DRAFT

MEMORANDUM

Date: May 16, 2001

To: The Honorable Chair and Members
Pima County Board of Supervisors

From: C.H. Huckelberry
County Administrator

Re: **Lower Cienega Basin Source Water Study**

When Critical Habitat for the pygmy-owl was designated in 1999 by the United States Fish and Wildlife Service, Pima County's Tucson Mountain Park was included due to the importance of this location to the conservation of pygmy-owls and because the Tucson Mountain Park plan itself did not assure that future land management of the park would be compatible with pygmy-owl protection. Pima County, through the Sonoran Desert Conservation Plan, will write such assurances into the Tucson Mountain Park plan, and institute, in partnership with other stakeholding government agencies, the programs that will contribute to the recovery of the species.

This commitment requires that we understand the variables that can lead to or detract from recovery of the species. Pima County has undertaken a series of studies that have enhanced the state of knowledge with regard to pygmy-owl locations, life activities, habitat needs, and genetic make up. Now that we have a clearer idea of how to configure our land management plans to meet the federal purpose of endangered species protection, we can provide the assurances that we lacked at the time of the designation of critical habitat.

Pima County is a landowner in another part of Eastern Pima County that is vital to the goal of conserving vulnerable species under the Sonoran Desert Conservation Plan: that is, the Cienega Creek Natural Preserve. The mapping of species locations indicates that the Cienega Creek Natural Preserve and surrounding areas are essential to the conservation of a number of priority vulnerable species. The attached study entitled *Lower Cienega Basin Source Water Study* provides basic information about the source of surface water in Cienega Creek at the downstream end of the Preserve, which will contribute to our effort to conceptualize and implement effective land management proposals for the Sonoran Desert Conservation Plan.

The study results, two years in the making, indicate that the surface flow or subflow from Agua Verde Creek do not significantly influence the water in the Cienega Creek. The study goes on to conclude that "the isotopic and chemical signature of water from Cienega Creek is significantly different from that of water from Posta Quemada Spring." However, similarities were found between water in the Cienega Creek and water in the Del Lago Well, which "in combination with the geologic interpretation of the area, suggest that water in the creek may be in hydraulic connection with water in the well."

These are the types of findings that will allow us to formulate more effective land and resource protection plans. I am forwarding this study to participating jurisdictions with the invitation to improve the content or suggest additional studies that we might jointly pursue to enhance the community's knowledge about the connections that exist between land, water and wildlife protection as we finalize and implement the Sonoran Desert Conservation Plan.

Attachment

Lower Cienega Basin Source Water Study

FINAL PROJECT REPORT

Prepared by Pima Association of Governments for Pima County

ACKNOWLEDGMENTS

PAG would like to thank the following people who assisted on this project: Julia Fonseca at Pima County Flood Control District for including the project in PAG's work program for the District and for providing guidance on various aspects of the project; Elizabeth Hill of Pima County Flood Control District for critical review of the manuscript; Gary Hicks of Saguaro Well & Pump for helping PAG staff sample Vail Water Company's Del Lago Well #1; Chris Eastoe of the University of Arizona's Laboratory of Isotope Geochemistry for critical review of the document and providing the ^{14}C, $\delta^{13}C$, $\delta^{34}S$, and tritium analysis results; Steve Richard at the Arizona Geological Survey for assisting with the geologic interpretation of the Pantano Dam area; Howard Grahn for providing critical review of the manuscript; and Cheryl Karrer who started this project and collected much of the data, when she was a Water Quality Planner at PAG.

This study was funded by the Pima County Flood Control District.

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LOWER CIENEGA BASIN SOURCE WATER STUDY

PURPOSE

The purpose of this study was to determine the source of surface water in Cienega Creek at the downstream end of the Cienega Creek Natural Preserve. The project included using the isotopic signatures for hydrogen and oxygen in combination with water chemistry data to determine similarities and differences between the waters at several locations within the study area. The connection between surface water in Cienega Creek above and below its confluence with Agua Verde Creek with water in a well which taps the local bedrock aquifer was of particular interest.

This two-year project was conducted by Pima Association of Governments (PAG) as part of the FY 1998-1999 and FY 1999-2000 Work Program with Pima County Flood Control District. The project was conducted jointly, with the Pima County Flood Control District staff primarily supervising the progress of the work.

BACKGROUND

Study Area

Cienega Creek is an important water, recreation, and wildlife resource located southeast of Tucson, Arizona. The creek originates in the Canelo Hills at an elevation of approximately 5,700 feet and continues roughly 40 to 50 miles toward the northwest where it becomes Pantano Wash, at an elevation of about 3,100 feet, near the community of Vail, Arizona (Figure 1). It is one of the few low-elevation streams in Pima County that exhibit significant perennial flow. However, surface water flow is interrupted, with perennial reaches located both upstream and downstream of Interstate 10. The remainder of the stream has either intermittent or ephemeral flow.

The focus of this study is a perennial reach of Cienega Creek upstream of Pantano Dam (Figure 2). Generally, the upstream end of this reach begins at approximately 3240 feet in elevation and ends at 3,193 feet, the elevation of Pantano Dam. The reach extends approximately 1,130 feet upstream from the dam. Upstream is a two mile long intermittent reach that contains the juncture of Agua

