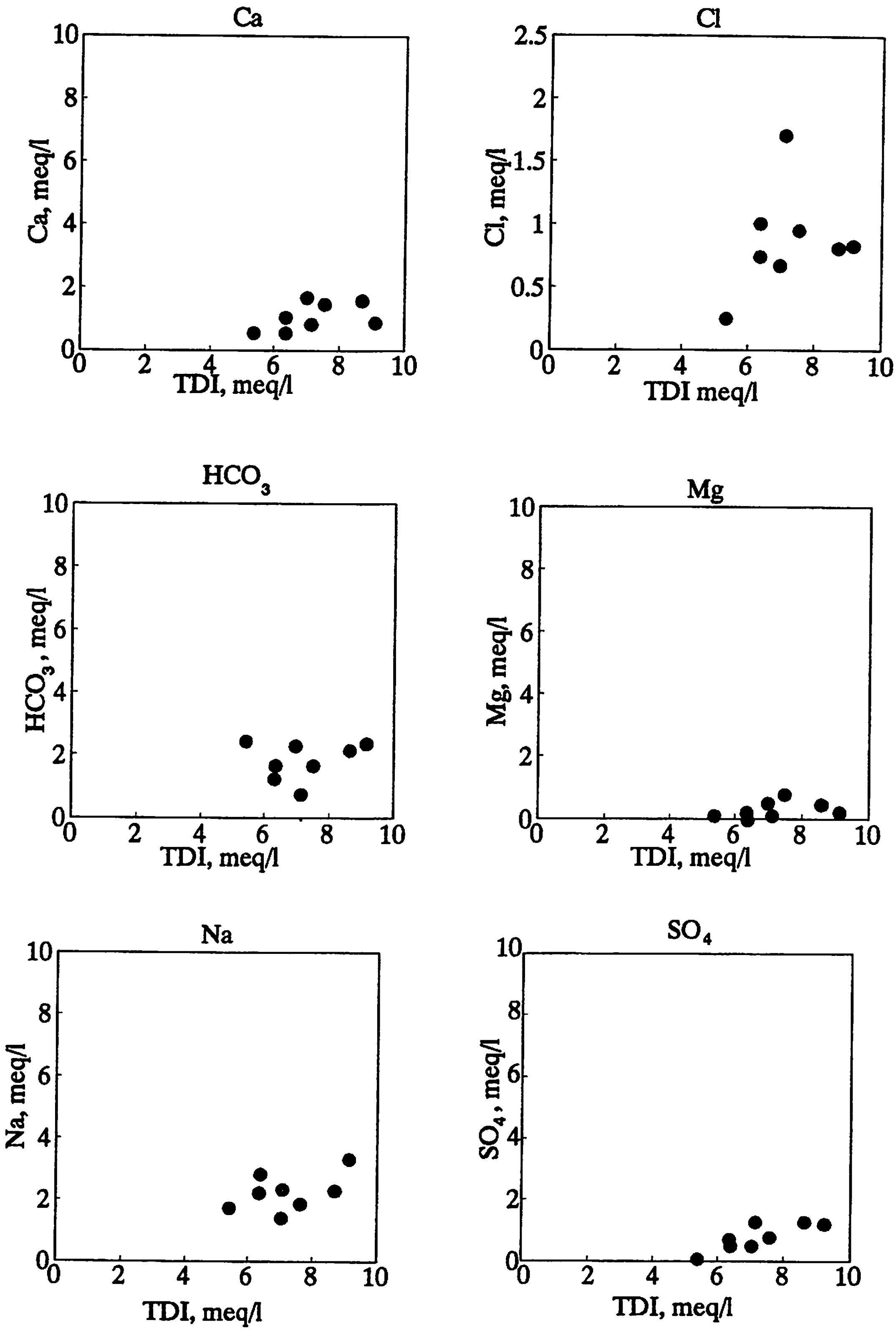


Figure 16. Compositional Diagrams for Group A Samples: TDI vs Ions

equilibrium with silica from west to east. The western most sample A2, is undersaturated with respect to silica. Samples become increasingly saturated with respect to silica toward the playa, approaching equilibrium. This trend indicates that ground water is flowing from the southwest to the east dissolving silica as it travels along the flow path.

TABLE 7. SATURATION INDICES FOR GROUP A.

SAMPLE NUMBER	SATURATION INDEX	
	QUARTZ	SiO_2 AMORPH.
A2	-1.372	-2.37
A5	0.720	-0.260
A10	0.931	-0.059
A9	0.977	-0.016

Samples are listed in geographical order from west to east.

Other evidence of ground water flow from the southwest to the playa are the ground water elevation contour maps (Figures 5 and 6). If flow lines are drawn perpendicular to the ground water contours they show that ground water in the southwest is moving toward the playa. Prior to the cone of depression created by the pumping of the domestic wells ground water would have flowed toward the playa or toward the area of lowest hydraulic head (analogous to water flowing downhill).

The Sierran streams located in the group B area are not likely sources for the group A ground waters. Figure 17 shows that the Sierran streams have overall higher

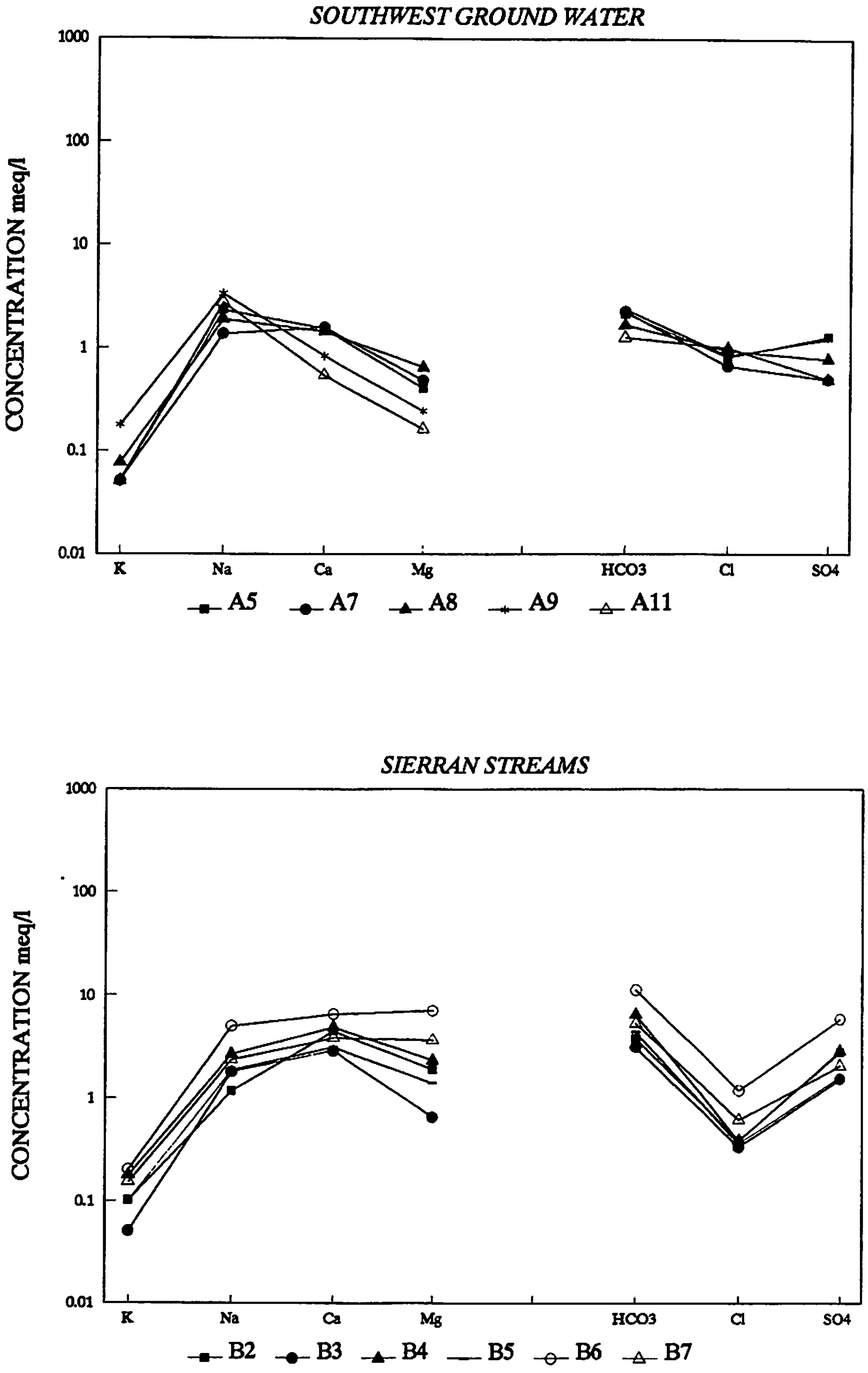


Figure 17. Fingerprint Diagrams: Group A Samples and Sierran Stream Samples.

TDI values and dissimilar fingerprint patterns than group A ground waters. Figure 18 shows similarities between group D and group A fingerprint patterns. These similarities suggest that the source for the group A ground waters may be similar to group D water in composition.

Isotopically the group A samples (A4 and A5) that are closest to the proposed southwest source plot close to the calculated meteoric water line (Figure 13). Samples taken farther east in the valley (A6 and A9) plot farther from the meteoric water line. Samples A6 and A9 are lighter than A4 and A5 with respect to δD but have similar values with respect to $\delta^{18}O$. Isotopic values can be affected by many factors including evaporation, temperature, interaction of ground water with sediments and amount of rain or snowfall (Mazor, 1991). Isotopic values for samples A6 and A9 may be the result of evaporation of a surface water that is isotopically similar to sample D1 prior to infiltration or they may have originated from surface waters that occurred during a higher or lower period of rainfall than samples A4 and A5. Additional isotopic analysis of samples which includes analysis of δD, $\delta^{18}O$, tritium and carbon-14 are needed to investigate the changes in isotopic values along the flow path of the group A ground waters. (Tritium and carbon-14 analysis are used to determine ages of ground water).

There is no correlation between pH, alkalinity and the geographic location of the group A samples. The highest temperature values were obtained in the Inyokern area. The higher temperatures may have been due to geothermal heating, however, the isotopic data did not indicate that any of the group A ground waters had been subjected to geothermal conditions. All other samples in group A did not show a correlation between temperature and geographic location.

