Contribution of Davidson Canyon to Base Flows in Cienega Creek

November 2003

Pima Association of Governments

PIMA ASSOCIATION OF GOVERNMENTS

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Acknowledgments

PAG would like to thank Julia Fonseca and Tom Helfrich at the Pima County Flood Control District for supporting the inclusion of this project in PAG's annual work plan. Pima County Flood Control District contributes funds annually in support of PAG's water quality planning and research program. The District paid for all of the solute analyses used in this study.

PAG would also like to thank Chris Eastoe at the Laboratory of Isotope Geochemistry at the University of Arizona for providing all of the stable isotope analytical results in this report.

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Contribution of Davidson Canyon to Base Flows in Cienega Creek

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Purpose

The purpose of this study was to determine the relative contribution of Davidson Canyon to base flows in Cienega Creek at the Marsh Station Road bridge crossing. Cienega Creek is a perennial stream that has been designated a Unique Water by the State of Arizona; its lower reaches are the principal feature of Pima County's Cienega Creek Natural Preserve.

Davidson Canyon is a large tributary to Cienega Creek, entering roughly 1500 feet upstream of the Marsh Station bridge. The Davidson watershed drains the Empire Mountains and the northeast extent of the Santa Rita Mountains, whereas the much larger Cienega Creek watershed drains the eastern slopes of the Santa Rita Mountains, the western slopes of the Whetstone Mountains, and the southern slopes of the Rincon Mountains. An understanding of the effect that Davidson Canyon has on Cienega Creek's base flows is important for the long-term management of the Cienega Creek preserve, particularly any management activities related to water quality protection and land use planning in the watershed.

Under base flow conditions, Davidson is usually dry at the surface where it meets Cienega Creek, but it is an intermittent stream with seasonally sustained base flows a few hundred feet upstream of the confluence. In addition, Davidson has a perennial reach roughly two miles farther upstream, south of Interstate 10. Davidson Canyon is known to contribute significant flood flows to Cienega Creek during runoff events, but the contribution from Davidson Canyon underflow to Cienega Creek base flows had not been assessed prior to this study.

Methods

This project was a water chemistry and stable isotope study. It did not include numerical modeling or other quantitative hydrologic methods. The approach involved identification of the chemical and isotopic characteristics of base flows in Davidson Canyon and in Cienega Creek upstream and downstream of Davidson. The basis for this approach was an assumption that if Davidson had a significant impact on Cienega Creek, then the chemical and isotope data for water in Cienega Creek downstream of Davidson would reflect a mixture of Davidson water and upstream Cienega water.

PAG collected samples of base flows on a quarterly basis from June 2002 through May 2003 at locations in Davidson Canyon as close to its mouth as possible, and in Cienega Creek upstream and downstream of the point where Davidson Canyon enters Cienega Creek. Table 1 lists the dates and sites for all of the samples collected. Sampling locations are illustrated on Figure 1. Analytes included major cations and ions, other inorganic constituents (aluminum, arsenic, fluoride, silica), and stable isotopes of hydrogen and oxygen. We did not conduct any sampling during or immediately following significant precipitation events.

The upstream Cienega samples ("Cienega #1") were collected within a few hundred feet immediately upstream of the Davidson confluence. The downstream Cienega samples

(“Cienega #2”) were collected at the Marsh Station Road bridge where the Arizona Department of Environmental Quality has previously monitored water quality and PAG has conducted monthly stream flow measurements for more than ten years.

Samples of Davidson Canyon base flows were collected either at “Davidson #1”, which is along the perennial reach upstream of Interstate 10, or at “Davidson #2”, which is along the intermittent reach within a thousand feet upstream of its entry into Cienega Creek. Davidson #2 was the preferred sampling point because of its proximity to Cienega Creek. Davidson #1 was sampled if the Davidson #2 location was dry. Both Davidson locations were sampled in June 2002 to establish a baseline in comparison to Cienega Creek and to determine whether the project approach was feasible.

Cienega Creek was sampled for stable isotopes but not solutes in June 2002. Previous solute monitoring data for Cienega Creek at the Marsh Station bridge were used to evaluate the project’s feasibility.