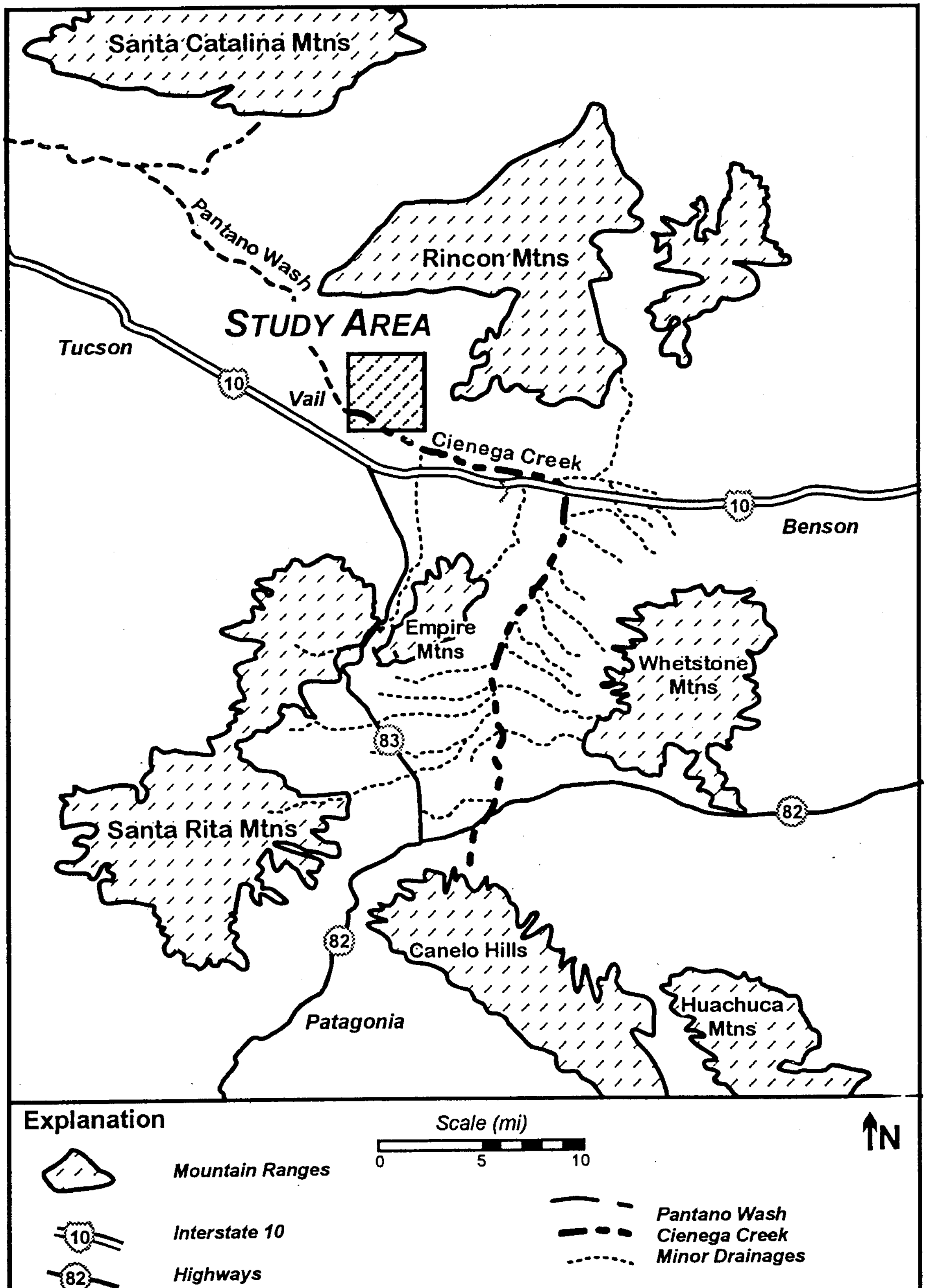

Figure 1. Study Area Location Map

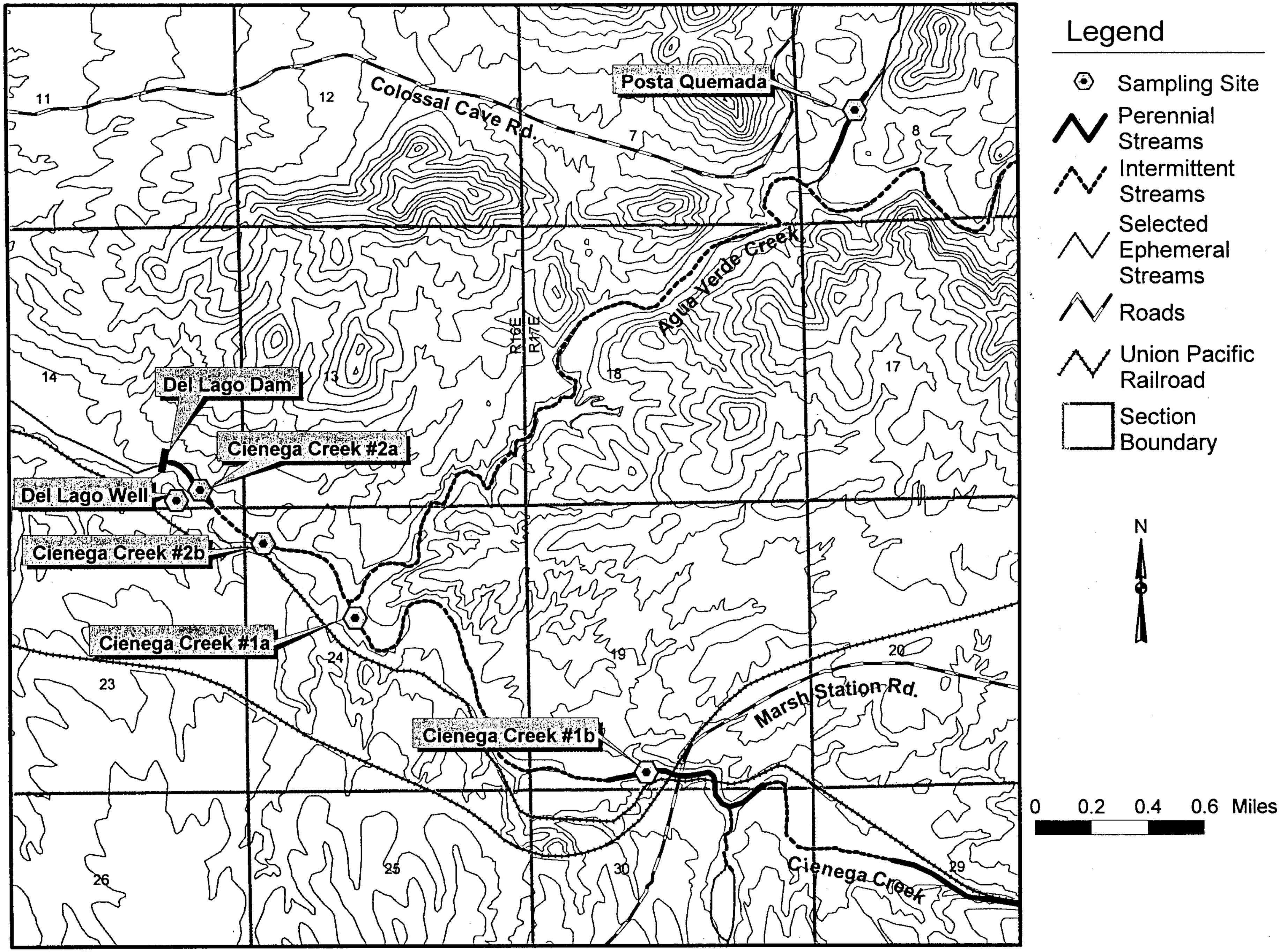

Figure 2. Sampling Site Locations. (Contours, Roads, Railroads & Stream Channels from PCLIS Version 12.0)

Verde Creek and Cienega Creek. This intermittent reach also contains two short perennial reaches (both too short to be displayed on Figure 2), that are downstream of the Agua Verde Creek confluence (the PAG Southern Pacific Mile Post 1006 monitoring site see PAG 1998). Upstream of the long intermittent reach is a perennial reach of the creek that ends downstream of the Marsh Station Road bridge and begins upstream of the Cienega Creek and Davidson Canyon confluence (Figure 2) (PAG 2000, PAG 1998).

Pantano Dam is owned by the Vail Water Company. The dam is located in T16S, R16E, Section 14, roughly 1.5 miles upstream from Colossal Cave Road. The dam effectively ends the perennial reach of the creek by diverting water for irrigation at the Vail Valley development to the northwest. The dam, constructed in 1911, is an at-grade concrete structure built directly on bedrock creating a complete barrier to subsurface flow (Hill 1998). A United States Geological Survey stream gage and a Pima County ALERT station are located on the north bank of the creek 60 feet upstream from the dam.

Three areas were sampled to determine the inputs of water into the reach, Cienega Creek upstream from Agua Verde Creek, Posta Quemada Spring, and the Vail Water Company Del Lago Well #1 (Del Lago Well). Del Lago Well is located in the same section as the Pantano Dam, but it is approximately 300 to 500 feet south of the dam. The land surface elevation of the well is 3,241 feet. The well was drilled in June and July of 1959 and was never used because of high sulfate content. A driller's log of the well is found on Table 1. The well diameter is 16 inches and the well is perforated from 20' to 263'. The static water level in the well before the sampling event was 79.8 feet below land surface.

Table 1. Driller's log of Vail Water Company Del Lago Well #1 (Arizona Department of Water Resources 1997).

From (feet)	To (feet)	Description of formation material
0	50	Large boulders - loose
50	141	Limestone
141	234	Sand and gravel, some clay
234	280	Clay with limestone streaks
280	308	Limestone

Posta Quemada Spring is a perennial water source that feeds Posta Quemada Creek, which is a major tributary of Agua Verde Creek (PAG 2000). The spring is located in T16S, R17E, Section 8 in Colossal Cave Park at an elevation of approximately 3500 feet. Agua Verde Creek and its tributary, Posta Quemada Creek, are the only perennial or intermittent tributaries of Cienega Creek downstream of the Marsh Station Road Bridge and one of only two in the lower Cienega Creek Basin. The only other perennial or intermittent tributary to Cienega Creek is Davidson Canyon. Agua Verde is also the only major tributary of Cienega Creek that has its headwaters in the Rincon Mountains.

Geologic Background

The lower Cienega Creek source water study area is located in a region with very complex geologic relationships. Geologic maps of the area include a regional map by Drewes (1977) and an unpublished map by Tom Finnell, USGS. Steve Richard of the Arizona Geological Survey provided PAG staff with map and assisted with field interpretations for the area.

In the area near Pantano Dam, Cienega Creek is underlain by streambed alluvium that consists of unconsolidated silt, sand, and gravel deposits. This alluvium was deposited within Cienega Creek; it probably does not extend more than 10's of feet below the river bottom, and it does not extend laterally beyond the river channel, which is incised in this area.

Bedrock units in the study area include Paleozoic limestone, Tertiary Pantano Formation, and a fanglomerate of uncertain age. Paleozoic and Tertiary units are highly faulted and they occupy the hanging wall of a regional low angle normal fault (detatchment fault). Granitic and gneissic rocks exposed in the core of the Rincon Mountains occur in the footwall of the fault.

The Posta Quemada Spring is located in a fault-bounded block/mass of Paleozoic limestones. Numerous stratigraphic transitions and fault zones have been mapped between the Posta Quemada Spring area and Cienega Creek. The only likely hydrologic connection between these areas would be through surface flow or through subflow within streambed sediments.

The Paleozoic Horquilla Limestone is well exposed on both sides of Cienega Creek at Pantano Dam and it is probably the limestone unit that was intersected at 50 feet below land surface in Del Lago Well (Table 1). This unit underlies the Cienega Creek alluvial aquifer at and near Pantano Dam. At Pantano Dam, the Horquilla consists of pinkish-gray fine-grained to micritic limestone that is interbedded with reddish colored fine-grained clayey siltstones. Geologic mapping indicates that there is probably a pre-Miocene fault within the Horquilla rocks that may be trending parallel with Cienega Creek. On the northern side of Cienega Creek, most of the exposed rock consists of massive limestone beds, with lesser amounts of interbedded siltstones. These units are relatively flat lying, although they are cut by north-south trending joints that dip approximately 70 degrees to the west and are spaced at irregular intervals of approximately 0.5 –2 feet. Joints are best developed in the massive limestone units. On the southern side of Cienega Creek, approximately half the exposed Horquilla consists of reddish brown calcareous siltstone and the rocks have been highly deformed. At depth, joints within the Horquilla may be providing a bedrock fracture aquifer.

In the lower Cienega Creek area, the Tertiary Pantano Formation overlies Paleozoic and Mesozoic rocks in tilted fault blocks. The Pantano Formation is exposed along Cienega Creek east of Marsh Station Road, where Interstate-10 crosses Cienega Creek. It is very heterogeneous, containing volcanic rocks, conglomerates, sandstones, and siltstones. Recognizable Pantano Formation is not present in the Pantano Dam area, where a well cemented fanglomerate, of uncertain age, unconformably overlies the Paleozoic Horquilla formation.

The fanglomerate exposed near Pantano Dam is an evenly bedded conglomeratic unit that was probably deposited as an alluvial fan. Alluvium sources included granitic and gneissic rocks from the Rincon Mountains and sedimentary rocks from nearby Paleozoic units. The fanglomerate is either a young part of the Pantano Formation, deposited after the granitic core in the Rincon Mountains was exposed, or it may be younger than the Pantano Formation. The fanglomerate is gently tilted and is cut by minor faults, but these faults are not very regular or abundant, making it an unlikely bedrock aquifer. The fanglomerate is best exposed on the southern bank of Cienega Creek approximately 500 feet downstream from Pantano Dam. It is also exposed along the cliff faces on the southern side of Cienega Creek approximately 50 feet northeast of Del Lago Well, and approximately 20 feet below the elevation of the top of the well.

The alluvial terraces near Pantano Dam consist of non-consolidated gravel and sand deposits that contain clasts from the Bisbee Group, probable Tertiary volcanic rocks, and older granite, limestone, and quartz clasts from upland areas. Exposures of this unit can be found in road cuts south of Pantano Dam and the terrace surfaces throughout the Dam area. It is possible that this unit is somewhat gypsiferous because it is partially derived from the Pantano Formation, which is known to contain gypsum deposits.

Based on the geology of the area, as described above, the most likely aquifer at Del Lago Well is a fractured bedrock aquifer in the Horquilla Limestone. The well is not in contact with the streambed alluvial aquifer in Cienega Creek. However, water flowing within or beneath the creek surface could penetrate fractures within the Horquilla causing recharge of recent waters to the bedrock system. Based on PAG's ongoing water level monitoring, water levels in Del Lago Well are generally 10 to 25 feet below the elevation of the streambed in the area upstream from Pantano Dam. The Horquilla also contacts the streambed aquifer downstream from Pantano Dam, where it may provide an additional source of subflow to the downstream portion of the creek. When water levels in Del Lago Well are high, they are above the elevation of the streambed in areas downstream from Pantano Dam. It is also possible that surface flow crossing the terrace deposits may infiltrate and reach the bedrock aquifer either by recharging through near-surface perforations in the well bore, or by recharge in nearby drainages or low areas.

