Groundwater Recharge in the Western Indian Wells Valley

Interim Report

by
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EXECUTIVE SUMMARY

PROJECT OBJECTIVE

The primary objectives of this project are to 1) determine the source and amount of recharge to the western part of the Indian Wells Valley alluvial aquifer using surface and subsurface hydrogeological measurements in conjunction with chemical analyses of both surface and groundwaters, and 2) to delineate areas of high quality water (total dissolved solids less than 500 parts per million) within the basin aquifer.

PROJECT DESCRIPTION

For the hydrogeologic tasks, the amount of groundwater flowing toward the China Lake playa in the Indian Wells Valley was estimated using Darcy's Law calculations for the north, northwestern and southwestern sub-areas of the valley. These estimates were compared to calculations of the amount of surface water (precipitation and stream runoff) available for aquifer recharge in each area. Precipitation and stream runoff were determined from precipitation data collected in the Sierran watershed and stream gaging in the Indian Wells and adjacent Rose Valleys during the 94-95 season. Where groundwater flow estimates were significantly higher than surface water recharge measurements, groundwater inflow from other basins was considered to provide a significant component of aquifer recharge in the Indian Wells Valley.

For the geochemical tasks, groundwater and surface water samples were analyzed for dissolved concentrations of various ions and isotopes. These ionic and isotopic data were interpreted using graphical methods. Plots of chemical data from various recharge sources were compared to the groundwater and conclusions were drawn based on these plots. Where the water sample fingerprints were similar, the samples were assumed to be related. Conversely, when the plots were different, they indicated that the samples did not share the same background.

MAJOR FINDINGS

The quantity of groundwater flowing into the Indian Wells Valley from the:

- north is approximately 4800 ac-ft/yr. Roughly half of this amount comes from stream flow out of the southern Rose Valley near Little Lake and from precipitation as runoff from the mouths of Fivemile and Deadfoot Canyons. The other half is derived from groundwater which flows southward from the Rose Valley. The water is of poor quality with total dissolved solids (TDS) of 900 -1000 parts per million (ppm).

- northwest is approximately 3200 ac-ft/yr. This amount compares favorably to recharge from precipitation in the adjacent canyons: Ninemile, Noname, Sand, Grapevine, and Short Canyons. The water is of average quality with a TDS of 500-850 ppm.

- southwest is approximately 33,500 ac-ft/yr. This water is of extremely high quality with a TDS of 120-350 ppm. Local precipitation in the adjacent Sierran canyons is insufficient to account for the high groundwater flux observed in this area. It is, therefore, hypothesized that most of the aquifer recharge in the southwest is derived from groundwater inflow from other areas/drainage basins. The most probable sources are Sierran recharge from north of Indian Wells Valley or surface water from west of the topographic drainage divide.

CONCLUSIONS AND RECOMMENDATIONS

Most of the water within the aquifer is coming from the southwest part of the basin. Geochemical data indicates that this water is of very high quality. Most future groundwater development should concentrate upon this area with the objective of verifying the parameters used to estimate the amount of groundwater flux. In particular, more information regarding transmissivity values in the southwest aquifer is needed. Additional data to confirm the presence or absence of potential groundwater flow barriers through this part of the aquifer (i.e. well tests, shallow seismic surveys) should also be gathered. More geochemical analyses should be performed to determine the source areas for these deep southwestern waters. Existing groundwater flow models should be re-evaluated and updated with the new information so that different groundwater management options can be simulated.

INTRODUCTION

The Indian Wells Valley is located in the Mojave Desert in southeastern California, approximately 200 km (125 mi.) north of Los Angeles. The basin is bounded on the west by the Sierra Nevada Mountains, on the east by the Argus Range, on the north by the Coso Range and low-lying basaltic lava flows, and on the south by the El Paso Mountains (Figure 1). The margins of the basin are characterized by coalescing alluvial fans. The surface of these alluvial fans slope gently toward China Lake, a playa lake in the basin's topographic axis in the east-central part of the valley.

The annual precipitation on the valley floor is approximately 10-15 cm and falls mainly during the winter and spring months (Berenbrock and Martin, 1991). Most of this rainfall is lost to evaporation which averages 200 cm/yr from surface water impoundments (Farnsworth et al., 1982). Only one small perennial stream exists in the area. Therefore, the municipal, agricultural, military and industrial water needs of the communities of Ridgecrest, China Lake and Inyokern are met solely by groundwater supplies.

This study employs surface and subsurface hydrogeological measurements in conjunction with chemical analyses of both surface and groundwaters in the north, northwest and southwest (Fig. 1) parts of the Indian Wells Valley to determine the source and amount of recharge for each of these sub-areas of the Indian Wells Valley alluvial aquifer. Recharge is defined as water which enters the aquifer from both surface and subsurface sources. This data will help to determine the amount of water which can be safely withdrawn from the valley aquifer without adversely affecting groundwater supplies. It will also delineate areas of high-quality water within the basin. This study makes extensive use of the new multi-completion wells installed as part of a joint project by the U.S. Bureau of Reclamation, China Lake Naval Air Weapons Station, North American Chemical Company and Indian Wells Valley Water District.