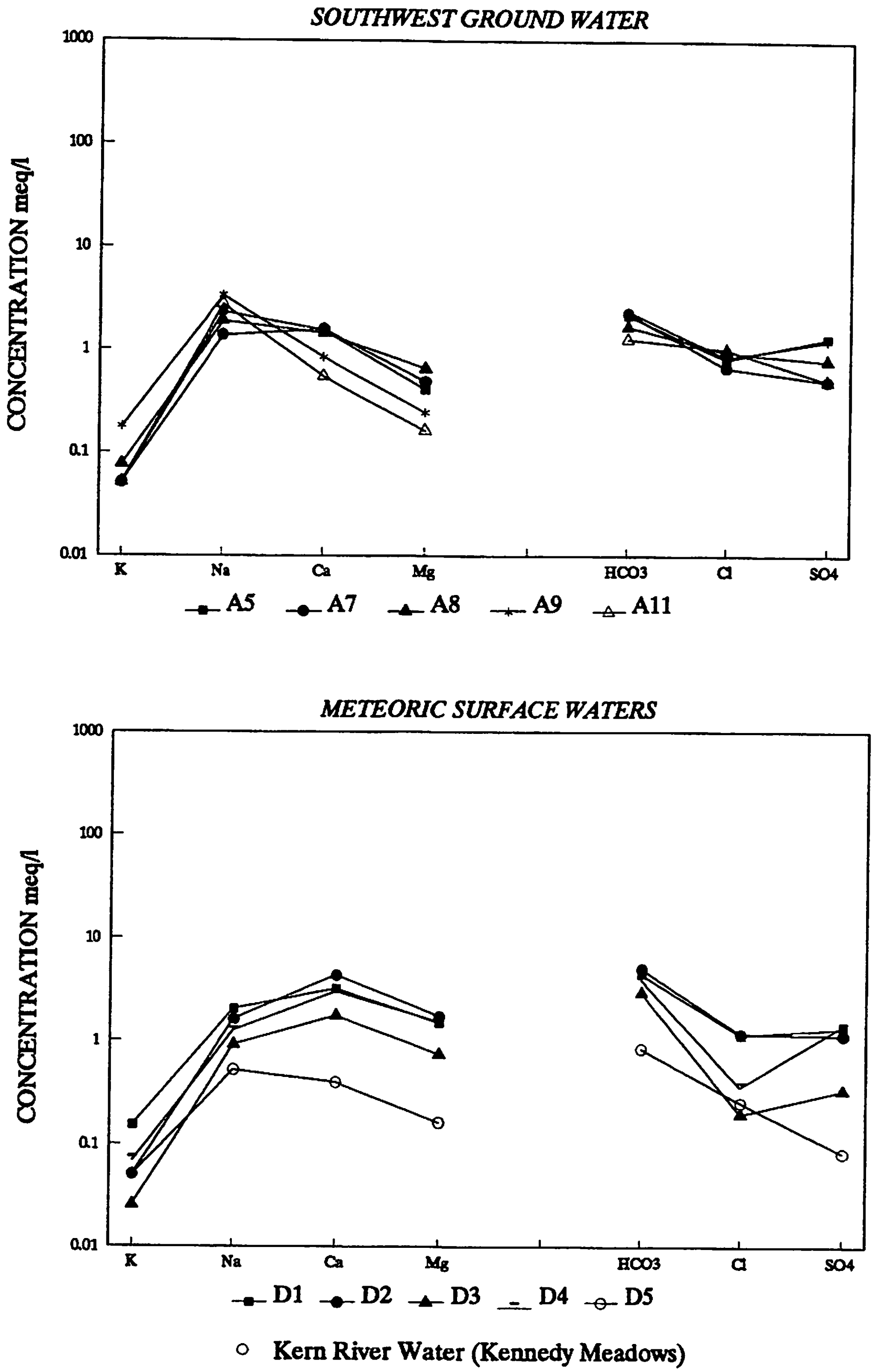


Figure 18. Fingerprint Diagrams: Group A Samples and Group D (Meteoric) Samples.

Interpretations of the fingerprint and compositional diagrams, saturation index calculations, flow data and isotopic analysis suggest that ground water found in the south and southwest portion of the Indian Wells Valley is probably from the same source and moves along a flow path from the southwest to the playas on the east. The source of the group A ground water is probably located southwest of the valley. Topographically the southwest portion of the valley consists of a large alluvial fan that has formed as a result of at least three drainages that are located southwest of the valley. Surface water similar in composition to the meteoric waters in group D probably enters the fan and moves rapidly through the alluvial material into the valley. This rapid movement does not give the ground water much time to react with the alluvial sediments so the ground water maintains a low TDI value and remains undersaturated with respect to silica. Once the ground water reaches the valley it flows at a slower rate due to a change in hydraulic gradient (topographic gradient is less in the valley than on the margins). Sediment permeability may also change affecting flow rate. The slower rate allows the ground water time to approach equilibrium with respect to silica as it moves towards the playa. However, ground water movement is still rapid enough that TDI remains stable along the flow path.

GROUP B

Fingerprint diagrams for group B waters are shown on Figures 19, 20 and 21. Figure 19 shows the Sierran streams (samples B2 through B7). Figure 20 shows some of the group B ground waters along with surface water from Little Lake (B1) and Short Canyon (sample B3, which was chosen as representative of all the Sierran streams

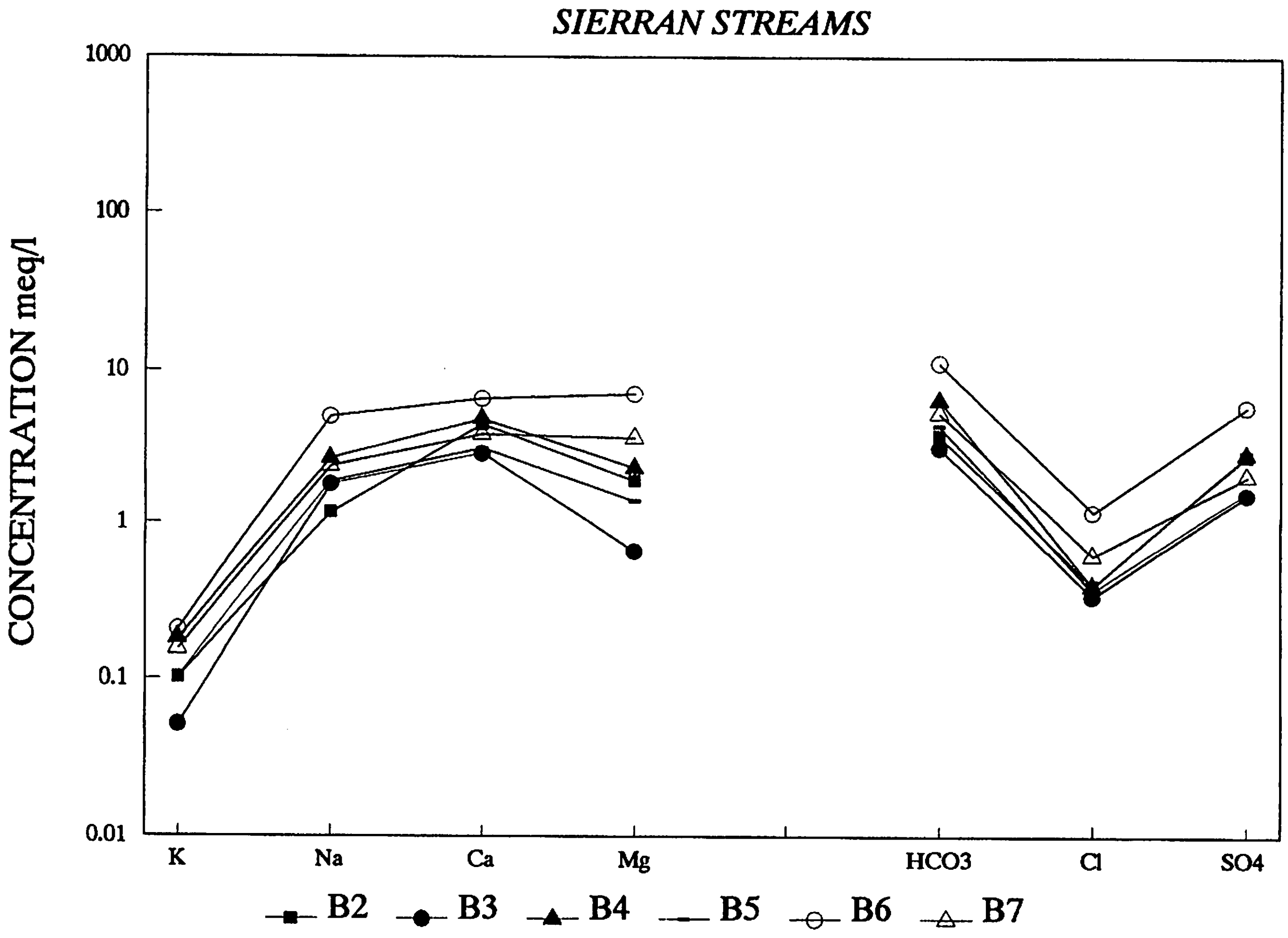


Figure 19. Fingerprint Diagram: Sierran Stream Samples.