Study Approach

This study attempts to determine the source of water in Cienega Creek downstream from the confluence with Agua Verde Creek and upstream from Pantano Dam. The project approach involved sampling both groundwater and surface water and analyzing samples for the stable isotopic composition of hydrogen and oxygen and the inorganic chemical composition of the water. This work was supplemented by geologic interpretations in the field and a review of groundwater and streambed elevations. Tracer tests and hydrogeologic models were not used in this study.

Stable isotopes of hydrogen and oxygen are accurate indicators of sources of water because the major changes to the isotopic composition of water occur in the atmospheric part of the water cycle. Changes also occur in surface waters due to evaporative effects. Therefore, groundwaters 'inherit' the isotopic signatures of their 'parental' atmospheric and surface waters (International Atomic Energy Agency 1981). However, oxygen isotopes in groundwater potentially can be shifted if there is sufficient interaction between water and carbonate rocks. Kalin (1994) measured the isotopic signatures of precipitation at different elevations during different seasons in the Tucson area as well as the isotopic signature of the water that infiltrated in two riparian corridors (values found on Table 2). General trends in isotopic signatures are that "lighter" values are found in winter precipitation and at higher elevations.

Table 2. Isotopic signatures of Tucson area precipitation and recharged water (after Kalin 1994).

Source	Average $\delta^{18}O$	Average δD	Average d parameter
Basin Summer Precipitation	-5.43	-38.63	4.98
Basin Winter Precipitation	-8.62	-57.76	11.14
Mountain Summer Precipitation	-7.2	-47.66	12.6
Mountain Winter Precipitation	-11.93	-71.44	24.0
Santa Cruz River Recharge	-8.60	-63.10	7.25
Rillito Creek Recharge	-9.20	-60.72	12.91

While stable isotope data are useful in determining the source of the precipitation of water and whether the water has undergone evaporation, the isotopic data say little about the processes that affect the water after it has infiltrated into the earth. The inorganic chemical composition of the water reflects the post-precipitation environment of the water. The major components of post-precipitation environment are climate, structure and position of rock strata, and the biochemical effects of both micro- and macroscopic plants and animals. The processes important to the water chemistry include weathering and erosion of rocks and soil, solution and precipitation reactions occurring beneath the land surface, and anthropogenic factors (Hem 1985).

METHODOLOGY

Site Selection and Sampling Dates

The Lower Cienega Creek Basin study involved sampling at four locations (Figure 2). Sampling sites were located along Cienega Creek, at Posta Quemada Spring (Posta Quemada), and the Vail Water Company Del Lago Well #1 (Del Lago Well). Cienega Creek samples were taken both upstream of the confluence with Agua Verde Creek (Cienega Creek #1a & #1b) and downstream of the confluence (Cienega Creek #2a & #2b). The creek was sampled above and below the Agua Verde confluence to determine the influence of surface flow and subflow from Agua Verde Creek on the chemistry and isotopic signature of surface water in Cienega Creek. Groundwater sampling was conducted at the Vail Water Company Del Lago Well #1. The Del Lago Well was sampled to estimate the connection of the local bedrock aquifer to surface water flow in Cienega Creek.

- Surface water sampling was conducted over a two-year time span to capture any seasonal effects on the relationship between surface water, groundwater, and mountain front-recharge. Cienega Creek was sampled seven times: 9/28/98, 11/19/98, 4/29/99, 6/17/99, 8/24/99, 11/19/99, and 3/31/00. Because of seasonal lack of flow, the Posta Quemada site was only sampled five times: 9/30/98, 11/19/98, 4/29/99, 6/17/99, and 8/24/99. Samples collected in August and September represent conditions during the summer rainy season. The November samples were taken during the dry fall season and the June sampling events occurred during the dry spring season. Winters in both 1998/1999 and 1999/2000 were unusually dry. Therefore, wet winter samples were collected in March and April, since substantial seasonal precipitation was not recorded earlier in the year. Because of access issues, the Del Lago Well was sampled only once, on 6/25/99.

Surface Water Sampling Procedures

In the field, PAG staff went through the following procedures for each sampling event:

1) Site selection based on availability of flow;
2) Measurement of field parameters;
3) Collection of isotope samples;
4) Collection of water chemistry samples; and
5) Measurement of flow when appropriate.

Upon arriving at the sampling area, PAG staff would locate appropriate sampling locations based on availability of flow. Because of occasional lack of flow in Cienega Creek near the confluence with Agua Verde Creek, various locations were sampled (Figure 2). When flow was available just east (upstream) of the point of confluence (Cienega Creek #1a) samples were taken there. When flow was unavailable at that location, samples were collected just downstream of the Marsh Station Road

Bridge (Cienega Creek #1b). For the downstream sampling location, most of the samples were obtained just upstream of the Pantano Dam (Cienega Creek #2a). When flow was unavailable in that location, samples were taken farther upstream, near Southern Pacific Mile Post 1006 (Cienega Creek #2b).

Field parameters, including temperature, specific conductivity, and pH, were measured in the field and at the laboratory for each of the sampling events. For the first three sampling events (9/28/98 & 9/30/98, 11/19/98, and 4/29/99), PAG staff used a Hydac meter in the field. For subsequent sampling events (6/17/99, 8/24/99, 11/19/99, and 3/31/00), PAG staff used a Myron 6P Ultrameter. The change in parameter meter was necessary because the Hydac meter stopped working.

Bottles for water chemistry samples were prepared and pre-preserved by Turner Laboratories. Isotope bottles were prepared in the field by rinsing the bottle three times with sample water prior to filling to assure that the bottle contained only the water being sampled. Water chemistry samples were filtered in the field using a 0.45-micron filter. The sample bottles for both isotope and water chemistry analyses were individually labeled in indelible ink with the sample name, date and time of collection. The samples were collected in containers that were tightly sealed, with minimal headspace, and chain-of-custody forms accompanied the samples from the field to the laboratory. Duplicate samples were collected in the 4/29/99, 6/17/99, 8/24,99, 11/19/99, and 3/31/00 sampling events. All water chemistry samples were stored in an ice chest until they were hand-delivered to the laboratory. The samples for stable isotope analysis were hand delivered to the University of Arizona's Laboratory of Isotope Geochemistry and the water chemistry samples were hand submitted to Turner Laboratories in Tucson, Arizona for cation/anion analyses.

Flow measurements were taken for Cienega Creek when flow volume was substantial enough to measure. A Qualimetrics brand, model 6660 digital water current meter was used for the measurements. Discharge was calculated from velocity and depth measurements made at equally spaced intervals across the stream channel. In extremely low flow situations, flow was estimated in the field by PAG staff. No flow measurements were taken or estimated at Posta Quemada Spring because of the broad and braided channel morphology of the site, as well as limited availability of flow.

Groundwater Sampling Procedures

PAG received permission from Vail Water Company in April 1999 to pump and sample the Del Lago Well. On June 25, 1999, PAG staff, with assistance from Gary Hicks of Saguaro Well & Pump, used a GrunFlos Model 30 SQ/SQE 15C-170 3-inch submersible pump to sample the well. The pump produced approximately 40 gpm. The water level recorded before pumping began was 79.8 ft, from the top of the casing. At a pumping rate of 40 gpm, an estimated four-hour pumping duration was calculated to purge the well four times. Over four full well volumes, approximately 9,332 gallons, were pumped from the well prior to sampling. Stable isotope and water chemistry samples were collected following the same procedures followed during surface water sampling. Field parameters were measured with a Myron 6P Ultrameter. Additionally during the well sampling event, samples for tritium, ^{13}C, ^{14}C, and ^{34}S were taken by Joy Gillick at the University of Arizona (Gillick and Eastoe unpublished data).

Lab Procedures & Quality Assurance/Control Procedures

Stable Isotopes

All stable isotope analyses were performed by the University of Arizona's Laboratory of Isotope Geochemistry in Tucson, Arizona. All $\delta^{18}O$ and δD measurements were made with a Finnegan DELTA-S mass spectrometer. $\delta^{18}O$ analyses were performed on carbon dioxide with which the water samples were equilibrated. δD analyses were performed on hydrogen that was liberated from the water samples by reaction with chromium. The laboratory calibrated relative to Vienna Standard Mean Ocean Water (V-SMOW), Standard Light Antarctic Precipitation (SLAP), and Greenland Ice Sheet Precipitation (GISP), which are international standards for stable isotope measurements in natural waters (Laboratory of Isotope Geochemistry 1992; Laboratory of Isotope Chemistry 1997).

Water Chemistry

Samples were submitted to Turner Laboratories in Tucson Arizona for analysis, except for the 11/19/99 metals analysis, which was sent to Severn Trent Laboratories in Pensacola, Florida. Severn Trent Laboratories had a lower practical quantitation limit (PQL) for aluminum analysis than Turner Laboratories. For each sample, analyses were run for silicon, aluminum, calcium, iron, magnesium, potassium, sodium, sulfate, alkalinity (as $CaCO_3$), specific conductivity, pH, and total dissolved solids (TDS). Chloride was analyzed in all samples except for the 4/29/99 sampling event when a chlorine analysis was erroneously requested. Bromide, fluoride, nitrite, and nitrate analysis were dropped from the sample plan because of non-detectable or low levels of these constituents. Analyses for boron, manganese, and arsenic were added. Sample dates and results are found in the discussion section.

PAG staff completed a quality assurance/quality control analysis for each set of results from the water chemistry laboratories. All of the samples were within the accepted range of less than 5% for the charge balance, except for the duplicate sample from Del Lago #1 Well, which was 6.63%. This may be a result of an elevated sulfate measurement in the duplicate.

RESULTS AND DISCUSSION

Stable Isotopes

δD vs. $\delta^{18}O$ values for the Cienega Creek sites, Posta Quemada, and the Del Lago #1 Well are included on Table 3 and on Figure 3. The δD and $\delta^{18}O$ values are plotted separately in Figures 4 and 5. The δD vs. $\delta^{18}O$ values of Cienega Creek #1, Cienega Creek #2, and Del Lago Well fall under the meteoric water line, which suggests that the water has undergone some evaporation. This is characteristic of water in semi-arid to arid regions. The relative "heaviness" of these samples also suggests that the precipitation responsible for both the creek water and ground water fell at relatively low elevations. The Posta Quemada values were significantly "lighter", which is indicative of water that originated at higher elevations. In addition, the Posta Quemada values plotted above the meteoric water line, possibly indicating a snowmelt origin.