HYDROGEOLOGIC ANALYSIS

Precipitation

Rain gauges placed at various elevations in both Ninemile and Freeman Canyons during the winter/spring of 94/95 indicate that precipitation increased with increasing elevation up to about 5500 feet. Precipitation that falls above 5500 feet is mainly snow which is not measured by the precipitation gauges. Therefore, the values for precipitation above 5500 feet were estimated by linear extrapolation of the lower elevation data.

In order to determine the amount of rainfall which actually infiltrated to the water table, the Maxey-Eakin method was used (Maxey and Eakin, 1949; Eakin et al., 1951). The Maxey-Eakin method uses an empirical coefficient to relate the annual precipitation rate to recharge efficiency in the Great Basin. In other words, the number of acres that lie within a given range of elevations was multiplied by the precipitation measurements/projections for that elevation to estimate the amount of rain (in acre-feet/yr) that falls within the study area. This value is then modified to reflect evapotranspiration losses by multiplication with a constant (Maxey-Eakin coefficient) whose value lies between 0 and 1 depending on environmental factors. Using this method, the total amount of aquifer recharge from precipitation in the Sierran watershed above 4000 feet was 7761 ac-ft during the 94-95 season. Of this total, recharge from precipitation in Fivemile and Deadfoot Canyons (which is treated as part of the recharge for the northern/Rose Valley area) is approximately 952 ac-ft/yr. Recharge from precipitation in the northwestern canyons (Short to Ninemile Canyons) contributes 2896 ac-ft/yr to the alluvial aquifer. Precipitation in the southwestern canyons (Freeman to Bird Springs) resulted in 3913 ac-ft/yr of recharge.

Streams

The only perennial stream flowing into the Indian Wells Valley is the south-flowing stream containing outflow from Little Lake in the southern part of the Rose Valley. The average outflow of this stream is approximately 1300 ac-ft/yr. This amount is added to the value for recharge from preciptation in Fivemile and Deadfoot Canyons in order to determine the total amount of surface-derived recharge attributed to the north/Rose Valley sub-area (2252 ac-ft/yr).

Ground Water Inflow

Using well data from the 1992 Bureau of Reclamation project wells, we calculated the amount of groundwater flowing through the three sub-areas of the Indian Wells Valley aquifer (Fig. 2). These simple groundwater flux calculations are based upon Darcy's Law and, as a result, are subject to all the assumptions contained therein. All values for hydraulic conductivity were taken from slug tests performed on the project wells by the U.S. Bureau of Reclamation (1993). The results of these tests are shown in the U.S. Bureau of Reclamation report (1993, Appendix 3, p. 16). Cross sectional areas were determined using drillers logs from these wells (depth component) and Dutcher and Moyles' (1970) map showing the limits of the Indian Wells Valley groundwater basin (width component). Due to uncertainties in calculating values for hydraulic conductivity from slug tests, the recharge estimates may have an error of as much as +/- one order of magnitude however, many scientists feel that estimates of hydraulic conductivity derived from slug tests are low. Therefore, the fluxes calculated in this manner may be somewhat conservative. If the values for groundwater flow in a sub-area are dissimilar to values for the total amount of recharge available from surface sources, we assume that groundwater inflow from another drainage area or basin provides a significant amount of recharge for the aquifer in that part of the valley.

North/Rose Valley Groundwater Flux

Groundwater flux from the North/Rose Valley sub-area was estimated using gradients between project wells BR-10 and BR-6. Groundwater flow was calculated at 4800 ac-ft/yr. This number is over twice as large as the sum of the total surface recharge (2252 ac-ft/yr) and suggests that a significant amount of groundwater from areas outside the study area (probably the Rose Valley) contributes to aquifer recharge in the northern Indian Wells Valley.

Northwest Groundwater Flux

Groundwater flux from the Sierran canyons in the northwest was estimated using gradients between wells BR-5 and NR-2. Groundwater flux through this portion of the alluvial aquifer was calculated at 3200 ac-ft/yr. The recharge from precipitation in Short to Ninemile Canyons (2896 ac-ft/yr for 94-95) is similar to the calculated groundwater flux value, indicating that nearly all of the groundwater flowing eastward from the northwest part of the basin can be attributed to infiltration of surface precipitation.

Southwest Groundwater Flux

Groundwater flux from the Sierran watershed southwest of the valley was estimated using gradients between wells BR-1 to MW-32. The cross-sectional area in this part of the aquifer was determined from recent gravity surveys. Groundwater flow through this part of the aquifer was calculated at 33,500 ac-ft/yr. This number is much larger than the 3913 ac-ft of recharge estimated from precipitation in the southwestern Sierran watershed and indicates that most of the groundwater in the southwestern part of the alluvial aquifer is derived from groundwater inflow from another basin or drainage area.