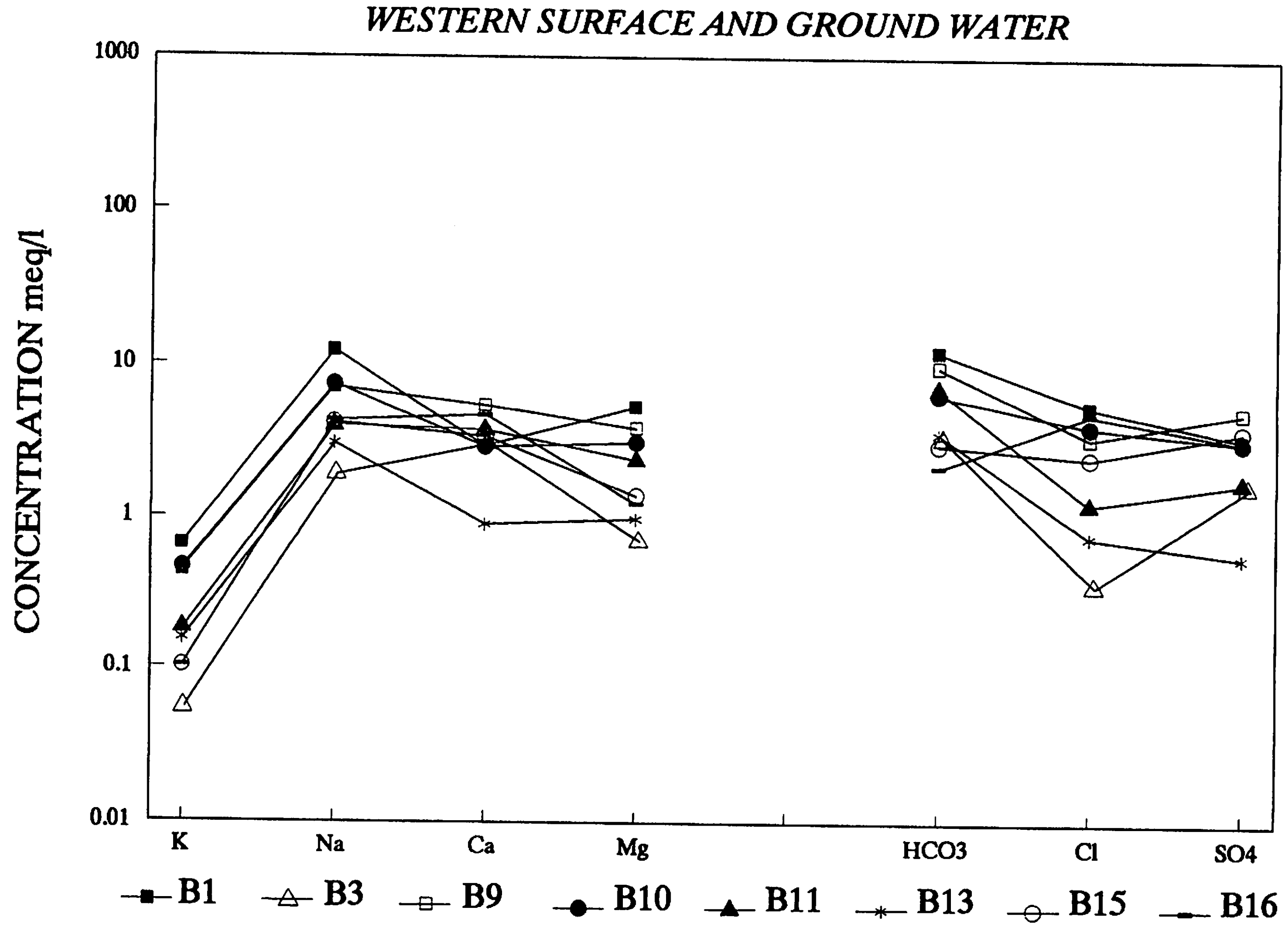


Figure 20. Fingerprint Diagram Group B Samples: B1 (Little Lake), B3 (Short Canyon) and Western Ground Waters.

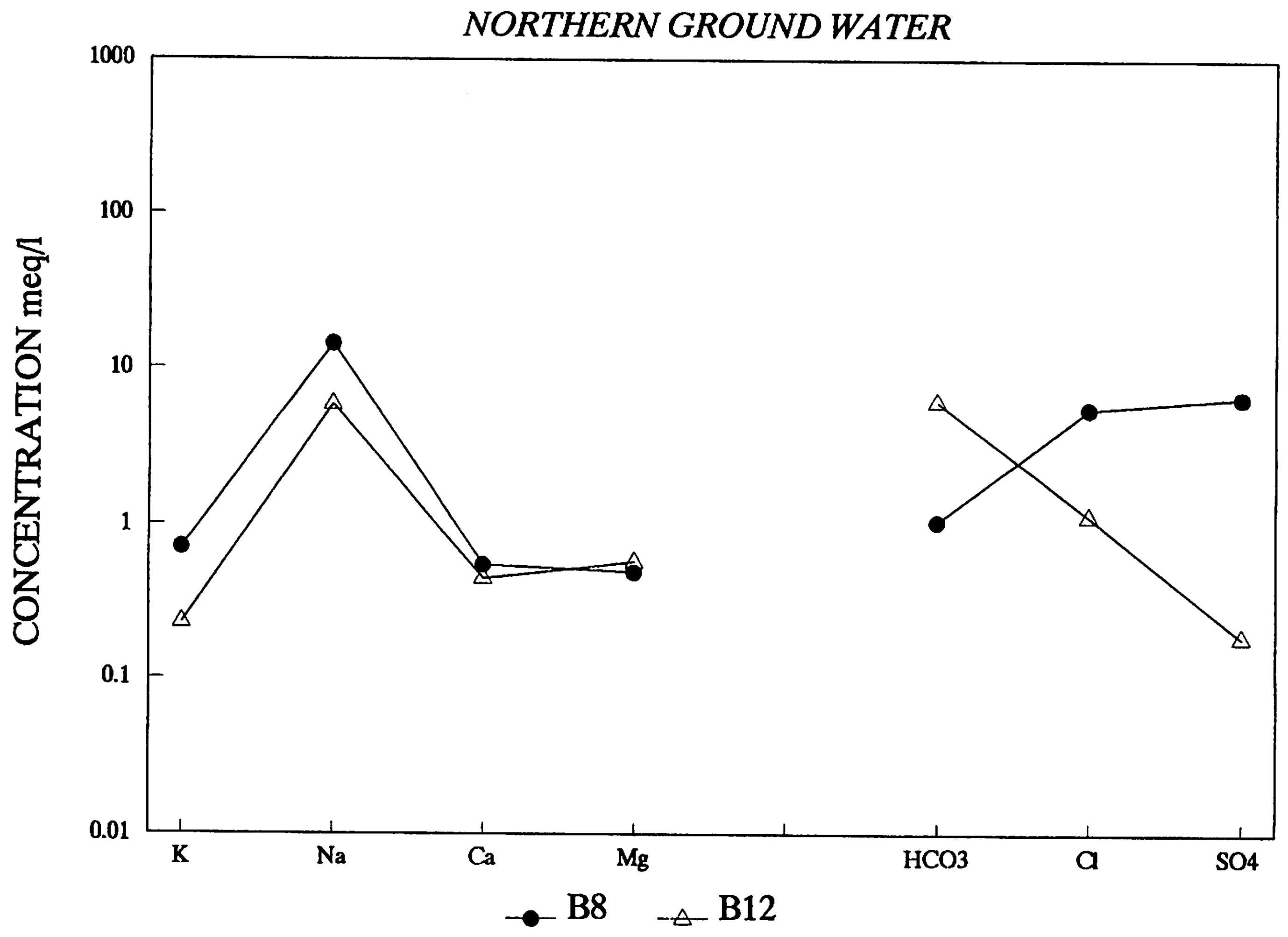


Figure 21. Fingerprint Diagram Group B Samples: Northern Ground Water Samples.

sampled). On the diagram the ground water samples (B9, B10, B11, B13, B15 and B16) fall between the Sierran stream sample and the Little Lake sample suggesting that the surface waters may be sources for the ground water samples. The position on the diagram of the Sierran streams and Little Lake samples indicate that they may be end members, meaning that Little Lake water which has the highest TDI is being diluted by (or mixed with) the Sierran stream waters, which have lower TDI, to yield the composition found in the ground water samples. Figure 22 showing compositional diagrams for dissolved ions versus chloride, and Figure 23 showing dissolved ions versus TDI, also indicate that many of the ground waters may be intermediate between the Sierran streams and Little Lake, again suggesting mixing. Many of these diagrams show random patterns which is indicative of more than one source. The ground waters have sodium cations dominant, while the Sierran streams and Little Lake have calcium and magnesium cations dominant. Cation exchange of calcium and magnesium for sodium has probably occurred as the ground water moved through the sediments.

The fingerprint pattern for sample B16 (Figure 20) shows a higher chloride content than the other ground water samples on the diagram. The higher chloride content may indicate that high TDI ground water from a clay layer that is located to the east may be influencing ground waters in the area where this sample was collected.

Samples B8 and B12 (Figure 21) show fingerprint patterns that are dissimilar to the patterns in Figures 20. Samples B8 and B12 also fall outside of the mixing boundaries on most of the compositional diagrams (Figures 22 and 23). Sample B8 is the northern most ground water sample retrieved in the valley for this study. It is the closest sample geographically to Little Lake (B1) but is not similar to the waters found

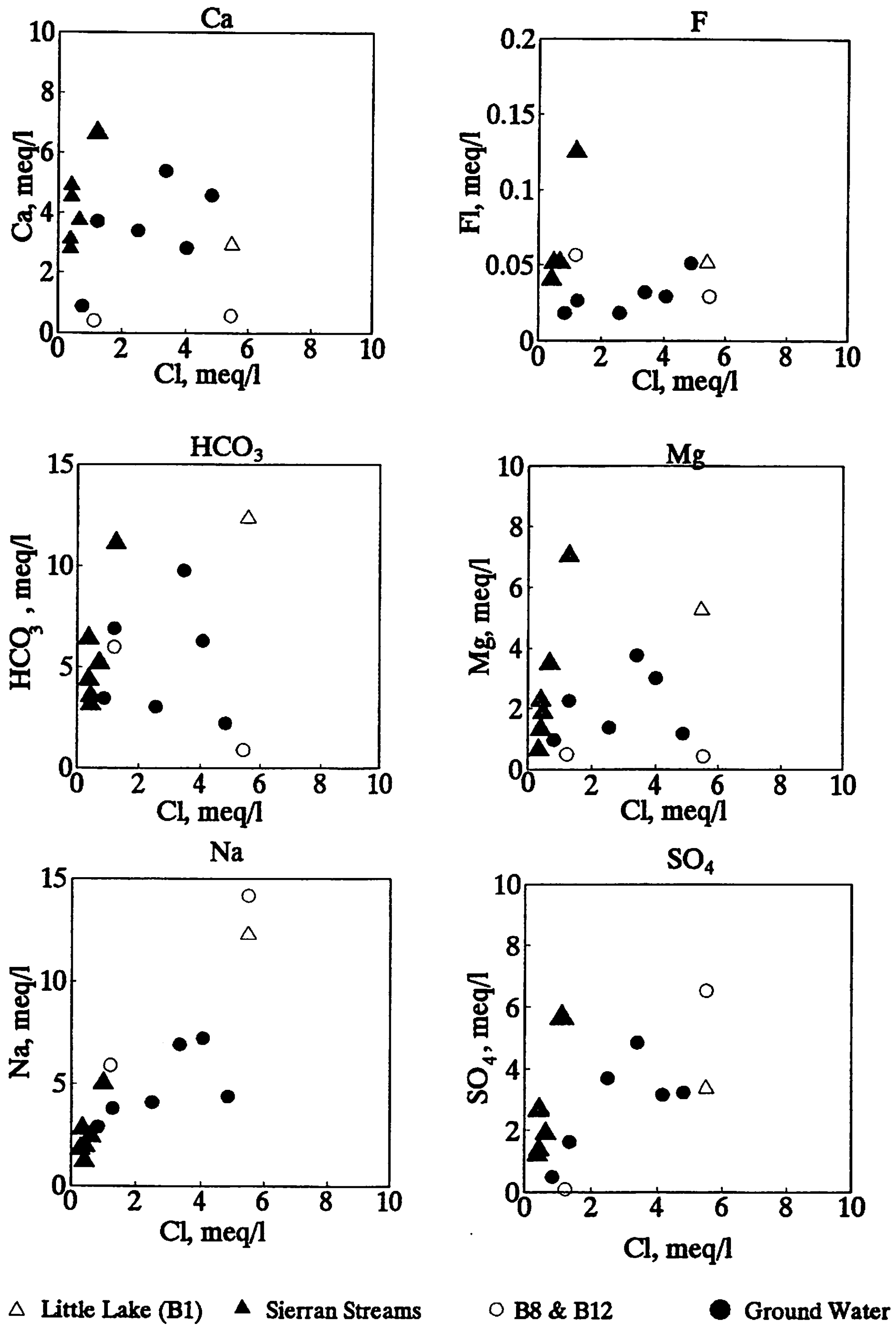


Figure 22. Compositional Diagrams for Group B Samples: Chloride vs Ions.