PAG staff collected all of the samples and measured field parameters (pH, temperature and electrical conductivity) using a Myron L 6P Ultrameter at the time the samples were collected. The samples for solute analysis were collected in tightly sealed containers provided by Turner Laboratories and stored on ice immediately. The samples were not filtered or treated with a preservative in the field. However, the metals samples were filtered and acidified by the laboratory so that dissolved concentrations would be measured. The stable isotope samples were collected in tightly sealed containers with minimal head space. The containers were rinsed three times with the sample water prior to collection to remove any moisture that might have been present in the containers.

Turner Laboratories in Tucson, Arizona, performed all of the inorganic constituent analyses, and the University of Arizona Laboratory of Isotope Geochemistry in Tucson performed all of the stable isotope analyses. All δD and δ18O measurements were made with a Finnegan DELTA-S mass spectrometer. The δ18O analyses were performed on carbon dioxide with which the water samples were equilibrated. The δD analyses were made on hydrogen that was liberated from the water samples by reaction with chromium. The laboratory calibrates relative to Vienna Standard Mean Ocean Water (V-SMOW) and Standard Light Antarctic Precipitation (SLAP), which are international standards for stable isotope measurements in natural waters (Eastoe, 1997; Laboratory of Isotope Geochemistry, 1992; Laboratory of Isotope Chemistry, 1997). Laboratory methods for the inorganic results are included on the analysis reports (Appendix A). Information on Turner Laboratories’ QA/QC procedures are available at *www.turnerlabs.com.*

PAG collected and submitted one duplicate sample to Turner Laboratories for the complete suite of inorganic analyses each quarterly sampling round. PAG did not collected any duplicate samples from Davidson or Cienega for stable isotope analyses. However, we regularly submitted duplicate isotope samples from other ongoing projects to the same laboratory during the same time period and found the results to be acceptable (see Appendix A).

In order to evaluate and interpret the major cation/anion sampling results, we created Piper trilinear diagrams using Aquachem v3.7. We interpreted the stable isotope monitoring results using standard δD vs. δ^{18}O plots. We used these graphical methods to identify whether samples of Cienega Creek base flows at Marsh Station reflected a mixture of Davidson Canyon and upstream Cienega flows, and if so, what the relative contribution of each source was. The relative contributions were estimated by plotting the data and measuring the location of the downstream Cienega data points along a mixing line between the upstream Cienega and

Davidson data points. The method is illustrated on Figure 2 for the stable isotope data. The same mixing-line approach was used for the Piper plots as well.

Limitations

This study was conducted during an extended period of drought in southern Arizona. The findings might not be applicable to wetter periods.

This study was limited to base flows. The effect on Cienega Creek of Davidson Canyon flood flows was not assessed.

The potential impact of geochemical processes such as cation exchange, solute dispersion, and mineral precipitation/dissolution was not assessed. The effect of such processes, if any, was assumed to be negligible, because the study involved relatively fast-moving surface or shallow subsurface flows in coarse stream-channel sediments. These processes would not have affected the stable isotope data.

The project approach assumed that the differences in solute concentrations and stable isotope data between the Cienega #1 and Cienega #2 sites were due entirely to contributions from Davidson Canyon. If other contributing sources exist between Davidson Canyon and Marsh Station, this would be a source of error. However, Davidson Canyon, which is a very large tributary that includes an intermittent reach immediately upstream of its mouth, is very likely the only substantial source of flows other than the Cienega channel itself. No springs have been mapped along this reach, and no significant tributaries enter Cienega Creek between Davidson Canyon and the Marsh Station bridge.

An additional source of error is the imprecision inherent in all laboratory analyses. However, analytical results for duplicate samples indicate that the precision was sufficient for purposes of this study, and the effects of laboratory error on the study's findings were minimal.

Results and Discussion

Results generated by this study include solute concentrations and stable isotope data for five quarterly sampling rounds between June 2002 and May 2003. Tables 2 through 6 provide the analytical results for solute concentrations. Table 7 lists average solute concentrations for each sample point. Table 8 lists the individual stable isotope analytical results for each sampling round. Table 9 presents average $\delta^{18}O$ and δD values for each sampling location. Figures 3 through 7 are separate Piper trilinear diagrams for each sampling round. A combined Piper plot for all of the sampling rounds is shown on Figure 8. Figures 9 through 13 are δD vs. $\delta^{18}O$ plots for each of the sampling rounds. Figure 14 is a combined δD vs. $\delta^{18}O$ plot for all of the samples, and Figures 15 and 16 are combined plots of δD vs. time and $\delta^{18}O$ vs. time, respectively. Appendix B contains the analysis reports from Turner Laboratories. Appendix C contains the analysis reports from the Laboratory of Isotope Geochemistry.