GEOCHEMICAL ANALYSIS

The geochemical analysis permits further corroboration of the recharge sources put forth in the hydrogeological analysis as well as delineates areas of high quality water which has total dissolved solids (TDS) of less than 500 parts per million (ppm). Groundwater and surface water sources were analyzed for dissolved concentrations of various components. Water samples with similar concentrations of components are assumed to be genetically related; that is, they share a similar water-rock interaction history, flowpath, and/or origin.

Water Quality Results

Results from chemical data analysis show that water samples can be divided into three general groups. These groups are shown in Figure 3. The first type, shown in green on the figure, is a Na-Mg-Ca-HCO_3 water with total dissolved solids of 900-1000 ppm. The second type, shown in red, is a Ca-Na-HCO_3-SO_4 water with a TDS of 500-850 ppm and includes most of the Sierran canyon stream and spring samples. With a TDS of 120-

350 ppm, the third type is a high quality Na-HCO3 water illustrated in blue. Figure 4 shows the areal distribution of the water types. Figure 5 is a cross section along line A-A' showing the vertical distribution of the water types.

Groundwater Source Results

Similar plots for different water samples illustrate that these samples have similar compositions and, thus, similar histories and/or flowpaths For instance, the similarity between plots for the Little Lake surface water and the northwest wells is clear. The conclusion is that underflow from southern Rose Valley contributes a significant portion of groundwater in the northwest as the hydrogeological data first suggested.

In contrast, the chemistry of the surface runoff from the northwestern canyons does not match that of the northern part of the aquifer (Type 2) due to the different shapes of their "fingerprints" - the red fingerprint pattern of the surface waters do not look like the signatures of the wells. Thus, in contrast to the hydrogeologic data, the chemical data from the aquifer implies that the surface runoff from the northwestern canyons does not form a significant component of the aquifer's water. However, this apparent discrepancy between the hydrogeological and chemical data may be explained by the high CO_2 content of the water in the northern valley. This high CO_2 content causes significant water-rock interaction to occur which continues long after the surface water enters the aquifer. This interaction causes a chemical change in the water and may mask the fact that the aquifer groundwaters are, in fact, a mixture of the northwestern canyon waters and the Rose Valley sources.

Finally, the high quality Na-HCO3 water (Type 3) in the southwestern wells appears not to be related to the adjacent surface sources. The TDS of most of the southwestern surface sources, as well as the rest of type 2 water samples, is too high to be the source of the Na-HCO3 groundwater. Based on TDS, the best potential source for large quantities of the type 3 water is unconventional recharge sources outside of the Indian Wells Valley - for example, samples from the Kern River and Kennedy Meadows. These unconventional recharge sources provide the only surface water with low TDS.

Isotopic data analysis of precipitation also yields strong clues as to the source of the groundwater in the Indian Wells Valley aquifer. The stable isotopes of oxygen and hydrogen vary in weight. These isotopes are separated (fractionated) as a function of the temperature and elevation at which the rain falls. For example, heavier isotopes constitute a larger fraction of the rain falling at lower elevations than the lighter ones. Rain from gauges placed at various elevations throughout the western canyons during the 94/95 season was analyzed to correlate the isotopic values versus temperature and elevation for the study area. As a result, it is possible to determine the sources of recharge for the aquifer by measuring the isotopic value of a groundwater sample. Figure

6 shows the stable isotopic data for samples from the rain gages and literature values to illustrate this trend.

All of the surface water samples and many of the samples from the shallow wells contain heavy isotopes ($\delta D > -100$) and a high TDS. This water is derived from rain that fell at elevations below 7000 feet. However, groundwater from many of the deep wells contains lighter isotopes ($\delta D < -100$) derived from elevations of 7000 feet or greater. Thus, the majority of the water in the aquifer is NOT from adjacent surface springs and streams fed by rain from elevations below 7000 feet. It is assumed that the source of this groundwater in the aquifer is either water from the north of Indian Wells Valley or from the west side of the surface drainage divide for the Indian Wells Valley where water samples exhibit the same isotopic and TDS signatures. The transport mechanism for these unconventional recharge sources requires further study but is hypothesized to be fractures.

CONCLUSIONS AND RECOMMENDATIONS

The groundwater flux data indicates that more than 80% of the water within the basin aquifer is coming from the southwest part of the basin. Geochemical data indicates that this water is of very high quality.

Therefore, most future groundwater development should concentrate upon this area with the objective of verifying the values for parameters used to estimate groundwater flux--especially transmissivity/hydraulic conductivity. Additional data to determine the presence or absence of groundwater flow barriers within this part of the aquifer (i.e. pump tests, shallow seismic surveys) should also be gathered. The presence of one or more flow barriers could increase the gradient across the area resulting in erroneously large groundwater flux calculations.

Given the evidence to date, the remaining geochemical samples collected for this study should be concentrated within the potential source areas for the groundwater in the deep southwestern aquifer. Determination of the source area for the southwestern waters is vital in order to establish wellhead protection programs and to determine the impact of future projects or developments in the Sierras upon the water quality and supply for the Ridgecrest area.