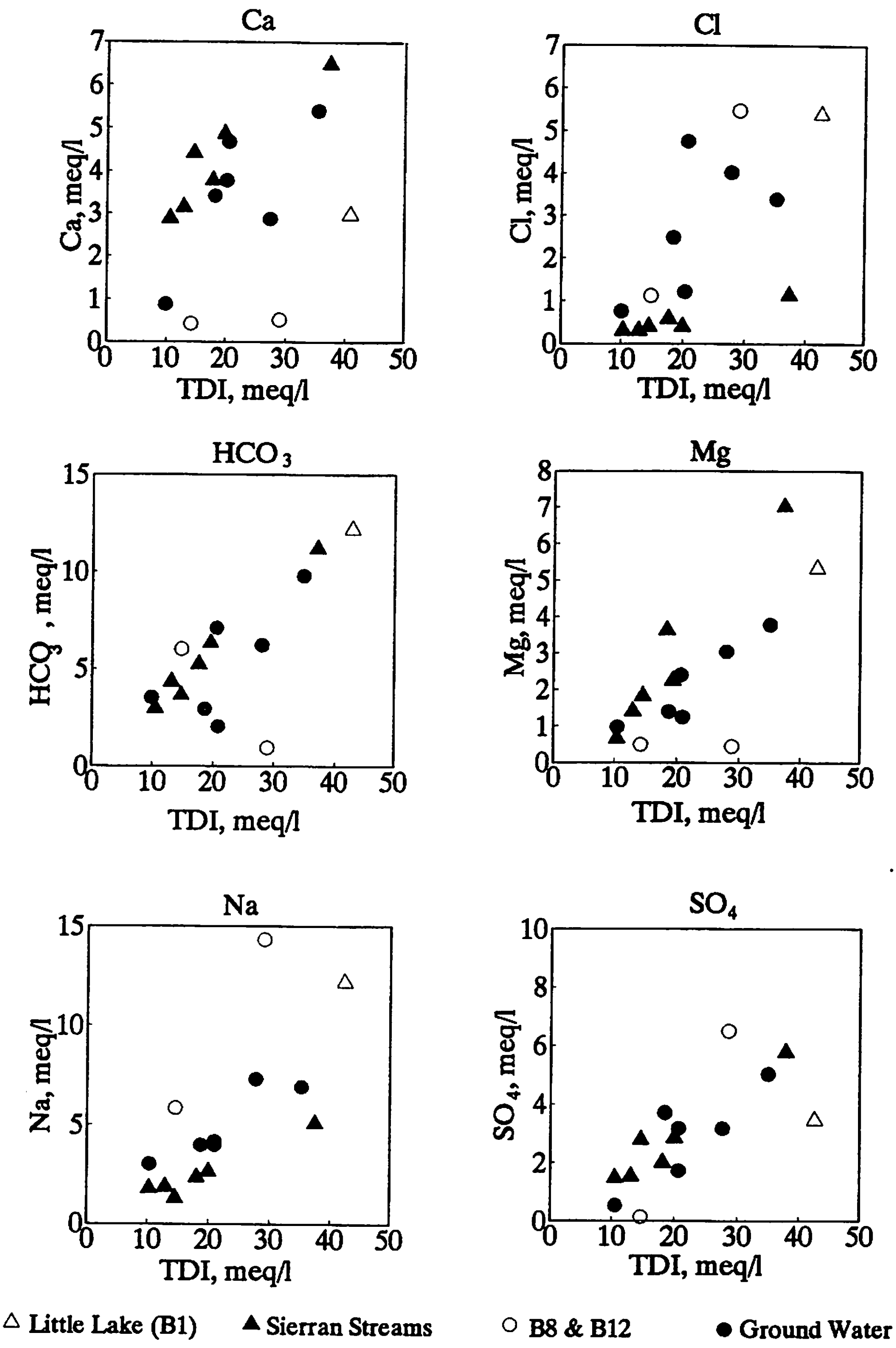


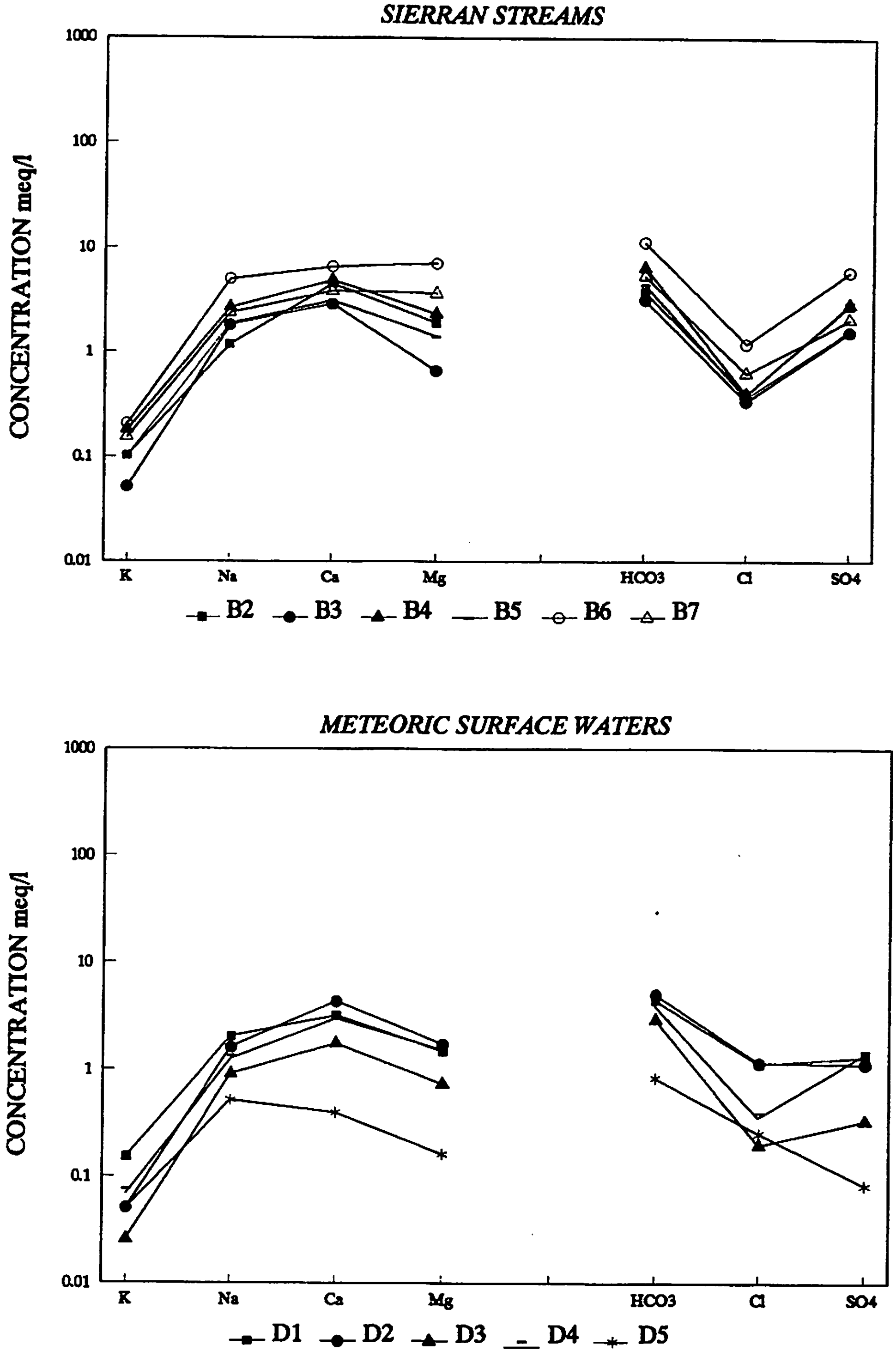
Figure 23. Compositional Diagrams for Group B Samples: TDI vs Ions.

in Little Lake or the Sierran streams (Figure 10). Sample B12 is the second northern most sample and is located in the north-central portion of the valley (Figure 10). Samples B8 and B12 have similar cation fingerprint plots, however, the anion plots are very dissimilar (Figure 21). These samples may be influenced by ground water coming from a source in the northern portion of the valley, possibly from the Coso Range, an area that was not sampled for this report. The different patterns shown for these two samples may also indicate these ground waters are not hydraulically connected to the other ground waters sampled in group B.

None of the fingerprint patterns of the group B (Figure 20) ground waters are similar to the fingerprint patterns of ground waters collected from group A (Figure 14). This suggests that group B and group A ground waters are not hydraulically connected.

Figure 24 shows that the fingerprint diagrams for the Sierran streams have some correlation with the fingerprint patterns for group D, but the Sierran streams have a higher concentration of dissolved ions. The higher TDI values may indicate that the stream waters have been physically and chemically altered from an original meteoric composition. The Sierran stream waters may have undergone evaporation and may also have reacted with organic materials and decomposing minerals found in the soils or leaf litter in the water. Evaporation and reactions with organic material and minerals could cause an increase in TDI of the surface water prior to infiltration into the ground.