Solute Data

Base flows in Davidson Canyon are a calcium-bicarbonate type water with TDS averaging about 450 mg/l. No differences in solute chemistry are apparent between samples collected at Davidson #1 and samples collected at Davidson #2. Base flows in Cienega Creek immediately upstream of Davidson are a calcium-sulfate type with TDS averaging more than 700 mg/l. Neither water source shows large seasonal variations in solute concentrations. The clear distinction between the chemical compositions of Davidson Canyon water and Cienega Creek water made it possible to estimate the contribution of Davidson subflow to base flows in Cienega Creek downstream of the confluence. The use of Davidson #1 vs. Davidson #2 samples probably did not affect the estimates, given the similar solute compositions of base flows at these sites.

For every sampling round, the downstream Cienega #2 samples plotted between the upstream Cienega #1 samples and the Davidson samples on the Piper trilinear diagrams, suggesting that base flows at the Marsh Station Road crossing are consistently a mixture of these two sources. By applying the mixing-line method illustrated on Figure 2 to the Piper plots on Figures 4 through 7, we estimated that Davidson contributed 8% to 18% of the base discharge at Marsh Station. Davidson's contribution to flows at Marsh Station for each of the quarterly sampling rounds, as determined from the Piper diagrams, are listed below. The relative contribution of Davidson at Marsh Station was higher when discharge at the Marsh Station Road bridge was comparatively low.

Date	Davidson Contribution	Discharge (cfs) at Marsh Station*	Surface Flow at Davidson 2?
August 2002	18%	0.28	No
October 2002	18%	0.43	Yes
January 2003	8%	1.0 (visual estimate)	Yes
May 2003	8%	0.71	No

* from PAG's monthly instantaneous discharge measurements reported annually to Pima County

Stable Isotope Data

The stable isotopic signature of base flows in Davidson Canyon are distinct from the signature of base flows in Cienega Creek. This makes it possible to use stable isotopes as a natural tracer to identify the contribution of Davidson Canyon to base flows in Cienega Creek. Using the mixing line method illustrated in Figure 2 for the δD vs. $\delta^{18}O$ plots on Figures 9 through 13, we estimated the contribution of Davidson Canyon to base flows in Cienega Creek at the Marsh Station Road bridge as follows:

Date	Davidson Contribution	Discharge (cfs) at Marsh Station**	Surface Flow at Davidson 2?
June 2002	16% - 24%*	0.74	Yes
August 2002	47%	0.28	No
October 2002	24%	0.43	Yes
January 2003	12%	1.0 (visual estimate)	Yes
May 2003	21%	0.71	No

* 16% calculated using Davidson #2 data, 24% calculated using Davidson #1 data
** from PAG's monthly instantaneous discharge measurements reported annually to Pima County

In contrast to the solute data, the stable isotope data for Davidson Canyon base flows varied markedly between the Davidson #1 and Davidson #2 sample points. Davidson #1 is farther upstream and reflects a higher-elevation water source than Davidson #2. The stable isotope data collected at Davidson #2 is presumably more representative of the water entering Cienega Creek, as this site is immediately upstream of the confluence. Use of Davidson #1 stable isotope data very likely overestimated the contribution of Davidson flows to Marsh Station in August 2002 and May 2003. The October 2002 and January 2003 estimates that are based on stable isotope data for Davidson #2 agree fairly well with the estimates from the Piper diagrams. The isotope-based and solute-based estimates are also consistent in that they indicate a higher relative contribution from Davidson when base flow at Marsh Station is comparatively low.

Conclusions and Recommendations

Concentrations of most major dissolved ions, particularly sulfate, are consistently much lower in Davidson Canyon base flows compared to Cienega Creek base flows.