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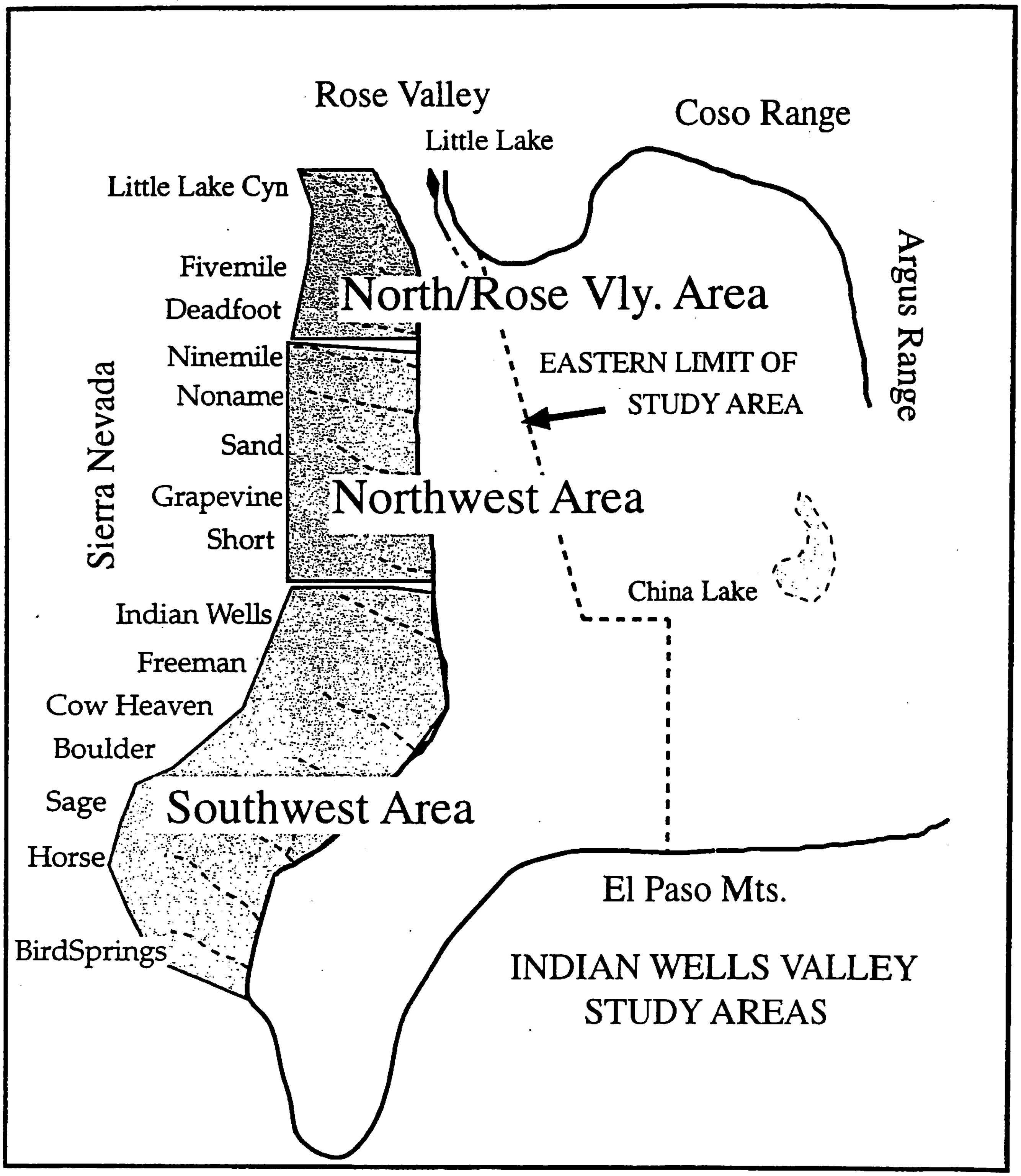
Rose Valley
Coso Range
Little Lake
Little Lake Cyn
Fivemile
Deadfoot
North/Rose Vly. Area
Argus Range
Ninemile
Noname
Sand
Grapevine
Short
Sierra Nevada
EASTERN LIMIT OF
STUDY AREA
Northwest Area
China Lake
Indian Wells
Freeman
Cow Heaven
Boulder
Sage
Southwest Area
Horse
El Paso Mts.
BirdSprings
INDIAN WELLS VALLEY
STUDY AREAS