The isotopic analysis of the Sierran stream samples (B3 through B7) suggest that the streams have been affected by evaporation (Figure 13). The rain or snow that the stream water originated from was probably close to the calculated meteoric water line.



* Kern River Water (Kennedy Meadows)

Figure 24. Fingerprint Diagrams: Sierran Stream Samples and Group D (Meteoric) Samples.

Evaporation would have caused the water to become isotopically heavier with respect to oxygen-18 and deuterium (Mazor, 1991). Isotopic analysis of the Little Lake water indicates it has been affected by geothermal conditions. When water in contact with geologic materials is heated, oxygen exchange of lighter oxygen in the ground water for heavier oxygen in the geologic materials is accelerated causing the waters to become much heavier with respect to oxygen-18 (Fetter, 1988). Deuterium in geologic materials is minimal therefore δD values in ground water remain stable.

Two group B ground water samples were analyzed for isotopes (B9 and B15). B9 is similar isotopically to the Sierran streams and B15 is similar to the group A and group C ground waters. B9 is geographically close to the location where the Sierran streams infiltrate the valley sediments and therefore, is close to one of the proposed sources of recharge. Sample B15 is the eastern most sample in group B. B15 may have originated from surface waters with a composition similar to sample D1 that have undergone evaporation (Figure 13). The Sierran streams are intermittent streams and can have varied flow rates depending upon the amount of rain fall. Waters in the streams can also originate from different altitudes depending on where rain or snow fall occurs. Both these factors would affect the isotopic values of the water before it infiltrates into the soil, thus samples from the same aquifer could have differing isotopic values depending on what affected the surface water prior to infiltration.

Saturation index calculations, shown on Table 8, show that the Sierran streams and Little Lake are close to equilibrium or slightly saturated with respect to quartz. The ground water samples in group B are also close to equilibrium or slightly saturated with respect to quartz, with the exception of sample B8. Sample B8 is remarkably undersaturated with respect to quartz. This could be further indication that the northern most ground water samples in group B have been influenced by water from the Coso Range north of the valley.

TABLE 8. SATURATION INDICES FOR GROUP B.

SURFACE SAMPLES	SATURATION INDEX		WELL SAMPLES	SATURATION INDEX	
	QUARTZ	SiO_2 AMORPH.		QUARTZ	SiO_2 AMORPH.
B1	0.814	-0.212	B8	-6.165	-7.163
B7	0.894	-0.124	B10	0.640	-0.346
B6	1.127	0.096	B12	1.128	0.125
B5	0.915	-1.108	B15	0.800	-0.200
B4	1.045	0.019			
B3	0.932	-0.101			
B2	0.850	-0.173			

Samples are listed in geographical order from north to south.

There is no apparent correlation between pH, alkalinity, temperature and geographic location for the group B samples. Further data is needed in this area to determine if these parameters could be used as indicators of ground water source.

The only evidence for direction of flow of the group B ground waters is the ground water elevation contour maps (Figures 5 and 6). The maps suggest that when ground water is allowed to flow naturally (no pumping of ground water by wells) it will flow towards a clay layer located in the center of the valley where movement east is slowed causing the ground water to mound. There is no evidence that the ground water is traveling beyond the clay layer. The maps also suggest that group B ground water is not flowing south where it could mix with group A. Fingerprint and compositional diagrams, and saturation index calculations were not conclusive in determining a flow path for group B ground water.

Interpretations of fingerprint and compositional diagrams, and ground water elevation contour maps suggest that group B ground waters are probably a mixture of the Sierran streams to the west and Little Lake water entering the valley from the north. As ground water is recharged by the Sierran streams and Little Lake it would normally (if there was no ground water removal by wells) move east to the clay layer. Further flow east toward the playa is impeded by the clay layer. There are no indications that group B ground water is mixing with group A ground water or that ground waters from these areas are hydraulically connected.

The importance of recharge from the Coso Range should be investigated to determine if water from that area is an influential source. The two northern most ground water samples collected for this thesis indicate that there may be another recharge source possibly from the north. There was not enough information from the data to make further conclusions about the importance of a Coso source.

GROUP C

Fingerprint diagrams for group C ground water exhibit at least two distinct patterns. Figure 25 (samples C1 through C6) is similar to the group A fingerprint patterns shown in Figure 14. Similarities between the group A and group C patterns suggest that ground water from these two areas may be hydraulically connected. Group

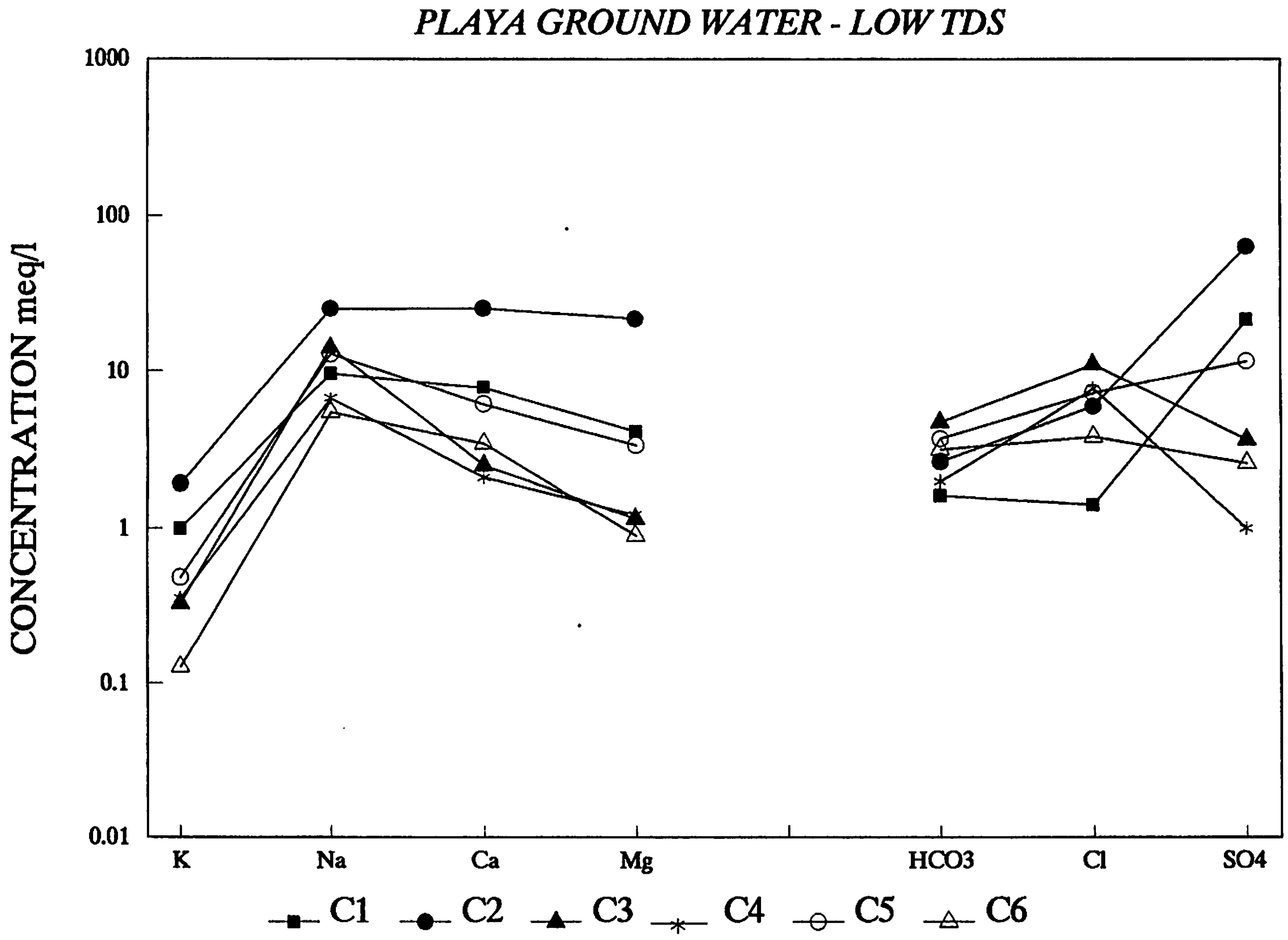


Figure 25. Fingerprint Diagram Group C Samples: TDS Between 600 to 6,000 mg/l.

A ground water may have been concentrated with respect to TDI due to evaporation of waters or dissolution of evaporite minerals.

Figure 26 (samples C7 through C10) includes the ground waters with the highest TDI of all the samples collected for this study. Samples C8 and C10 both have elevated TDI, sodium and chloride levels. These samples were collected next to the China Lake playa on the eastern side of the valley. The similar fingerprint patterns of these ground water samples suggest that they may have similar origins. Samples collected from the clay layer located in the central portion of the valley (C7 and C9) have the highest TDI of all samples collected. These two samples have no calcium or magnesium and very high levels of sodium and chloride. These samples may have had a longer time to react with the aquifer materials and therefore have a higher TDI and salinity.

Figures 27 and 28 show compositional diagrams constructed for group C ground water. Most of the samples (C1 through C6) form a cluster suggesting that ground water from these wells have one source. Samples C8, C10, and sometimes C2 are not part of the cluster. These samples have higher TDI and are located closer to the playas (Figure 10). Samples C8 and C10 may be affected by the treated waste water released into sewage ponds in the vicinity of the China Lake playa. This water may be mixing with the ground water located near the playa.