Statistical analysis (analysis of variance or ANOVA) was conducted on the δD and $\delta^{18}O$ values from each of the samples. This was done to determine if a significant difference in the isotopic signatures existed between the different sampling locations. The statistical analysis was conducted using SYSTAT 9.0 (SPSS 1999) software. When the values were grouped by site, significant differences ($p<0.05$) were found in both oxygen and hydrogen isotope ratios. Subsequent pairwise Bonferroni adjusted comparisons were conducted to determine which sites were different from each other. Significant differences ($p<0.05$) were found between Posta Quemada and all the other sampling sites in both δD and $\delta^{18}O$ values. The δD and $\delta^{18}O$ values for the two Cienega Creek sites were shown to be not significantly different ($p<0.05$) from each other. In addition, the δD and $\delta^{18}O$ values for the Del Lago Well and the Cienega Creek sites were not significantly different ($p<0.05$) from each other. These statistical comparisons confirmed that both the water in Cienega Creek and the Del Lago Well were derived from low elevation precipitation events that were significantly different isotopically from the precipitation that was responsible for the water at Posta Quemada.

Another set of ANOVAs was run to determine if any seasonal trends were present in the data. The differences from site mean were examined by season of sampling (summer monsoon, dry fall, winter rainy, and dry spring). No significant differences ($p<0.0.5$) were found in the data. However, the 08/24/99 Cienega Creek samples appear to be isotopically "heavier" suggesting that recent summer precipitation had diluted the baseflow of the creek. The data set analyzed is not long term and the test may not be powerful enough to detect seasonal differences with such a small data set. Additionally, the lack of winter precipitation during the sampling period has enhanced the uniformity of the stable isotope data.

Table 3. Stable Isotope Analysis Results, 9/98 - 3/00.

Sample	Cienega Creek #1 site			Cienega Creek #2 site			Posta Quemada			Del Lago #1 well		
Date	O-18	D	d-par	O-18	D	d-par	O-18	D	d-par	O-18	D	d-par
09/28/1998	-7.8	-55.0	7.4	-7.9	-56.0	7.2						
09/30/1998							-10.0	-67.0	13.0			
11/19/1998	-7.9	-55.5	7.7	-7.8	-54.5	7.9	-9.9	-67.0	12.2			
04/29/1999	-7.9	-55.0	8.2	-7.5	-53.0	7.0	-10.0	-66.5	13.5			
06/17/1999	-7.6	-54.5	6.3	-7.8	-54.0	8.4	-9.9	-66.0	13.2			
06/25/1999										-8.1	-55.8	9.1
08/24/1999	-8.5	-62.0	6.0	-8.4	-61.0	6.2	-10.0	-69.0	11.0			
11/19/1999	-7.8	-58.0	4.4	-7.9	-60.0	3.2						
03/31/2000	-7.8	-57.0	5.4	-7.9	-57.0	6.2						
Average	-7.9	-56.7	6.5	-7.9	-56.5	6.6	-10.0	-67.1	12.6	-8.1	-55.8	9.8

Note: All isotope measurements in o/oo V-SMOW

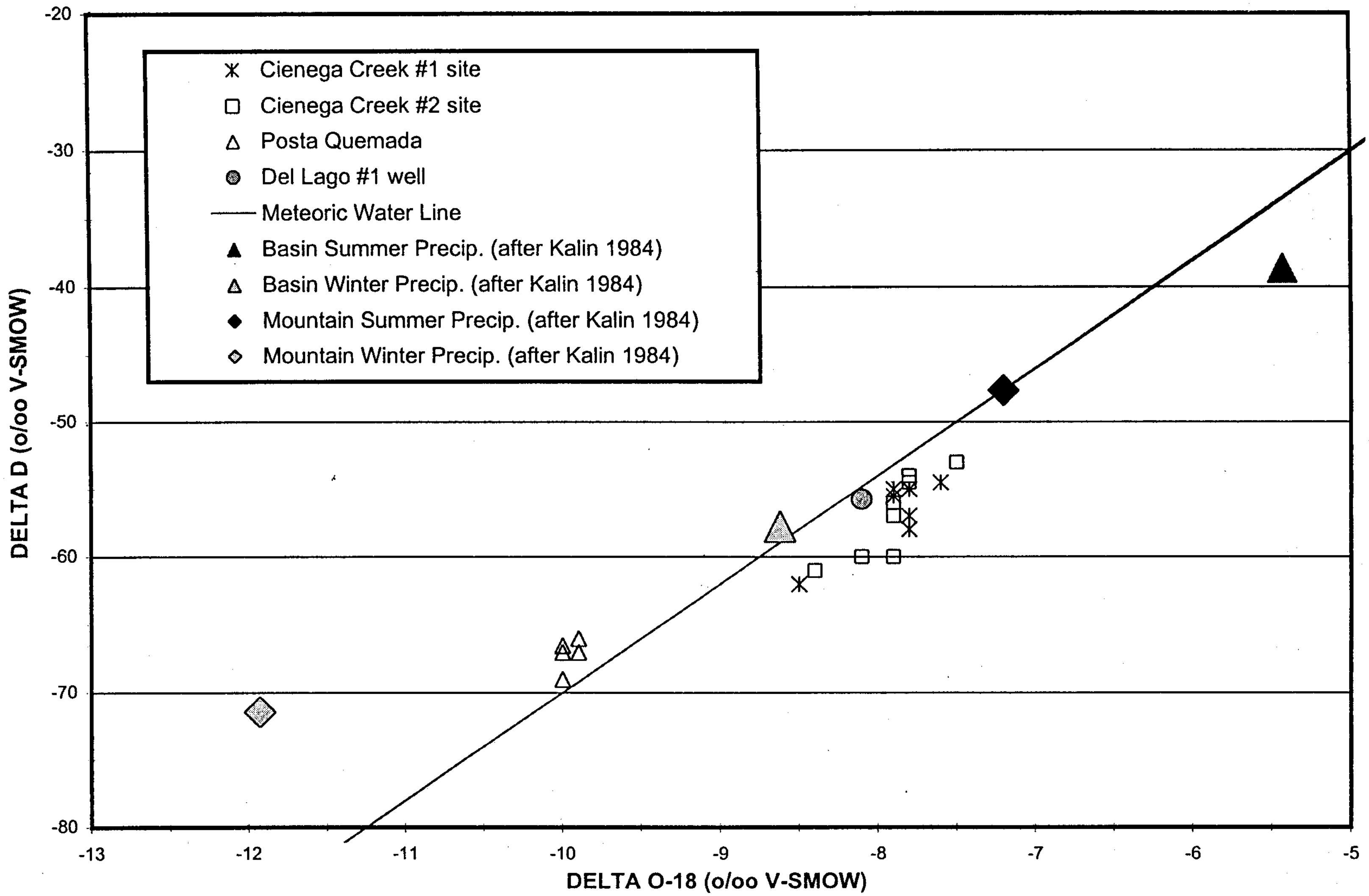

Figure 3. Delta D vs. Delta O18 , 9/98-3/00.

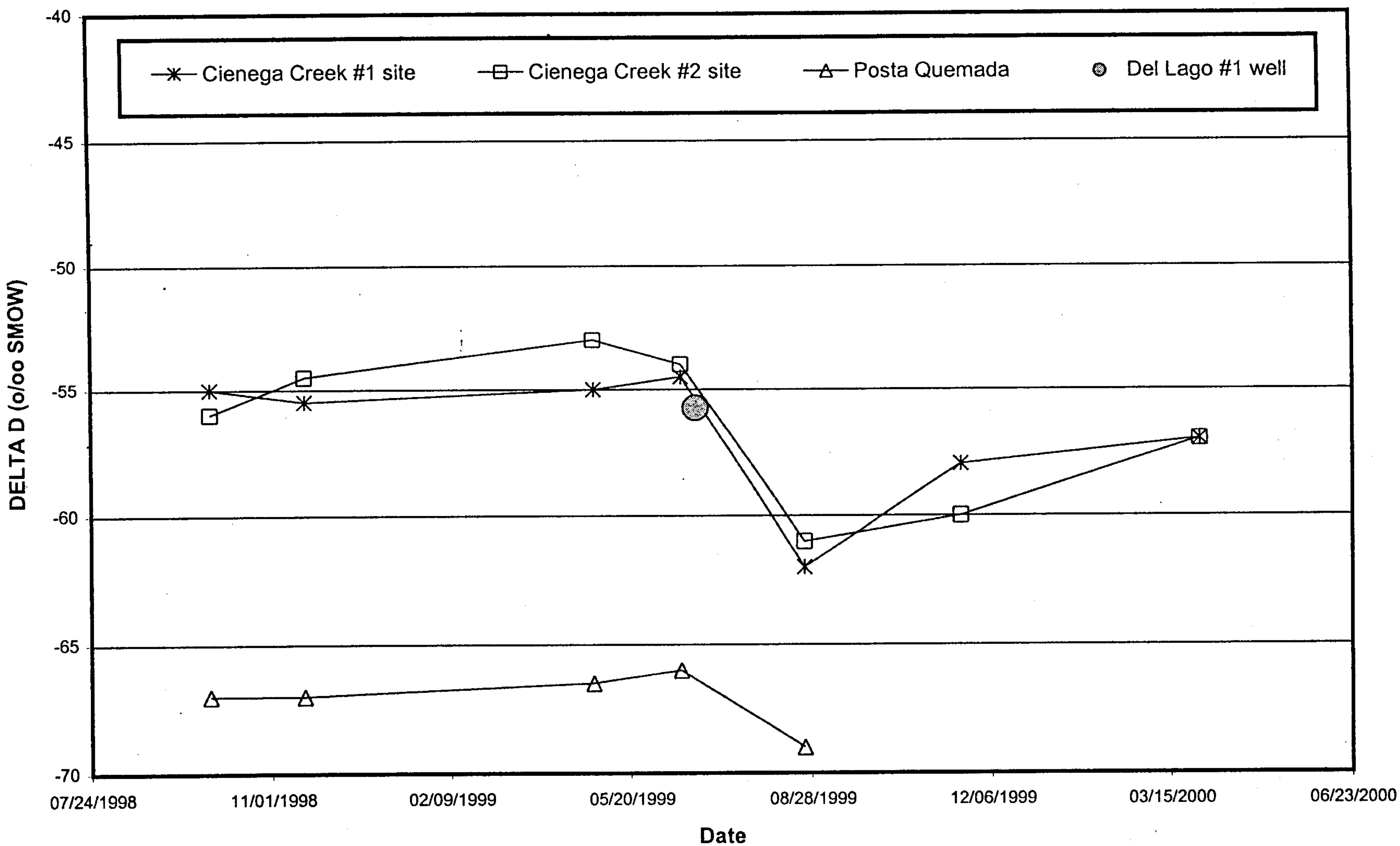

Figure 4. Deuteruim Isotope Results, 9/98 - 3/00.