Figure 1

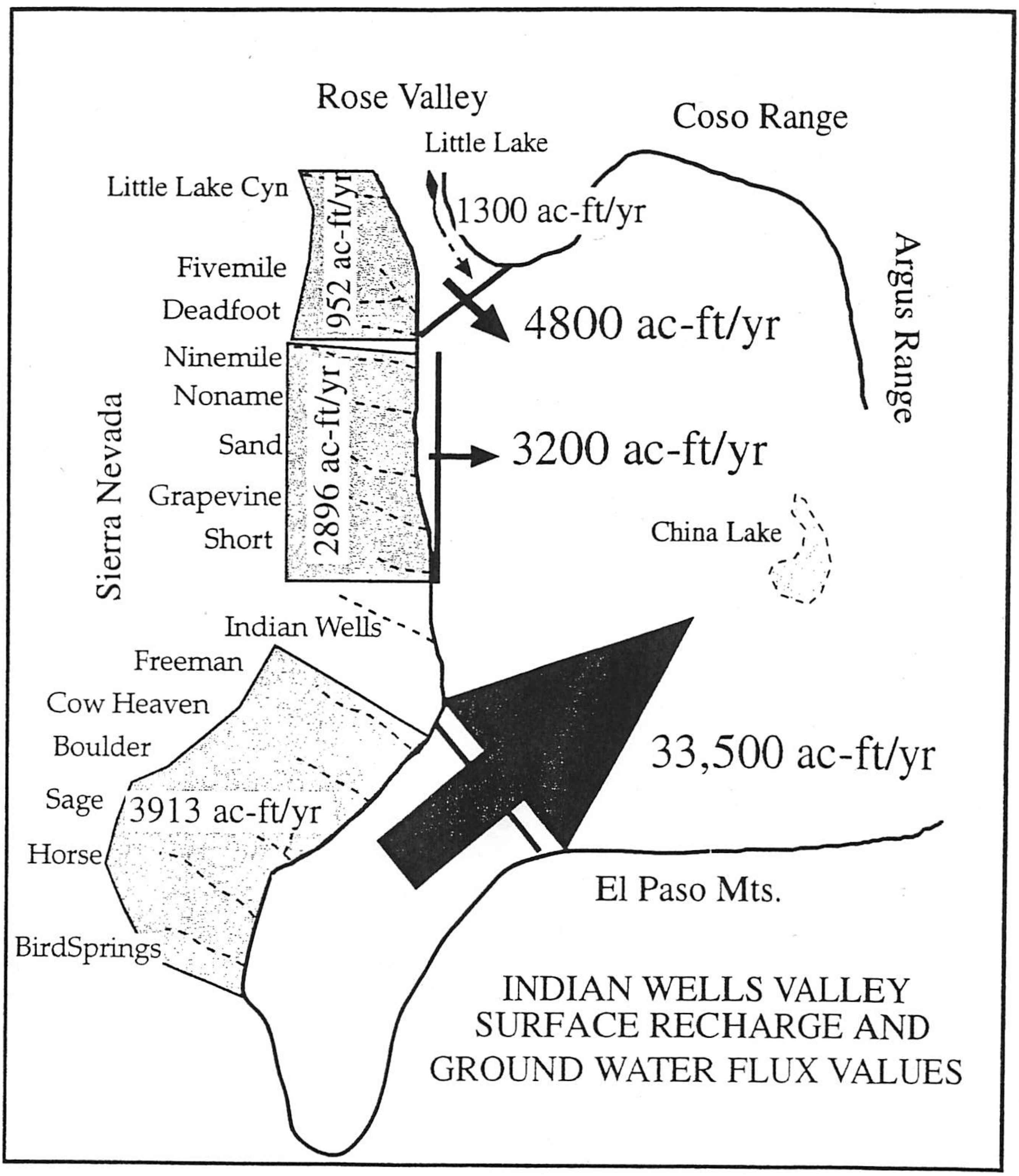
Rose Valley
Coso Range
Little Lake
Little Lake Cyn
952 ac-ft/yr
1300 ac-ft/yr
Fivemile
Deadfoot
4800 ac-ft/yr
Argus Range
Ninemile
Noname
Sand
Grapevine
Short
2896 ac-ft/yr
3200 ac-ft/yr
Sierra Nevada
China Lake
Indian Wells
Freeman
Cow Heaven
Boulder
Sage
Horse
BirdSprings
3913 ac-ft/yr
33,500 ac-ft/yr
El Paso Mts.
INDIAN WELLS VALLEY
SURFACE RECHARGE AND
GROUND WATER FLUX VALUES