Samples C7 and C9, the samples collected from ground water situated in the clay layer, have TDI's that plot off the scale of the compositional diagrams. Based on the geographic location of the samples, observations in the field and their similar

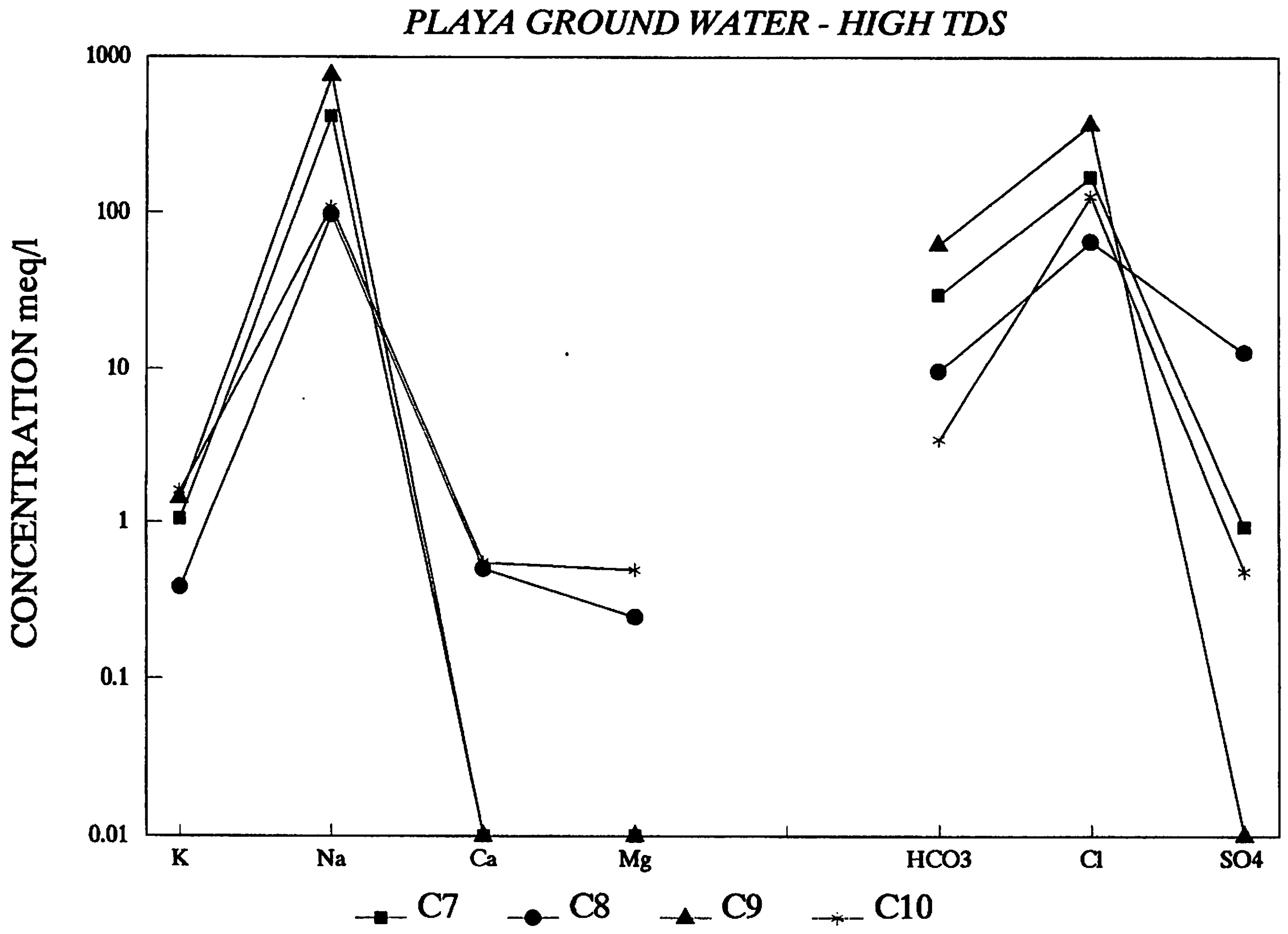


Figure 26. Fingerprint Diagram Group C Samples: TDS greater than 5,500 mg/l.

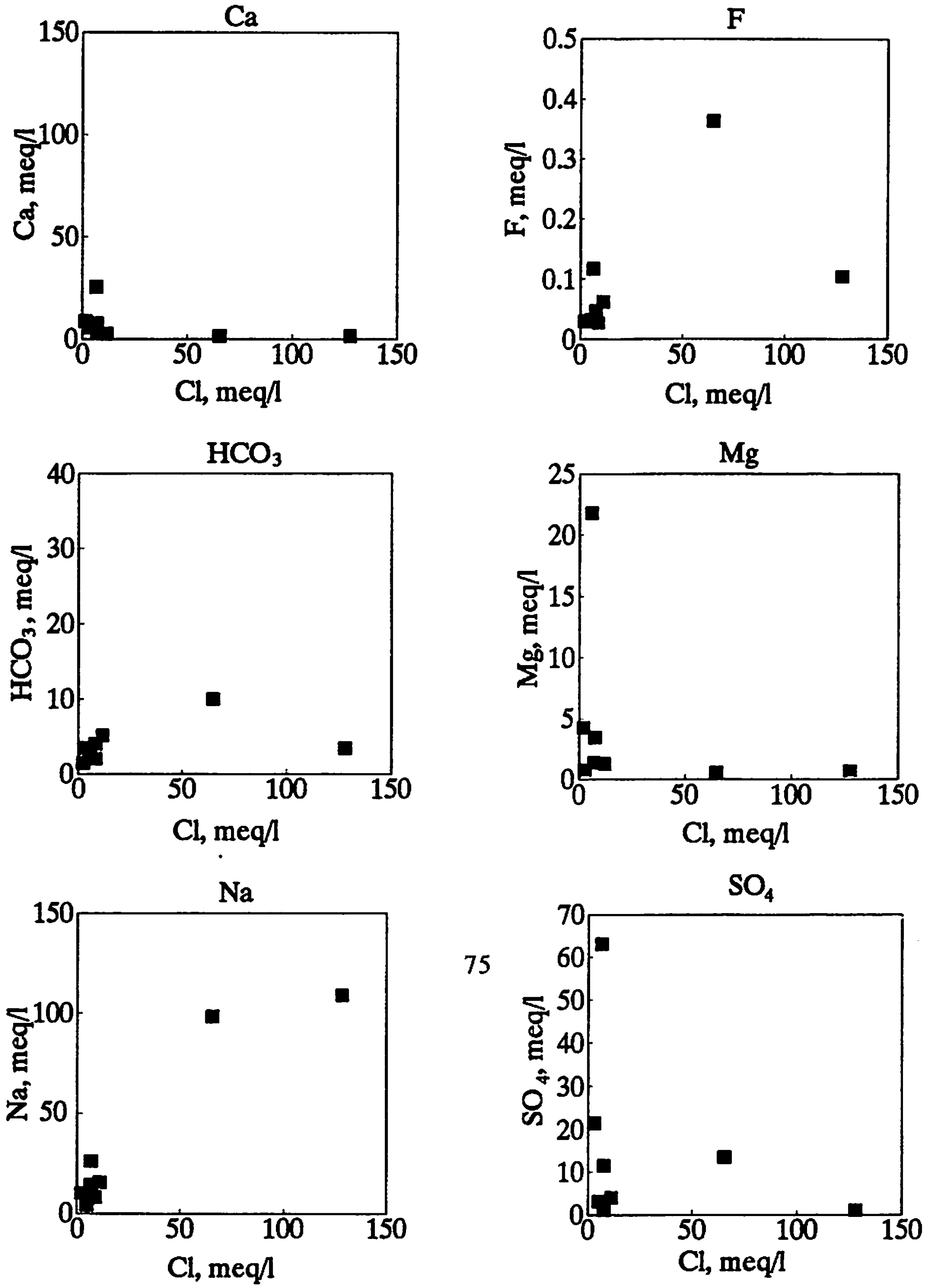


Figure 27. Compositional Diagram for Group C Samples: Chloride vs Ions. Samples C7 and C9 are not shown because of chloride levels that are greater than 150 meq/l.

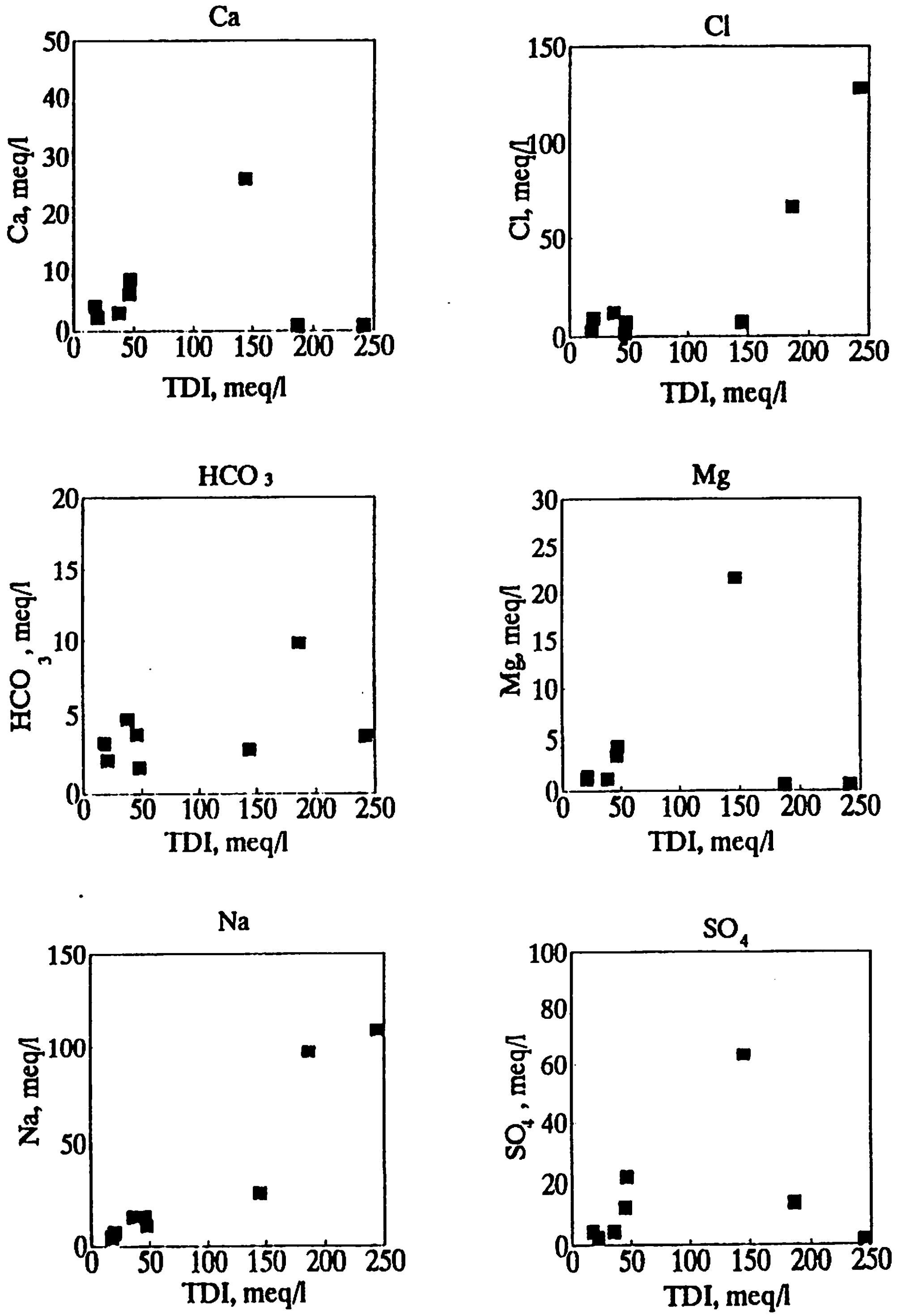


Figure 28. Compositional Diagram for Group C Samples: TDI vs Ions. Samples C7 and C9 are not shown as TDI concentrations are greater than 250 meq/l.

fingerprint patterns, it can be suggested that these two samples may have of the same origin and similar development.