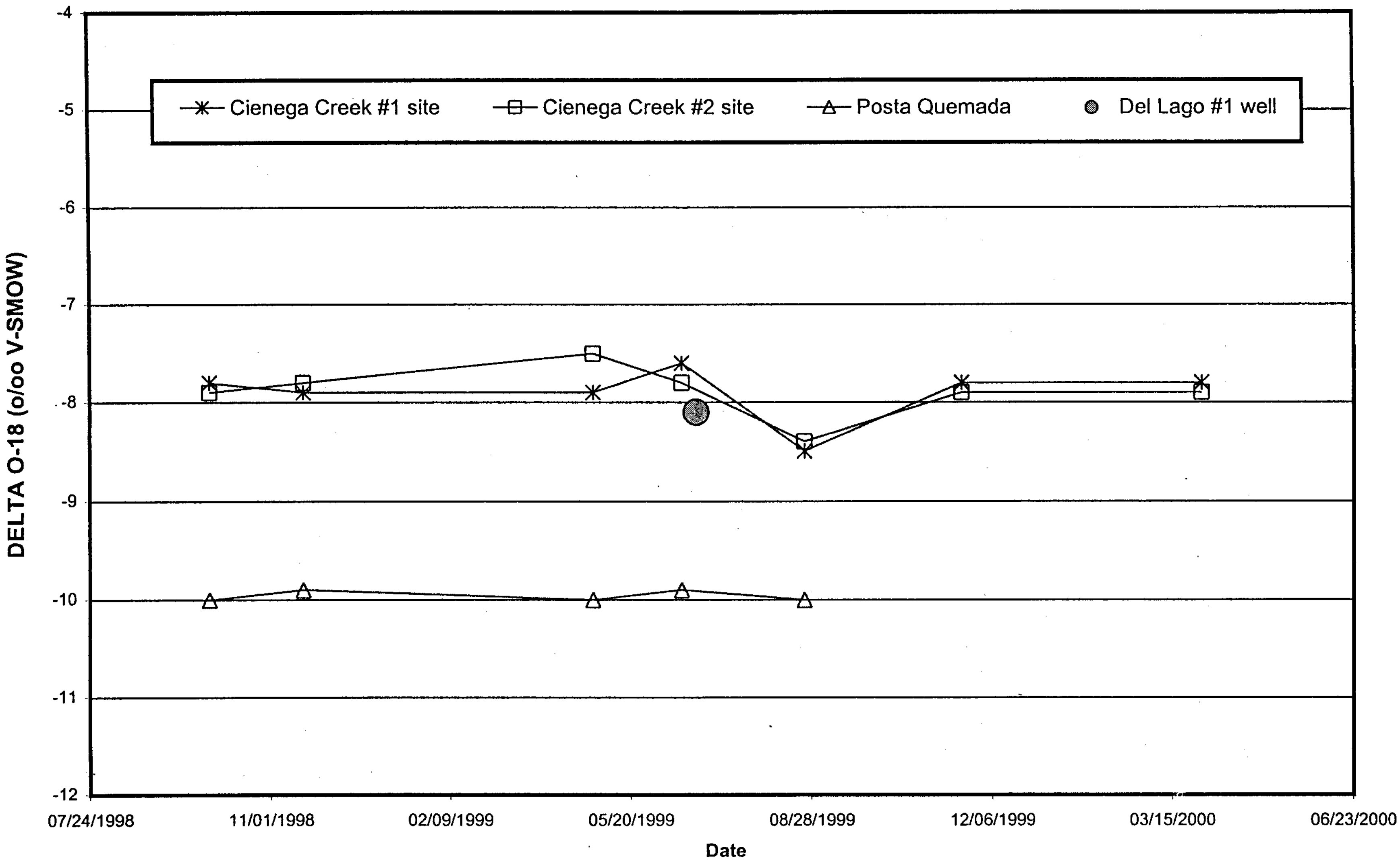

Figure 5. Oxygen-18 Isotope Results, 9/98 - 3/00.

Water Chemistry

The water chemistry data gathered for this report are summarized on Table 4. The major anion and cation values for each sampling event at Cienega Creek #1, Cienega Creek #2, and Posta Quemada are graphically depicted in Figures 6-8 and the parameters are graphed in Figure 9. Alkalinity (as $CaCO_3$), calcium (Ca), and silicon (as SiO_4) were consistent through all the sites with values of approximately 250 mg/l of alkalinity as $CaCO_3$, 100 mg/l of calcium, and 10 mg/l of silicon asSiO_4. Concentrations of sulfate (SO_4), sodium (Na), magnesium (Mg), and chloride (Cl) were considerably higher in water from the Del Lago Well than water from both Cienega Creek and Posta Quemada. Chloride (42 mg/l) and sulfate (630 mg/l) concentrations in the well water were more than double the average concentrations found at any other sites. Posta Quemada samples had lower concentrations of potassium (K), magnesium, sodium and sulfate than other samples. The Cienega Creek samples had similar ionic concentrations and generally were between the concentrations found in Del Lago well water and those found in Posta Quemada samples. As with the isotope data, no seasonal trend in either the parameter or water chemistry data was found. The lack of a discernible seasonal trend could be because of the short-term nature of the sampling, coupled with the climatic extremes (wet monsoon and extremely dry winter seasons) experienced during the sampling period.

Laboratory water chemistry parameters are shown in Figure 9. Field measured parameters were not plotted because two different parameter meters were used during the study. TDS, pH, and conductivity remained constant in samples taken from Cienega Creek upstream and downstream of its confluence with Agua Verde Creek.

The water chemistry concentrations (excluding the 4/29/99 sampling event when chloride concentrations were not analyzed) were plotted onto a Piper Diagram (Figure 10) using the HydroChem (Rockware Inc. 1998) software package. The Piper Diagram suggests that Cienega Creek is chemically consistant upstream and downstream of its confluence with Agua Verde Creek. However, the Posta Quemada samples are chemically different from the Cienega Creeks sites and the Del Lago Well because they have higher (on a percentage basis) levels of bicarbonate and calcium and lower levels of sulfate, chloride, and magnesium. The Del Lago Well sample plotted higher for sulfate, magnesium, and chloride, on the Piper diagram than samples from Cienega Creek or the Posta Quemada. The positions of the various site clusters suggest that the water found at Cienega Creek #2 could not have resulted from mixing of water from Cienega Creek #1 with water from either Del Lago Well or Posta Quemada.

Table 4. Water Quality Summary, 9/98-3/00.

Cienega Creek #1

	09/28/98	11/19/98	04/29/99	06/17/99	08/24/99	11/19/99	03/31/00
Silicon (as SiO_4)	12	12	10	12	11	10	12
Aluminum (Al)	0	0	0	0	0	0	0
Boron (B)	-	-	-	-	0.14	0	0.1
Calcium (Ca)	120	120	120	110	85	100	110
Magnesium (Mg)	35	34	34	33	26	30	32
Manganese (Mn)	-	-	-	0	0	0	0
Sodium (Na)	65	62	65	59	57	56	56
Arsenic (As)	-	-	-	0	0	0	0
Iron (Fe)	0	0	0	0	0	0	0
Potassium (K)	6.8	5.4	6.1	5.7	5.7	4.5	5.2
Chloride (Cl)	14.7	12.8	-	16.8	12	15	14
Sulfate (SO_4)	275	266	285	265	220	220	250
Fluoride (F)	-	0.6	0.7	-	-	-	-
Phosphate (PO_4)	-	-	-	-	-	-	-
Alk. as $CaCO_3$	266	306	258	228	210	230	240
Lab TDS	660	640	670	760	510	540	660
Lab TDS	1000	1000	990	980	860	870	960
Lab Conductivity	7.3	7.5	7.4	7.8	7.9	7.7	7.7
Flow (cfs)	n/a	0.71	0.2	<0.5*	0.54	0.08	0.25

Cienega Creek #2

	09/28/98	11/19/98	04/29/99	06/17/99	08/24/99	11/19/99	03/31/00
Silicon (as SiO_4)	13	12	9.6	11	10	10	12
Aluminum (Al)	0	0	0	0	0	0	0
Boron (B)	-	-	-	-	0.16	0.1	0
Calcium (Ca)	120	120	100	120	84	100	120
Magnesium (Mg)	32	36	32	35	25	28	30
Manganese (Mn)	-	-	-	0.033	25	0	0.035
Sodium (Na)	60	69	68	69	60	59	54
Arsenic (As)	-	-	-	0	0.0052	0	0
Iron (Fe)	0	0	0	0	0	0	0
Potassium (K)	6.7	6.8	6.4	7	6.1	5.2	5.2
Chloride (Cl)	13	15.6	-	15.5	12	14	14
Sulfate (SO_4)	230	309	283	287	250	240	220
Fluoride (F)	-	0.4	0.6	-	-	-	-
Phosphate (PO_4)	-	-	-	-	-	-	-
Alk. as $CaCO_3$	280	290	230	266	210	250	260
Lab TDS	580	750	610	800	550	460	630
Lab Conductivity	950	1100	990	1100	860	920	940
Lab pH	7.8	7.8	7.9	7.4	8.1	8	7.5
Flow (cfs)	n/a	0.06	0.02	n/a	0.47	n/a	n/a

NOTE:

"0" = constituent was not detected at the Pratical Quantitation Limit (PQL) used by Turner or Severn Trent Laboratories.