Figure 2

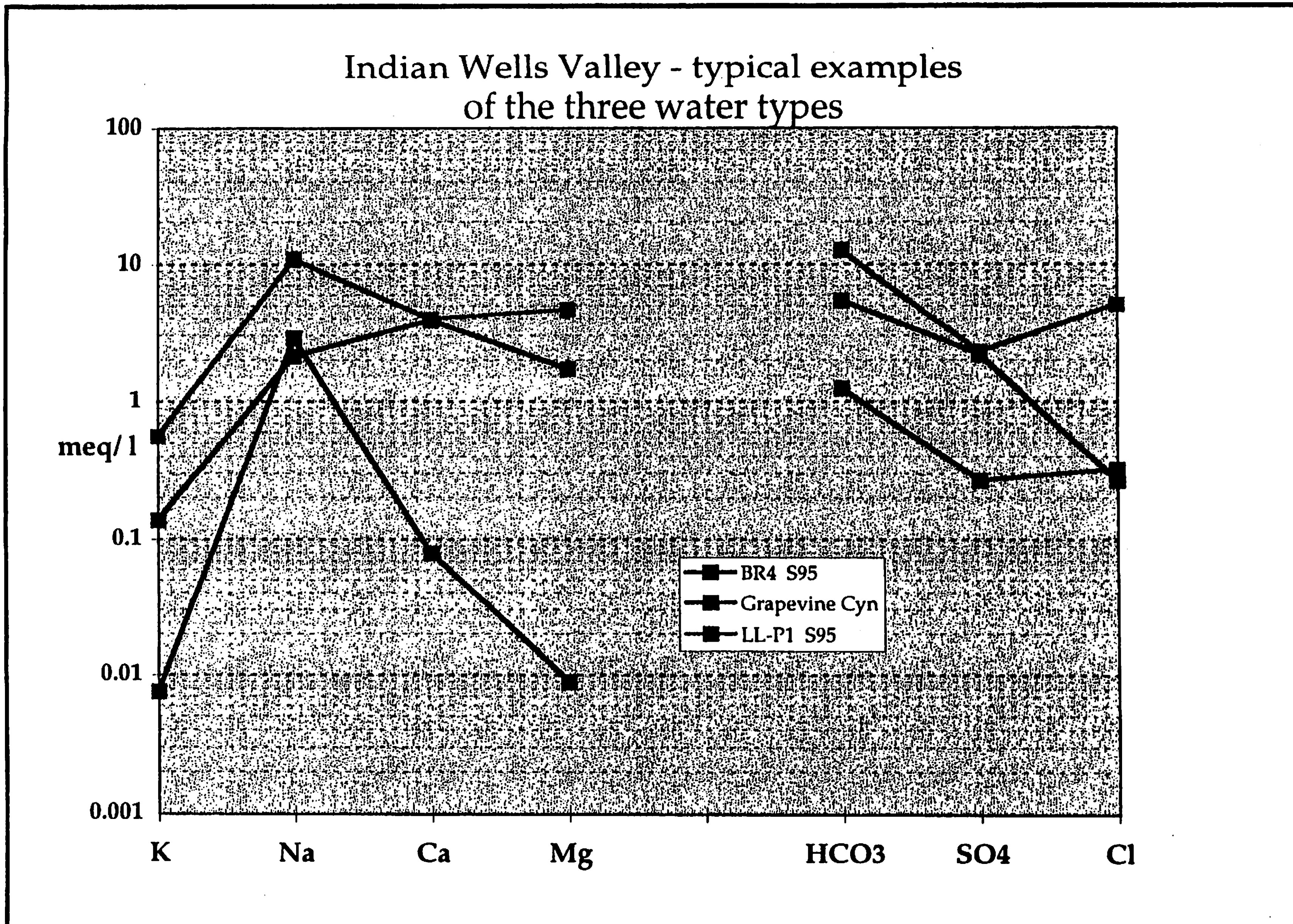
Indian Wells Valley - typical examples
of the three water types
100
10
1
meq/l
0.1
0.01
0.001
K
Na
Ca
Mg
HCO3
SO4
Cl
BR4 S95
Grapevine Cyn
LL-P1 S95