Two group C samples (C8 and C10) were analyzed for $\delta^{18}O$ and δD. Both samples were similar isotopically to group A samples (Figure 13). If extreme evaporation was affecting the group C ground waters (causing precipitation of evaporite minerals) these samples would be heavier with respect to $\delta^{18}O$ and δD than the group A samples. The isotopic similarity of the group A and group C samples suggests that ground waters from these two groups maybe hydraulically connected. However, more isotopic analysis of ground waters is needed to investigate the significance of the treated waste water discharge in the vicinity of the playa.

Evidence to support dissolution of evaporite minerals rather than evaporation of playa ground water is the saturation index calculations for group C, which are shown on Table 9. Saturation index calculations show that Group C ground waters are undersaturated with respect to gypsum and halite which is indicative of dissolution. Dissolution of these minerals could cause an increase in TDI and salinity in the ground water. This dissolution may be caused by the introduction of treated waste water to the playa which is probably undersaturated with respect to gypsum and halite allowing dissolution to occur. If evaporation was the cause of the increase in salinity and TDI the group C ground waters would probably be close to saturation (or supersaturated if minerals were precipitating) with respect to gypsum and halite.

Dissolution of halite by group C samples C7, C8, C9 and C10 is supported by the compositional diagrams shown on Figure 29. Two of these diagrams (Na versus Cl and Mg versus Cl) show highly elevated concentrations of sodium and chloride for

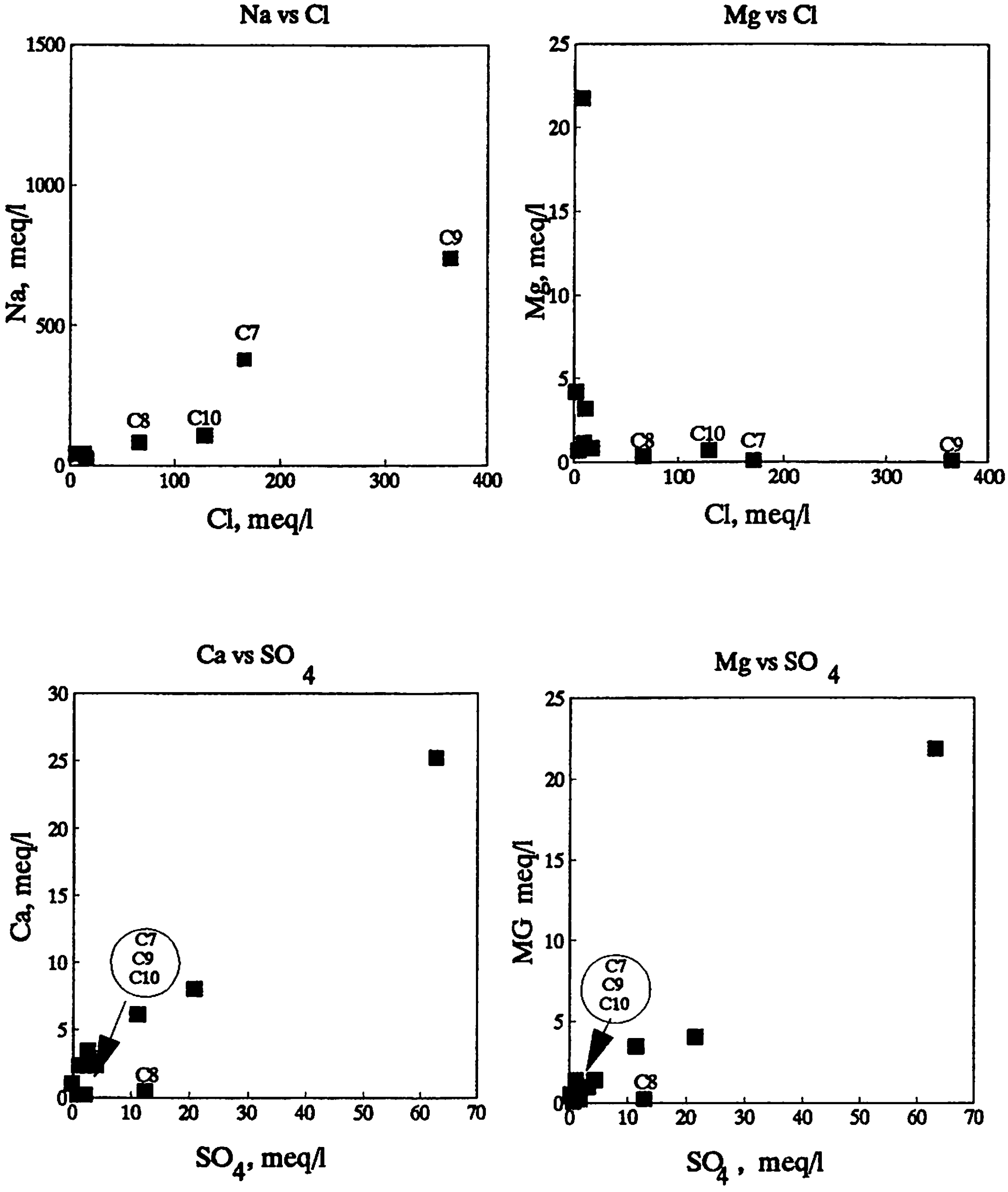


Figure 29. Compositional diagrams showing evidence of the dissolution of halite by ground water from samples C7 through C10.

these samples. The other two diagrams (Mg versus SO_4 and Ca versus SO_4) do not show increased concentrations of the other constituents. Evaporative processes will generally cause an overall increase in all ions present in the water. Dissolution processes cause an increase of ions that are present in the mineral being dissolved, as seen in samples C7 through C10.

TABLE 9. SATURATION INDICES FOR GROUP C.

SAMPLE NUMBERS	**SATURATION INDEX**	
	GYPSUM	**HALITE**
C6	-1.299	-6.364
C3	-1.378	-5.509
C1	-1.842	-6.581
C10	-3.397	-3.666
C7	-10.070	-3.082
C9	-16.607	-2.434

Samples are listed from lowest to highest TDI.

Before man-made influences such as pumping and introduction of treated water, group C ground water probably flowed towards the playas (Lee, 1913; Dutcher and Moyle, 1973). Current flow data derived from the ground water elevation contour maps (Figures 5 and 6) show that a cone of depression caused by pumping of domestic ground water has changed the flow direction away from some of the playas toward the wells. In addition, the introduction of treated waste water has probably affected flow by changing the head gradient. Fingerprint and compositional diagrams, saturation index calculations, pH, alkalinity and temperature did not show trends that would indicate a direction of flow.

Interpretations of fingerprint and compositional diagrams suggest that group C ground waters have one main source that is similar to group A ground waters. Group C ground waters probably originated as a result of the group A ground waters in the southwest migrating towards the playa. Before the discharge of treated waste water and pumping of domestic wells ground water probably moved toward the playa and evaporated (Lee, 1913, Kunkel and Chase, 1969, Dutcher and Moyle, 1973 and Berenbrock and Martin, 1991). Group C ground water became more saline and higher in TDI due to evaporation and transpiration of the water from the playa lakes. Currently the increase in salinity and TDI of group C ground waters probably occurs due to the dissolution of evaporite minerals.

CONCLUSIONS

In summary the data collected for this thesis indicate the following:

1. There are at least three sources of recharge for the shallow or domestic aquifer located in the Indian Wells Valley, a source that is similar to meteoric water in the southwest, the Sierran streams on the west and Little Lake to the north.
2. Ground water in the southern and southwestern portion of the Indian Wells Valley may not be hydraulically connected to ground water north of Inyokern on the western portion of the valley.

3. Ground water in the southwest probably flows from the southwest portion of the valley to the playas on the east.
4. The ground water in the western portion of the valley, north of Inyokern, may be blocked from flowing to the playas by an extensive clay barrier that exists in the central portion of the valley.
5. Treated waste water released in the vicinity of the China Lake Playa may have influenced the hydrochemistry and the hydrogeology of the ground water in this area.
6. None of the ground water samples collected for this study were indicative of a geothermal source.

RECOMMENDATIONS

In order to fully characterize the hydrogeology of the Indian Wells Valley more data is needed. The following information should be collected in the future to clarify questions concerning recharge, water quality, and availability of ground water:

1. The amount of water coming into the valley from the Sierran streams, Little Lake and any other surface sources present that flow into the valley needs to be quantified. This should be done on a seasonal basis for a number of years in order to account for high and low flow periods.
2. A new ground water flow model needs to be created that takes into account the clay layer and probable lack of hydraulic connection between ground waters in the west (north of Inyokern) and ground waters in the southwest.

3. More isotopic samples are needed from both surface waters and ground water. Samples should be analyzed for tritium and carbon-14 which can be used to determine age of ground water and for δD and $\delta^{18}O$ in order to make further conclusions concerning source of ground water and possible flow paths.
4. The deeper confined aquifers need to be thoroughly studied using hydrogeochemical sampling and modelling to determine hydrochemistry, to see if recharge is geothermal or meteoric in nature and to determine the feasibility for future ground water development.

Ground water in the Indian Wells Valley is a precious resource that must be protected and carefully monitored. As the population in the area grows the demands on ground water will continue to increase. It is for this reason that the quantity of ground water available must be determined and the quality of the ground water in the valley must be protected.