"-" = constituent was not included in the analysis.

"n/a" = flow was not measured during sampling event.

"*" = flow was estimated by PAG staff.

Concentrations in mg/l

Table 4 cntd. Water Quality Summary, 9/98-3/00.

	Posta Quemada					**Del Lago well**
	09/30/98	11/19/98	04/29/99	06/17/99	08/24/99	06/25/99
Silicon (as SiO_4)	13	11	8.8	8.4	9.5	8.6
Aluminum (Al)	0	0	0	0	0	0
Boron (B)	-	-	-	-	0	0.28
Calcium (Ca)	97	91	79	79	78	130
Magnesium (Mg)	12	11	11	11	11	57
Manganese (Mn)	-	-	-	0	0	0.76
Sodium (Na)	21	20	17	18	0	160
Arsenic (As)	-	-	-	0	0	0
Iron (Fe)	0.88	0.36	0	0	0	1.4
Potassium (K)	0	0	0	0	0	7.5
Chloride (Cl)	9.1	8.5	-	9.3	8	42
Sulfate (SO_4)	16.7	19.2	23.6	25.2	23	630
Fluoride (F)	-	0.6	0.4	-	-	-
Phosphate (PO_4)	-	-	-	-	-	0
Alk. as $CaCO_3$	320	290	248	250	240	244
Lab TDS	370	290	330	370	340	1200
Lab Conductivity	590	570	500	560	550	1700
Lab pH	6.8	7.2	6.9	7.1	7.1	7.3
Flow (cfs)	n/a	n/a	n/a	n/a	n/a	n/a

NOTE:

"0" = constituent was not detected at the Pratical Quantitation Limit (PQL) used by Turner or Severn Trent Laboratories.

"-" = constituent was not included in the analysis.

"n/a" = flow was not measured during sampling event.

"*" = flow was estimated by PAG staff.

Concentrations in mg/l

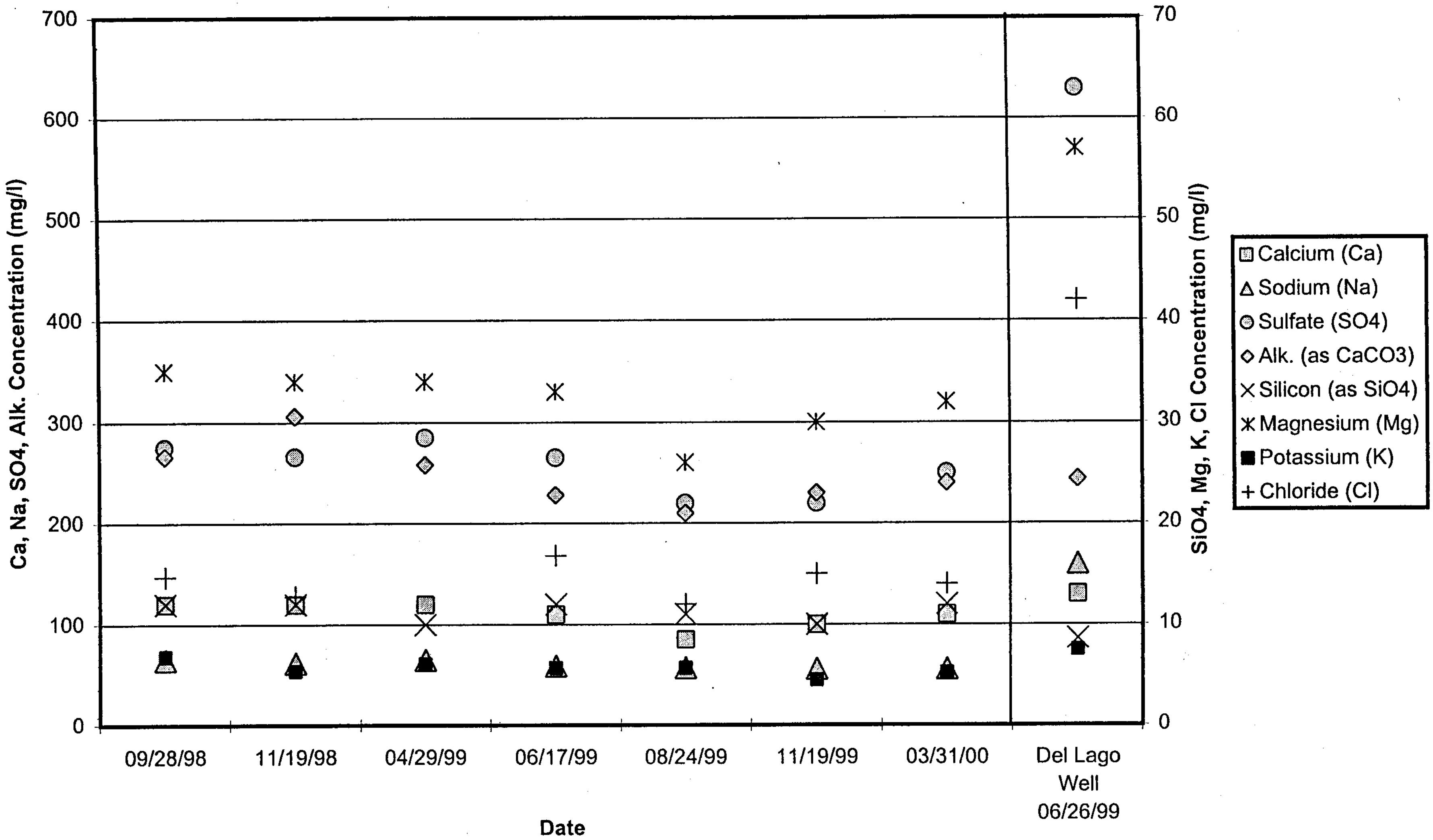

Figure 6. Water Chemistry Data for Cienega Creek Site#1, 9/98-3/00,

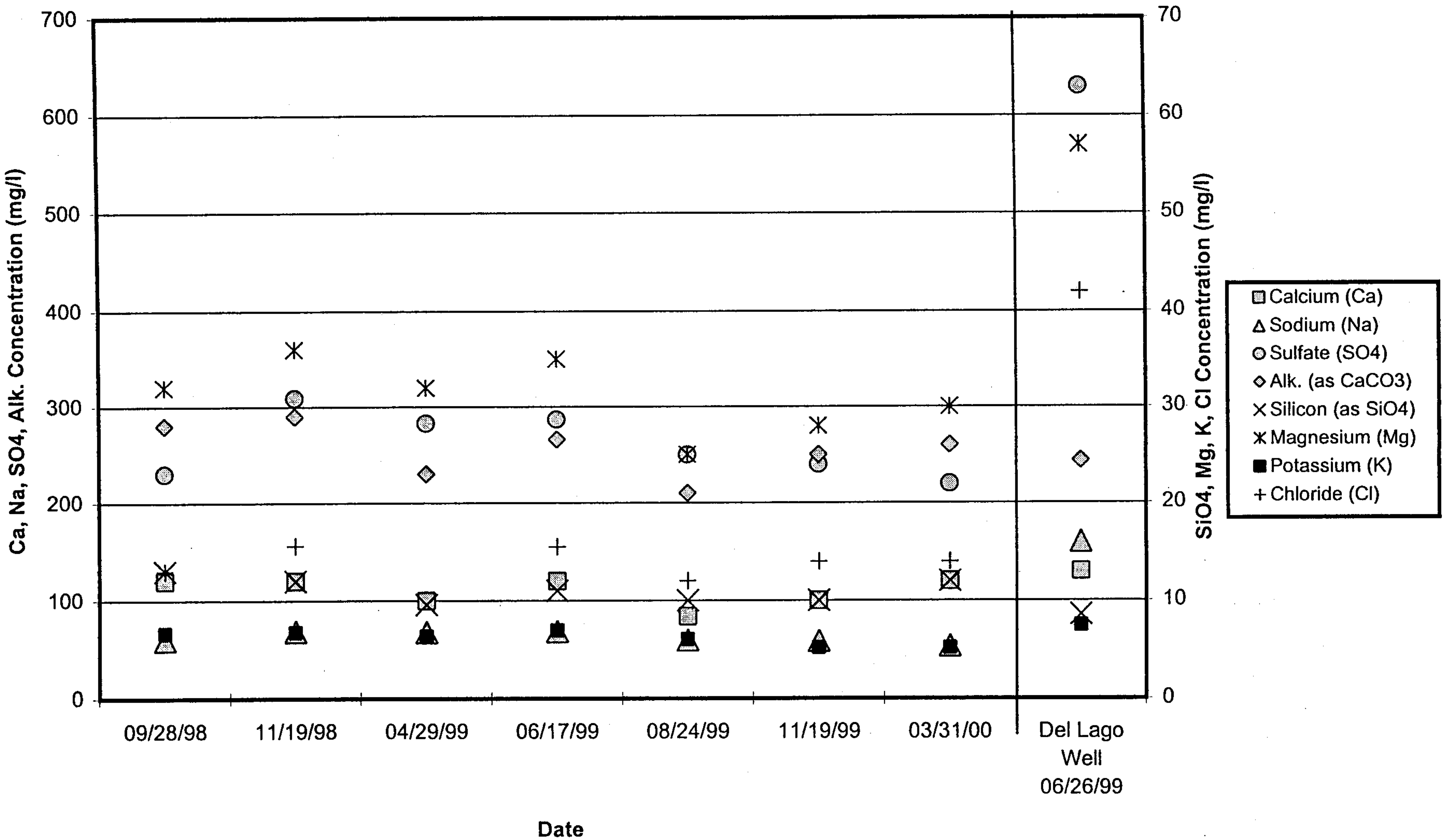

Figure 7. Water chemistry data for Cienega Creek Site #2, 9/98-3/00.