Figure 3

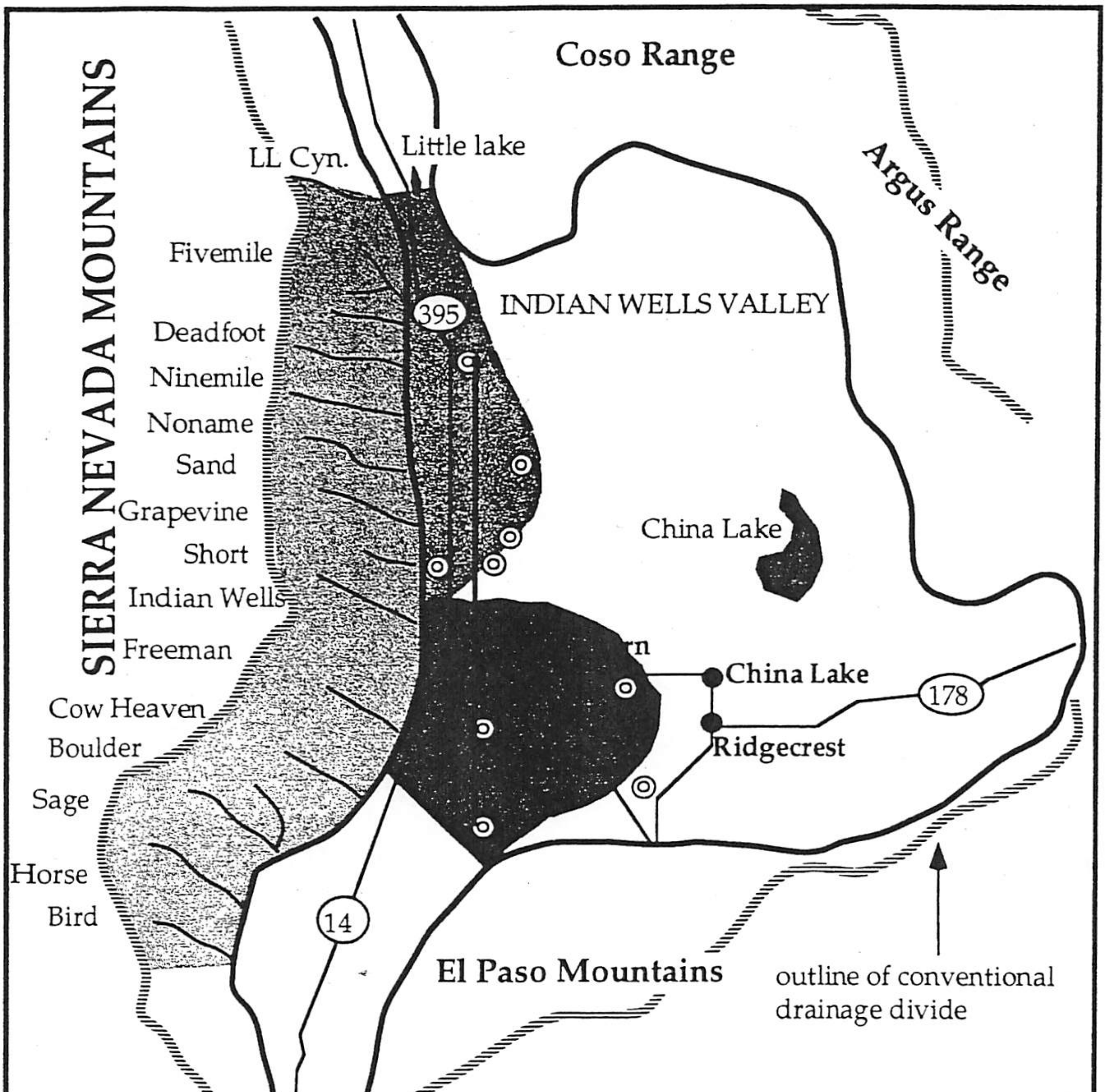

Figure 4. - Location of the three principal water types in the study area. Data is from samples of streams, springs and shallow wells. Cross section line A-A" is also shown.