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APPENDIX

Table A1. Isotopic Laboratory Analysis Results

ISOTOPIC DATA				
SAMPLE NO.	DATE SAMPLED	LOCATION	OXYGEN-18	DEUTERIUM
			o/oo SMOW	
		SURFACE SAMPLES		
B1	04/28/93	LITTLE LAKE	-10.100	-90.000
B2	04/28/93	INDIAN WELLS CANYON	-11.500	-87.000
B3	04/28/93	SHORT CANYON	-11.100	-86.000
B4	04/28/93	GRAPEVINE CANYON	-11.700	-87.000
B5	04/28/93	SAND CANYON	-11.200	-82.000
B6	04/28/93	NONAME CANYON	-10.900	-86.000
B7	04/28/93	NINE MILE CANYON	-11.700	-91.000
D1	05/06/93	HAIWEE SPRING	-13.700	-100.000
D2	06/03/93	WILD ROSE SPRING	-12.400	-91.000
D3	04/13/93	CANEBRAKE CREEK	-11.700	-84.000
D4	04/13/93	CHIMNEY CREEK	-12.500	-90.000
D5	04/13/93	KENNEDY MEADOWS - KERN RIVER	-14.300	-107.000
		WELL SAMPLES		
A4	03/17/93	27/39-19E01	-12.100	-89.000
A5	03/11/93	26/39-30J01	-12.300	-91.000
A6	04/28/93	26/39-28A01	-12.500	-96.000
A9	04/28/93	26/40-20J01	-11.900	-97.000
B9	03/18/93	25/38-02L01	-11.700	-90.000
B15	04/28/93	25/39-31R01	-12.000	-96.000
C8	05/03/93	26/41-07D01	-12.500	-98.000
C10	03/10/93	25/41-18Q01	-12.300	-99.000

Table A2. Field and Laboratory Analysis Data

SAMPLE NO.	DATE SAMPLED	LOCATION	FIELD pH	LAB pH	TEMP. DEG. C	TEMP. DEG. F	FIELD ALKALINITY as CaCO3 (mg/l)	LAB ALKALINITY as CaCO3 (mg/l)	FIELD CONDUCTIVITY µS/cm	LAB CONDUCTIVITY µmho/cm
A1 *	3/17/93	27/38-23F01	10	9.7	22	71	120	118	442	388
A2	3/17/93	27/38-02H01	10.3	8.1	23	73	22	37	392	402
A3*	3/17/93	27/39-08E01	10.6	10.3	22	72	25	29	372	346
A4**	3/17/93	27/39-19E01	8.96	8.8	22	72	95	83	362	337
A5	3/11/93	26/39-30J01	7.5	7.9	27	80	110	108	436	435
A6	4/28/93	26/39-28A01	7.85	8.2	29	84	77	81	336	340
A7	3/21/93	26/39-13R03	7.65	7.7	23	73	110	114	345	361
A8	3/19/93	36/40-29Q01	7.55	8	21	69	80	84	377	398
A9	3/19/93	26/40-20J01	8.2	8.1	24	75	125	119	445	471
A10	3/19/93	26/40-19N01	7.95	7.8	24	76	120	122	260	268
A11	3/19/93	26/40-32K01	8.45	8.5	20	69	72	77	359	354
B1	3/11/93	LITTLE LK	8.3	8.3	17	62	--	615	1900	1080
B2	3/21/93	INDIAN WELLS	8.05	8.3	17	63	--	187	694	643
B3	3/21/93	SHORT	8.28	8.2	15	59	--	156	495	492
B4	3/21/93	GRAPEVINE	8.06	8	17	62	--	321	830	831
B5	3/21/93	SAND	8.43	8.2	17	63	--	216	540	596
B6	3/21/93	NONAME	7.98	8	16	60	--	559	1381	1480
B7	3/21/93	NINEMILE	8.55	8.4	18	65	--	338	811	822
B8	3/18/93	24/38-21J01	9.72	9.5	23	73	160	147	1370	1500
B9	3/18/93	25/38-02L01	7.15	7.7	23	74	430	490	1346	1520
B10	3/18/93	25/38-12M01	7.15	7.7	26	78	290	321	1287	1390
B11	3/18/93	25/38-24K01	7.15	7.3	24	75	330	353	905	955
B12	3/11/93	24/39-34D01	8.13	8.1	22	71	280	302	610	676
B13	3/10/93	25/38-13J01	8	8.2	23	73	170	180	440	478
B14*	3/18/93	25/38-34J01	9.6	10.6	26	78	225	0	788	27600
B15	3/10/93	25/39-31R01	6.96	7.8	22	72	130	151	833	879
B16	3/11/93	26/39-18F01	7.35	7.8	19	67	--	108	1087	1120
B17*	3/21/93	26/39-17L01	9.05	8.9	22	71	133	115	251	264
C1	3/10/93	26/40-27D01	7.56	7.4	24	75	85	80	1871	2000
C2	3/21/93	26/40-22H01	7.39	7.5	23	73	112	132	5320	5440
C3	3/19/93	26/40-14B02	7.28	7.6	24	76	225	235	1713	1830
C4	3/10/93	26/40-35Q02	7.5	7.5	22	71	85	98	1085	1110
C5	3/21/93	26/40-26F01	7.44	7.6	22	72	175	184	2180	2180
C6	3/19/93	26/40-09A01	7.45	7.7	26	79	145	157	909	997
C7***	3/10/93	26/40-6D02	9.85	9.7	22	72	9800	11318	N/A	28200
C8	3/19/93	26/41-07D01	8.97	8.8	21	70	790	839	915	9410
C9***	3/10/93	25/39-30L01	9.7	9.6	23	73		18552	N/A	56000
C10	6/3/93	25/41-18Q01	--	9	--	--	--	388	--	13300
D1	5/6/93	HAIWEE SPG	7.6	7.6	12	54	--	221	645	645
D2		WLD ROSE SP	--	7.4	-18	--	--	252	--	665
D3	4/13/93	CANEBRK CK	8.04	8.1	16	61	--	147	304	327
D4	4/13/93	CHIM CK.	8.11	8.2	16	60	--	208	551	580
D5	4/13/93	KEN.MEAD	6.98	7.4	8	47	--	42	102.3	113

* Samples not used. Charge imbalance greater than ± 10%

** Sample not used in dissolved ion evaluation. Charge imbalance greater than ± 10%

*** Charge imbalance greater than ± 10%, but samples used in interpretation process because of uniqueness of physical characteristics.

Table A2. Field and Laboratory Analysis Data

SAMPLE NO.	K mg/l	Na mg/l	B mg/l	Ca mg/l	Fe µ/L	Mg mg/l	SiO2 mg/l	HCO3 mg/l	Cl mg/l	F mg/l	NO3 mg/l	PO3 mg/l	SO4 mg/l	TOTAL HARDNESS mg/l	TDS mg/l
A1 *	2	83	0.6	2	43600	0	0	13	18	0.8	1	0	44	5	370
A2	4	54	0.2	17	5280	0	1	45	61	0.8	0	0	64	43	310
A3*	2	46	0.1	11	7850	0	0	0	74	1.3	0	0	0	28	230
A4**	BD	72	1.5	4	3010	0	2	51	20	4	0	0	35	10	240
A5	2	54	0.2	31	BD	5	33	132	29	0.7	7.3	0	63	98	290
A6	2	52	1	20	150	0	53	99	27	0.4	10.8	0	31	50	270
A7	2	32	BD	32	460	6	40	139	24	0.5	0	0	24	105	250
A8	3	44	BD	29	BD	8	26	103	34	0.5	18.8	0	38	105	270
A9	7	77	0.1	17	BD	3	55	145	30	0.9	0	0	60	55	360
A10	8	41	BD	10	220	2	50	149	9	0.8	0	0	0	33	230
A11	2	64	0.2	11	BD	2	26	78	36	0.5	13.9	0	24	36	240
B1	26	282	5.5	59	BD	65	29	750	193	1	0	0	163	414	1240
B2	4	27	BD	89	60	23	32	228	14	0.8	0	0	133	317	460
B3	2	41	BD	57	0	8	36	190	12	0.8	0	0	74	175	360
B4	7	61	BD	97	140	28	49	392	14	0.8	0	0	137	357	590
B5	4	43	0.1	62	210	17	35	264	13	1	0	0	78	225	420
B6	8	115	0.3	131	50	86	54	682	42	2.4	2.6	0	279	680	1060
B7	6	54	0.2	76	210	44	35	322	22	1	1.1	0	98	370	570
B8	28	328	4.7	11	170	6	0	64	194	0.6	0.7	0	310	52	950
B9	17	163	2.8	108	BD	47	27	597	119	0.7	4.8	0	241	463	960
B10	18	171	4.5	58	160	38	26	391	142	0.6	1.2	0	154	301	830
B11	7	91	0.7	75	BD	29	35	430	44	0.5	5.1	0	84	306	620
B12	9	134	1.9	9	BD	7	71	368	40	1.1	1.5	0	9	51	500
B13	6	70	0.4	18	1090	12	4	220	27	0.4	0	0	27	94	330
B14*	19	182	1.6	3	45100	1	1	0	224	1.9	0.6	0	6180	12	5690
B15	4	96	0.9	68	BD	17	34	184	89	0.4	1.5	0	181	240	590
B16	4	99	0.3	94	100	15	26	132	171	1	45.7	0	155	297	770
B17*	4	52	0.5	5	440	0	22	64	7	1.8	0	0	1	13	200
C1	39	222	0.6	157	60	50	79	98	50	0.6	7.2	0	1020	598	1660
C2	75	576	2.8	504	1420	265	56	161	211	2.2	1.1	0	3030	2347	5670
C3	13	325	3.5	50	BD	14	62	287	390	1.1	2.9	0	175	182	1080
C4	14	154	1.5	42	240	15	50	120	272	0.8	0.6	0	48	167	670
C5	19	296	1.9	123	610	41	66	224	256	0.5	1.3	0	555	476	1500
C6	5	125	2.8	69	BD	11	53	191	135	0.6	2.7	0	123	218	620
C7***	41	9500	447	BD	70	BD	36	1830	5980	21.5	0.6	0	45	0	24300
C8	15	2240	29.8	10	2000	3	23	595	2320	6.9	0	0	620	37	5650
C9***	56	17300	641	BD	270	BD	45	3810	12900	44.8	1.9	0	0	0	91500
C10	63	2500	24.8	11	250	6	3	212	4530	2	0.6	0	23	52	7870
D1	6	47	1.5	64	70	18	41	269	40	0.2	2.6	0	63	234	400
D2	2	37	0.3	86	0	21	26	307	41	0.2	2.9	0	54	301	440
D3	1	21	1.3	35	380	9	61	179	7	0.6	0	0	16	124	210
D4	3	31	0.6	64	0	20	30	254	14	0.6	0	0	72	242	400
D5	2	12	0.8	8	690	2	22	51	9	0.1	2.1	0	4	28	110

* Samples not used. Charge imbalance greater than ± 10%

** Sample not used in dissolved ion evaluation. Charge imbalance greater than ± 10%

*** Charge imbalance greater than ± 10%, but samples used in interpretation process because of uniqueness of physical characteris

BD = Below Detection