Delta D and Delta O-18 values are consistently higher in Davidson Canyon base flows compared to Cienega Creek base flows, suggesting an overall lower-elevation water source for Davidson.

Estimates of Davidson Canyon's relative contribution of base flows in Cienega Creek at Marsh Station Road between June 2002 and May 2003 range from 8% to 24%. These estimates are derived from solute data for the Davidson #1, Davidson #2, Cienega #1 and Cienega #2 sample points, and stable isotope data from the Davidson #2, Cienega #1 and Cienega #2 sample points. Use of stable isotope data for the Davidson #1 sample point causes Davidson's contribution to Cienega Creek to be overestimated.

The relative contribution from Davidson Canyon varied somewhat during the study period. Davidson's relative contribution was highest in August 2002 and October 2002 when Cienega base flows at Marsh Station were comparatively low, and lowest in June 2002, January 2003 and May 2003 when base flows at Marsh Station were comparatively high.

Future plans to protect the water quality of Cienega Creek in the vicinity of Marsh Station Road should include efforts to maintain the quality of flows in Davidson Canyon, because of Davidson's significant contribution to perennial base flows at the Marsh Station Bridge crossing. In addition, base flows in Davidson Canyon are lower in dissolved solids than Cienega Creek; the dilution caused by Davidson Canyon's contributions could be beneficial to some aquatic species.

References

Eastoe, C. J., 1997. Internet communication with staff scientist at the Laboratory of Isotope Geochemistry, University of Arizona, Department of Geosciences on June 16, 1997.

Laboratory of Isotope Geochemistry, 1997. Oxygen Isotopes in Water: Procedures Manual. Version February 10, 1997. University of Arizona, Department of Geosciences.

Laboratory of Isotope Geochemistry, 1992. Hydrogen Isotopes in Water: Procedures Manual. Version March 6, 1992. University of Arizona, Department of Geosciences.

Tables

Table 1. Sampling Schedule

Sample ID	Location	6/4/02	8/2/02	10/3/02	1/3/03	5/7/03
Cienega 1	Upstream of Davidson confluence	isotopes only	x	x	x	x
Cienega 2	Marsh Station Bridge	isotopes only	x	x	x	x
Davidson 1	Upstream of I-10	x	x			x
Davidson 2	Above mouth	x		x	x	

Table 2. June 4, 2002, Sampling Results
Inorganic Constituents and Physical Parameters

	Davidson 1	Davidson 2
	Conc. (mg/L)	Conc. (mg/L)
Al	ND	ND
Ca	81	93
Mg	21	23
K	ND	ND
Na	48	45
F	0.48	0.52
Cl	17	19
NO3 as N	ND	ND
SO4	79	100
Alk as CaCO3	300	290
Alk as HCO3-	366	354
As	ND	ND
SiO2	26	25
Lab Cond. (uS)	740	790
Lab pH	7.6	7.1
Lab TDS (mg/L)	420	390
Field Cond. (uS)	726.6	794.1
Field pH	7.93	7.57
Field Temp. (C)	20.4	23.3

Table 3. August 2, 2002, Sampling Results
Inorganic Constituents and Physical Parameters

	Davidson 1	Davidson 2	Cienega 1	Cienega 2
	Conc. (mg/L)	Conc. (mg/L)	Conc. (mg/L)	Conc. (mg/L)
Al	nd		nd	nd
Ca	87		160	140
Mg	20		44	39
K	nd		5.8	6
Na	50		72	67
F	0.48		0.57	0.58
Cl	15		12	14
NO3 as N	nd		nd	nd
SO4	91		440	380
Alk as CaCO3	250		270	290
Alk as HCO3-	305		329	354
As	nd		nd	nd
SiO2	29		20	20
Lab Cond. (uS)	600		1200	1100
Lab pH	7.7		7.3	7.4
Lab TDS (mg/L)	550		780	790
Field Cond. (uS)	723.3		1262	1195
Field pH	7.88		7.45	7.55
Field Temp. (C)	28		19.4	22

Table 4. October 3, 2002, Sampling Results
Inorganic Constituents and Physical Parameters