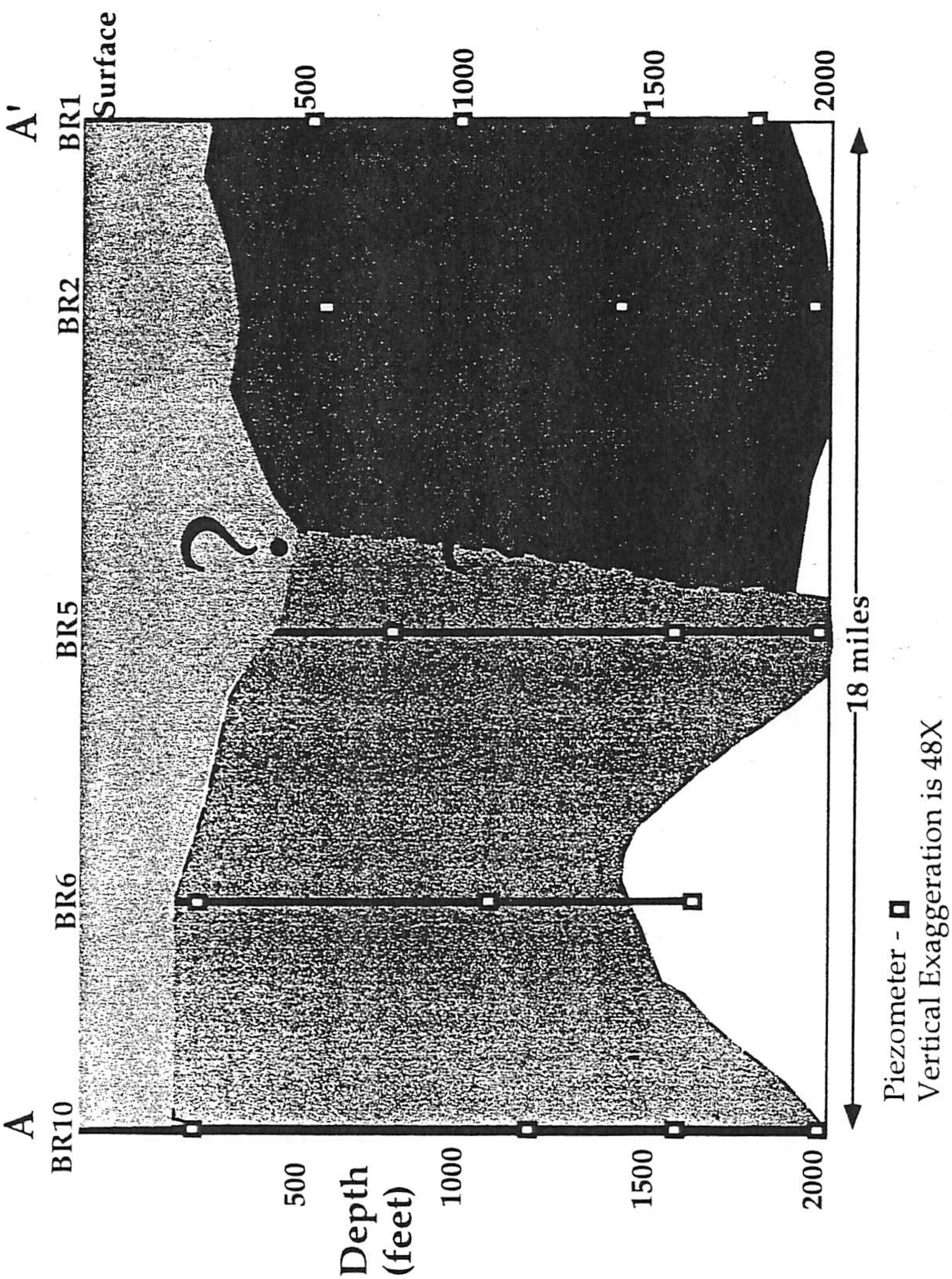

Figure 5. - Cross section A-A' showing location of the three water types in the study area.

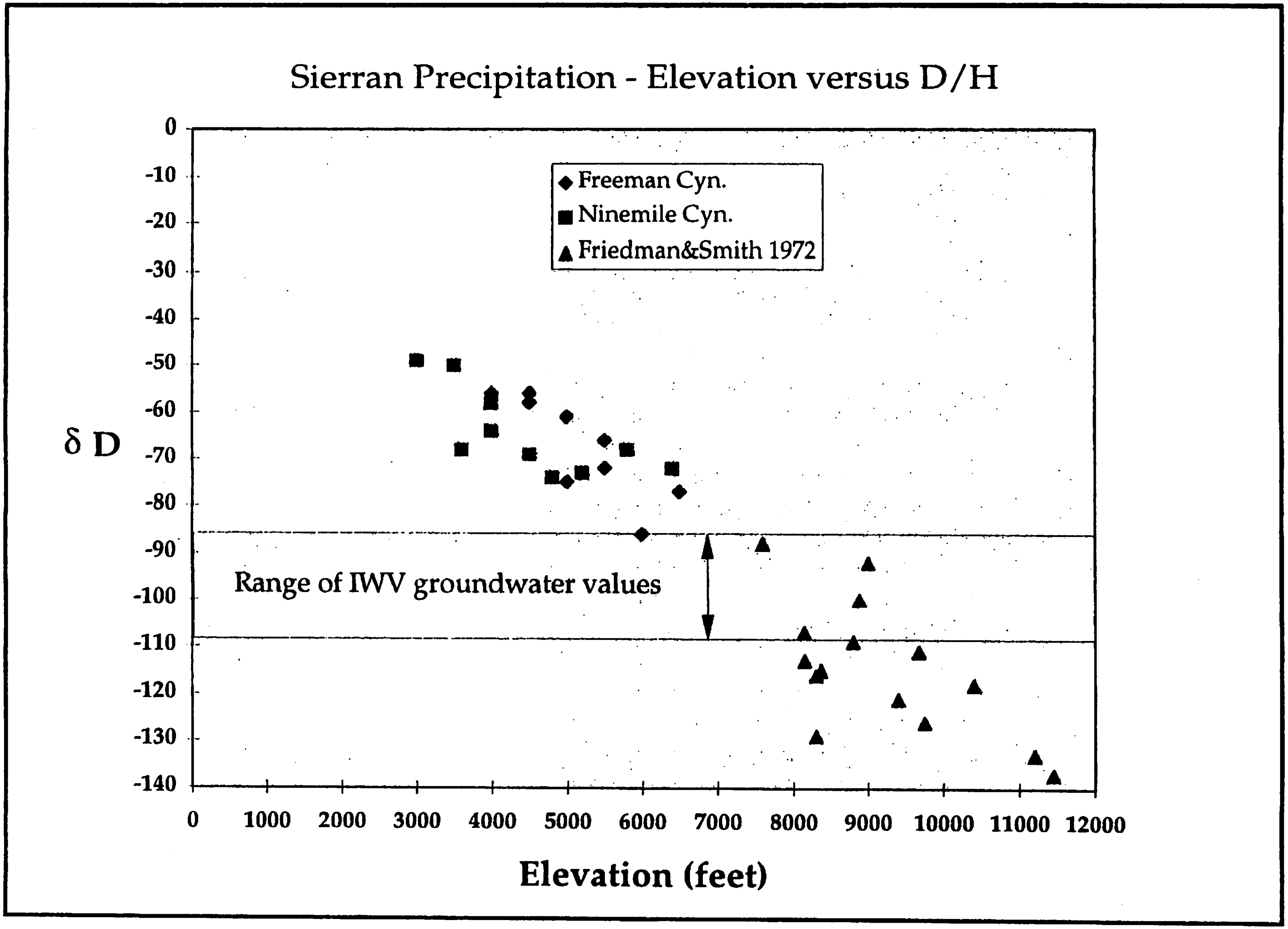
Sierran Precipitation - Elevation versus D/H
Freeman Cyn.
Ninemile Cyn.
Friedman&Smith 1972
Range of IWV groundwater values
δ D
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
Elevation (feet)

Figure 6