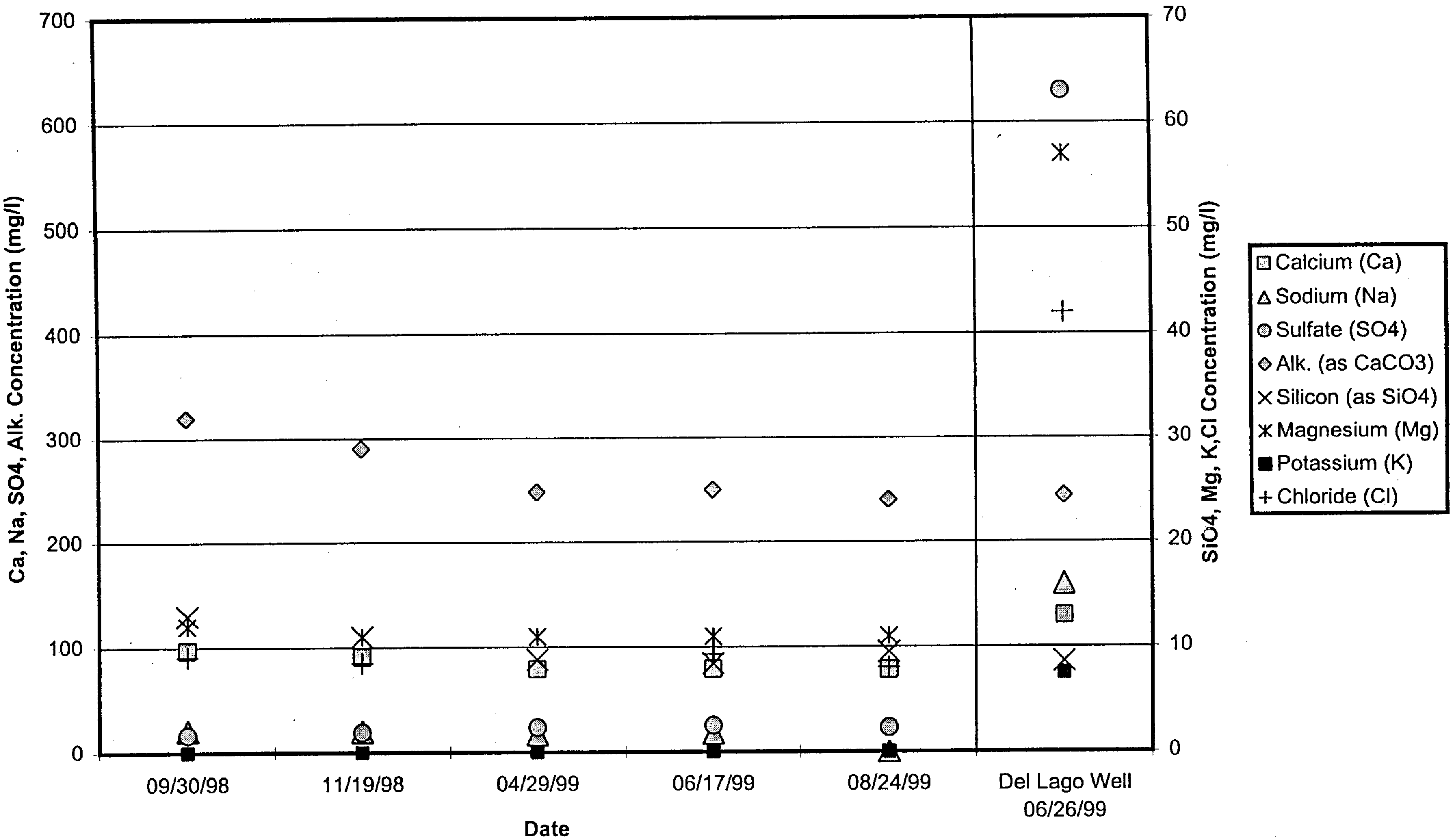

Figure 8. Water Chemistry Data for Posta Quemada, 9/98-3/00.

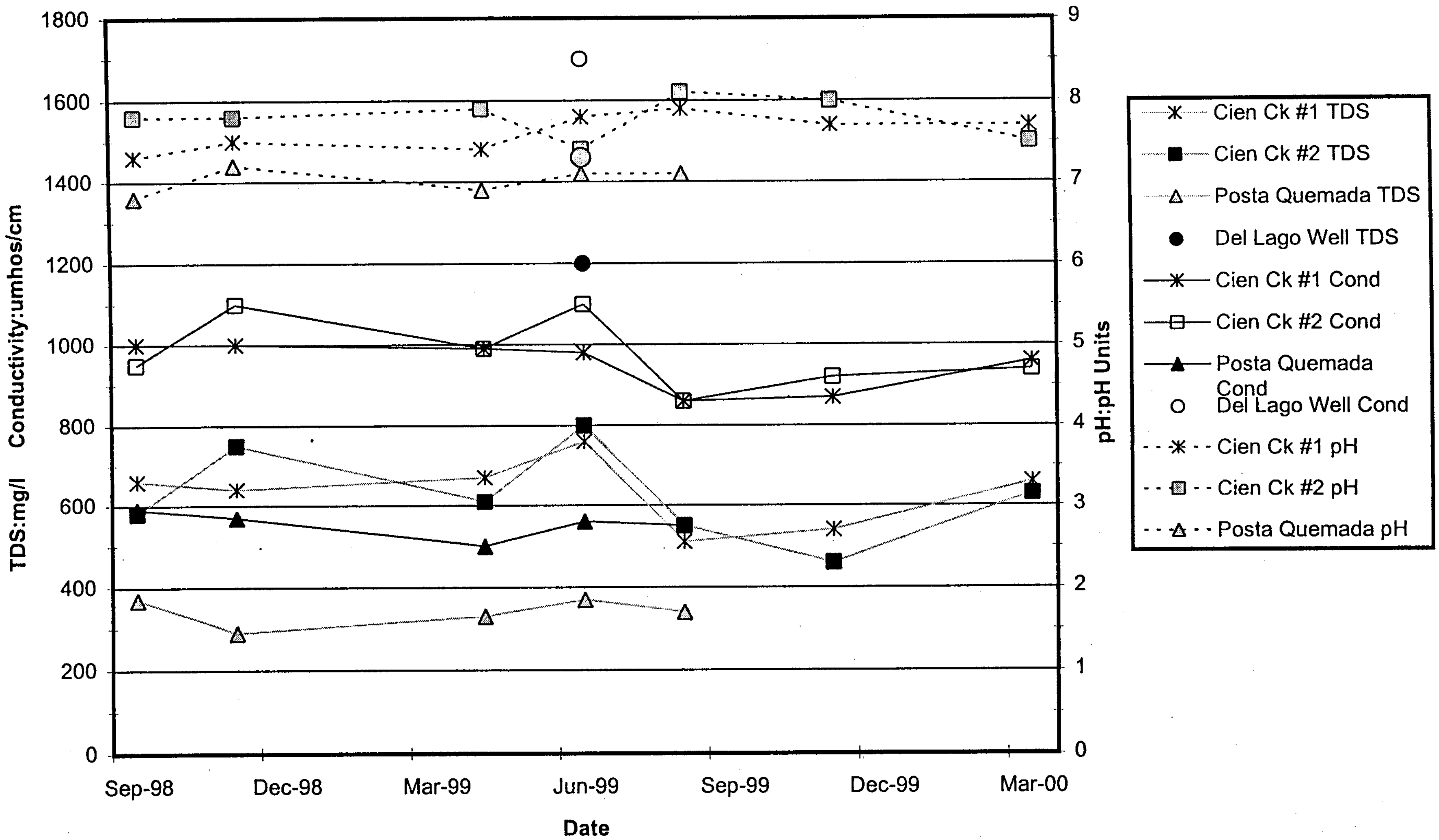

Figure 9. Laboratory TDS, Conductivity, and pH.

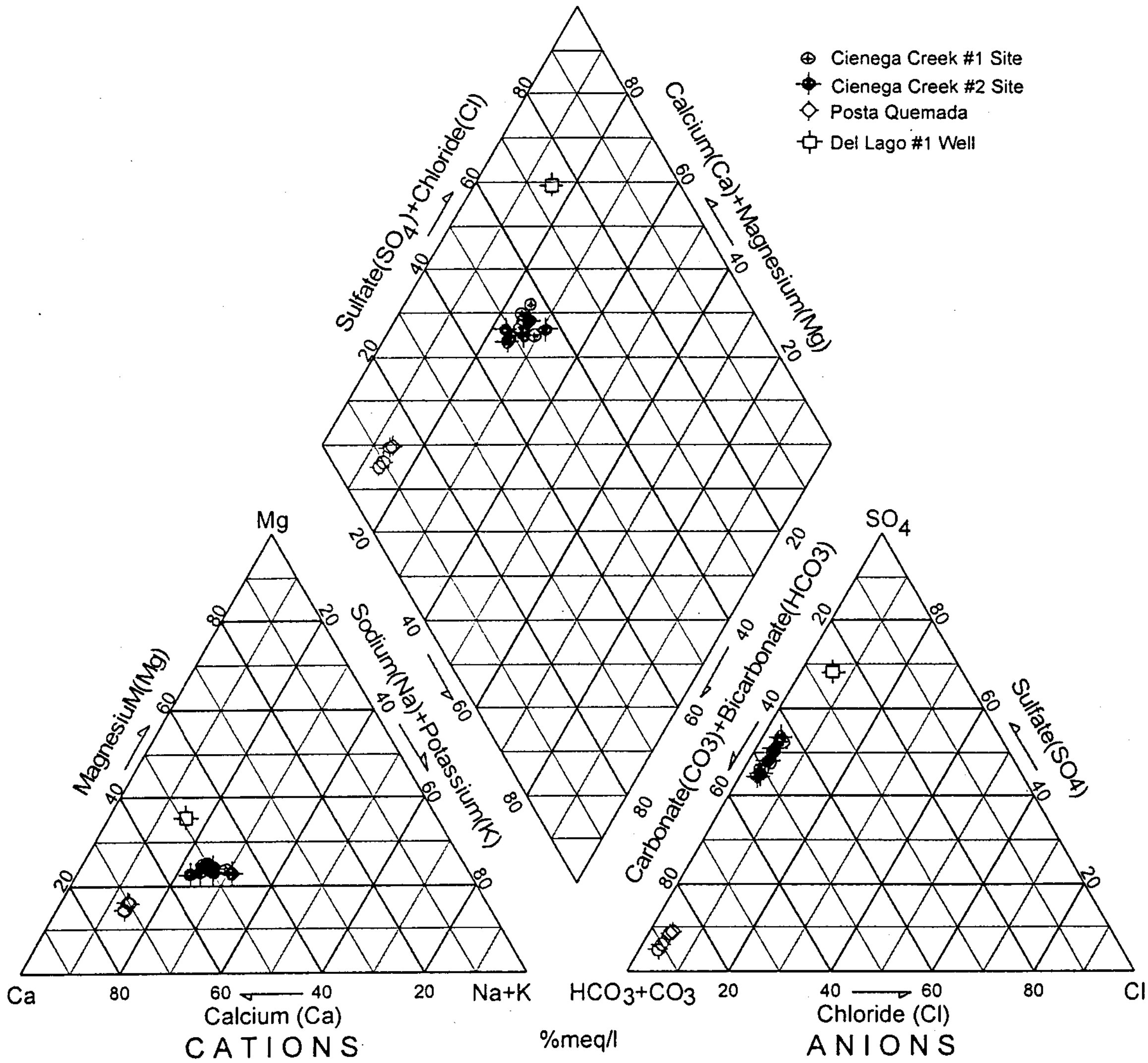

Figure 10. Piper Diagram of samples, 9/98-3/00.