	Davidson	Davidson 2	Cienega 1	Cienega 2
	Conc. (mg/L)	Conc. (mg/L)	Conc. (mg/L)	Conc. (mg/L)
Al		nd	nd	nd
Ca		98	150	140
Mg		23	43	39
K		nd	6.5	6.3
Na		43	72	67
F		0.48	0.63	0.57
Cl		15	9.9	12
NO3 as N		nd	nd	nd
SO4		92	390	340
Alk as CaCO3		250	200	230
Alk as HCO3-		305	244	280
As		nd	nd	nd
SiO2		34	24	26
Lab Cond. (uS)		780	1200	1100
Lab pH		7.3	7.4	7.5
Lab TDS (mg/L)		470	680	660
Field Cond. (uS)		793	1200	1152
Field pH		7.45	7.62	7.76
Field Temp. (C)		19.8	15.5	18.4

Table 5. January 3, 2003, Sampling Results
Inorganic Constituents and Physical Parameters

	Davidson	Davidson 2	Cienega 1	Cienega 2
	Conc. (mg/L)	Conc. (mg/L)	Conc. (mg/L)	Conc. (mg/L)
Al		nd	nd	nd
Ca		96	150	140
Mg		24	43	40
K		nd	6.1	5.7
Na		49	72	69
F		0.64	0.81	0.77
Cl		15	12	12
NO3 as N		nd	nd	nd
SO4		90	400	360
Alk as CaCO3		340	290	280
Alk as HCO3-		415	354	341
As		nd	nd	nd
SiO2		31	22	21
Lab Cond. (uS)		760	1200	1100
Lab pH		7.3	7.3	7.6
Lab TDS (mg/L)		520	760	760
Field Cond. (uS)		791.3	1234	1178
Field pH		7.51	7.47	7.85
Field Temp. (C)		17.6	16.6	15.3

Table 6. May 8, 2003, Sampling Results
Inorganic Constituents and Physical Parameters

	Davidson	Davidson 2	Cienega 1	Cienega 2
	Conc. (mg/L)	Conc. (mg/L)	Conc. (mg/L)	Conc. (mg/L)
Al	nd		nd	nd
Ca	99		140	140
Mg	25		41	40
K	nd		5.5	5.5
Na	44		71	68
F	0.47		0.68	0.65
Cl	15		10	11
NO3 as N	nd		nd	nd
SO4	84		380	370
Alk as CaCO3	330		260	280
Alk as HCO3-	402		317	341
As	nd		nd	nd
SiO2	28		18	20
Lab Cond. (uS)	770		1200	1100
Lab pH	7.2		7.2	7.4
Lab TDS (mg/L)	340		650	640
Field Cond. (uS)	778.3		1178	1149
Field pH	7.39		7.51	7.67
Field Temp. (C)	17.8		19.1	20

Table 7. Average Solute Concentrations
Major Cations and Anions

	Davidson Conc. (mg/L)	Davidson 2 Conc. (mg/L)	Cienega 1 Conc. (mg/L)	Cienega 2 Conc. (mg/L)
Ca	89	96	150	140
Mg	22	23	43	40
K				
Na	47	46	72	68
Cl	16	16	11	12
SO4	85	94	403	363
Alk as CaCO3	293	293	255	270
Alk as HCO3-	358	358	311	329
LAB TDS	437	460	718	713

Table 8. Stable Isotope Sampling Results
(o/oo SMOW)

June 4, 2002

Sample	Delta O18	Delta D
Davidson1	-7.2	-51
Davidson2	-6.8	-48
Cienega1	-8	-57
Cienega2	-7.8	-56

August 2, 2002

Sample	Delta O18	Delta D
Davidson1	-7.2	-51
Davidson2		
Cienega1	-7.9	-58
Cienega2	-7.6	-54

October 3, 2002

Sample	Delta O18	Delta D
Davidson1		
Davidson2	-6.8	-48
Cienega1	-7.7	-55
Cienega2	-7.5	-53

January 3, 2003

Sample	Delta O18	Delta D
Davidson1		
Davidson2	-6.7	-46
Cienega1	-7.6	-54
Cienega2	-7.5	-53

May 8, 2003

Sample	Delta O18	Delta D
Davidson1	-6.9	-49
Davidson2		
Cienega1	-7.8	-56
Cienega2	-7.6	-55

Table 9. Average Stable Isotope Sampling Results
(o/oo SMOW)