CONCLUSIONS

The water in Cienega Creek is not significantly influenced by surface flow or subflow from Agua Verde Creek. Both isotopic ratios and ionic concentrations are consistent above and below the confluence of Agua Verde Creek, indicating that Agua Verde Creek does not impact the isotopic or chemical nature of the water. In addition, the isotopic and chemical signature of water from Cienega Creek is significantly different from that of water from Posta Quemada Spring. The water in Cienega Creek is isotopically "heavier" than the water found at Posta Quemada Spring, and TDS levels in Cienega Creek are approximately double what they are at Posta Quemada. Also, the dominant cation in solution at Posta Quemada is calcium whereas the Cienega Creek cations are more evenly balanced between calcium, sodium, and magnesium. In addition, the major anion at Posta Quemada is bicarbonate whereas the anions in Cienega Creek are almost equal parts bicarbonate and sulfate.

Stable isotopic similarities between water in Cienega Creek and water in Del Lago Well, in combination with the geologic interpretation of the area, suggest that water in the creek may be in hydraulic connection with water in the well. The stable isotopic signature of water from Cienega Creek and the Del Lago Well suggest that both waters are derived from similar low elevation basin precipitation, which may potentially be the same source. However, tritium and carbon isotope analysis suggest that while there could be some input from the creek to the aquifer tapped by the well, older water is also present. Tritium analyses of well water found 1.2 +/- 0.5 Tritium Units (Gillick and Eastoe unpublished data), which indicates that the water in the well is a mixture of recharge since 1953 and older water. The proximity to Cienega Creek suggests that the creek is the source of the tritium. This finding is supported by ^{14}C and $\delta^{13}C$ analysis of the Del Lago #1 well water. The ^{14}C value was -68.0±0.6 pMC (percent modern carbon) and the $\delta^{13}C$ value was -8.3‰ (Gillick and Eastoe unpublished data). The carbon isotope data indicated input from older water.

The chemistry of the well water was found to be distinct from Cienega Creek surface water. The differences could be explained by enrichment of surface water in sulfate, magnesium, chloride, and sodium during transit through the bedrock system. The molar balances between the ions of gypsum ($Ca \approx 6.5$ mmol/l and $SO_4 \approx 14$ mmol/l) suggest that processes other than dissolution of gypsum by creek water have occurred. Calcite may have precipitated while gypsum was brought into solution, or additional sulfate minerals (Na_2SO_4 or $MgSO_4$) may have been dissolved. Addition of water that has infiltrated from the surface through surficial terrace deposits, may have provided chemically distinct, salt-rich water to the bedrock aquifer.

Gillick and Eastoe (unpublished data) found a $\delta^{34}S$ value of approximately +12‰ for the Del Lago #1 well. A similar $\delta^{34}S$ value was found for Cienega Creek (Gu unpublished data). Since the hydrogen and oxygen isotopes suggest that the well water has not undergone evaporation, and sulfate levels in the well are much higher in the well than in Cienega Creek, another sulfate source is indicated. The likely source of the sulfate is the Pantano formation or, less likely, Permian evaporites. The gypsum of both have $\delta^{34}S$ values of approximately +12‰ (Gu unpublished data, Claypool et al. 1980).

Reconnaissance mapping of geologic structures in the area suggest that there is probably a fractured bedrock aquifer within the Horquilla Limestone. The driller's well log confirms that the Horquilla is likely the primary water-bearing formation intersected by the well. The fractured Horquilla formation probably contacts the alluvial streambed aquifer beneath Cienega Creek both upstream and downstream from the Pantano Dam. The elevation of water in the well is lower than the elevation of the streambed above Pantano Dam, suggesting that water in Cienega Creek could be recharging the bedrock aquifer upstream of the dam. However, water from the bedrock aquifer could be recharging the streambed aquifer downstream from the dam. Because chemical and isotopic data are not available for subflow downstream from the dam, this hypothesis cannot be verified.

The connection between the bedrock aquifer and surface flow in Cienega Creek is substantiated by graphs showing depth to water at Del Lago Well versus average monthly flows in Cienega Creek. Flows are based on measurements taken at USGS flow gauge station at the nearby Del Lago Dam. Figure 11 shows that groundwater level appear to rise in response to flood flows in the Creek because groundwater levels rise after months with large flood flows. These data suggest that during stormflows, the creek provides significant amounts of recharge to the bedrock aquifer. However, statistical analysis of the data should be conducted before conclusions are firmly drawn.

The perennial reach of Cienega Creek near the Pantano Dam originates from upstream base flows and subflow along Cienega Creek. The Agua Verde/Posta Quemada watershed does not appear to contribute significantly to the flow in the creek upstream from Pantano Dam. However, this study was conducted during a period of minimal winter-season precipitation. During a period of wetter winters, there might be more contribution from the Agua Verde Creek drainage.

The bedrock aquifer at Del Lago Well (T16S, R16E, Section 14) does not contribute to flows in Cienega Creek upstream of Pantano Dam. However, there appears to be a hydraulic connection

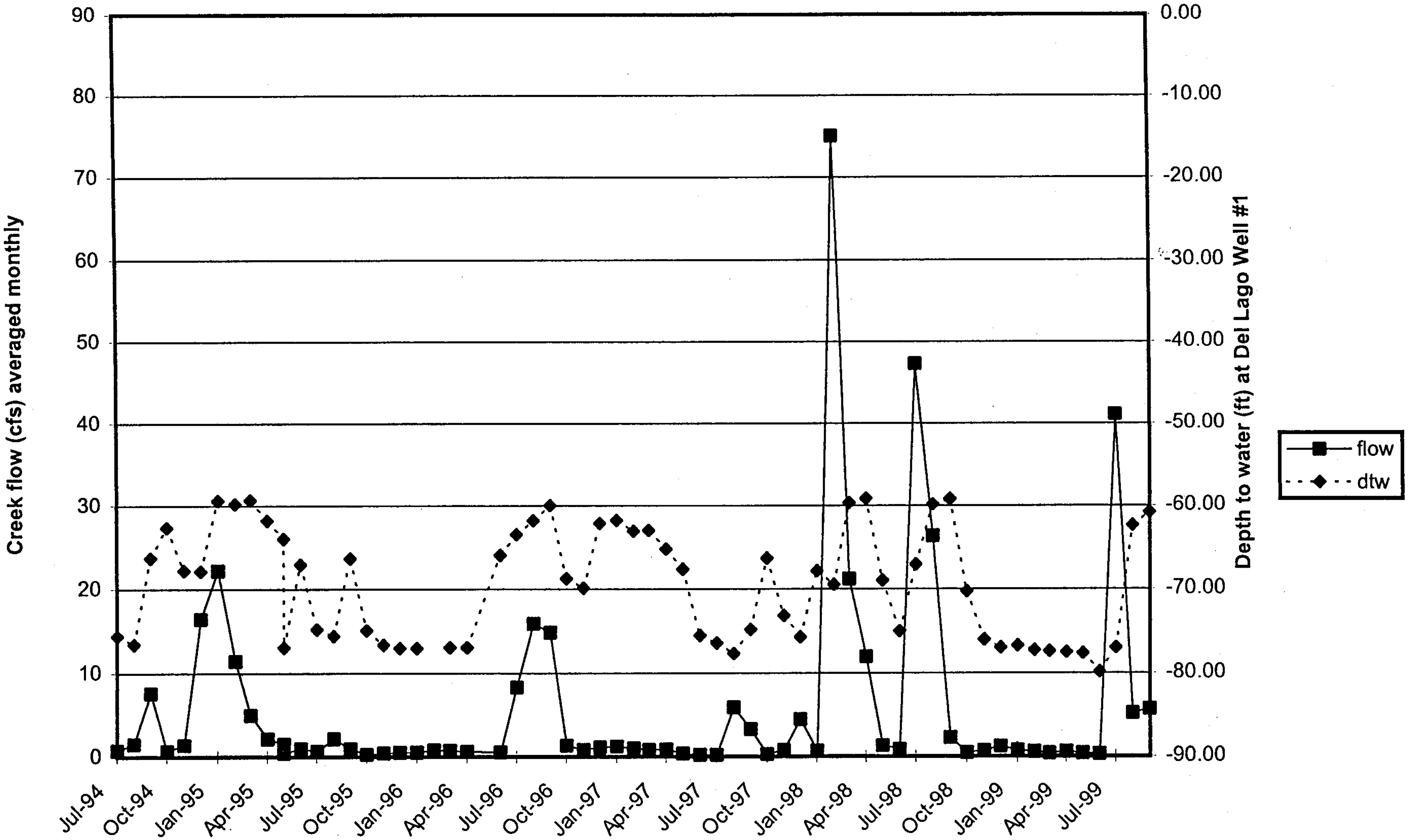

Figure 11. Average creek flow at Pantano Dam & Groundwater Depth at Del Lago Well #1.

between the bedrock aquifer and the Cienega Creek alluvial aquifer. Although the connection is complex and may involve contribution of waters from different sources, the bedrock and alluvial aquifers cannot be considered separately when managing groundwater resources in the Cienega Creek Natural Preserve.

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