Average Delta O18		Average Delta D	
Davidson1	-7.1	Davidson1	-50.3
Davidson2	-6.8	Davidson2	-47.3
Cienega1	-7.8	Cienega1	-56.0
Cienega2	-7.6	Cienega2	-54.2

Figures

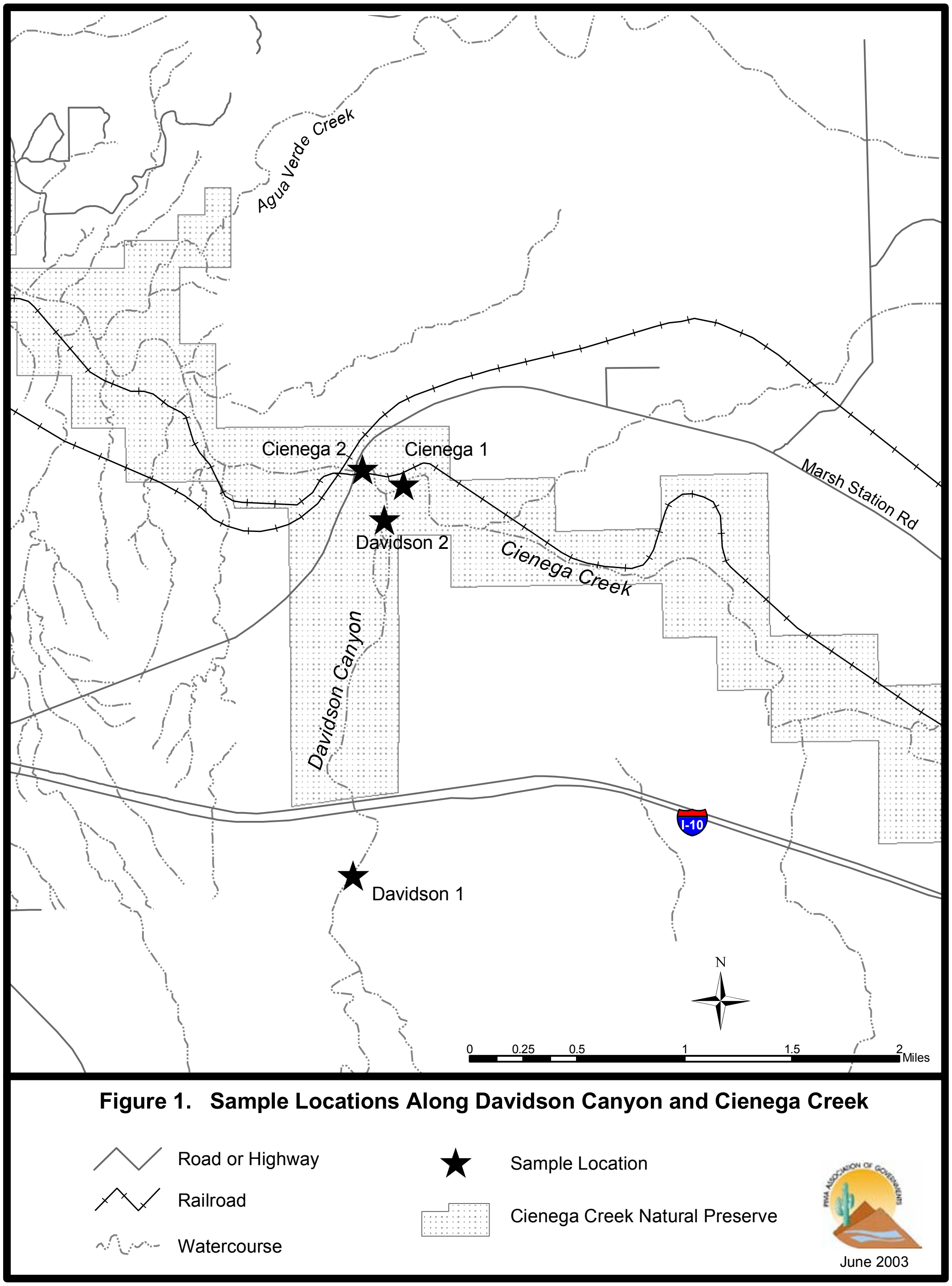
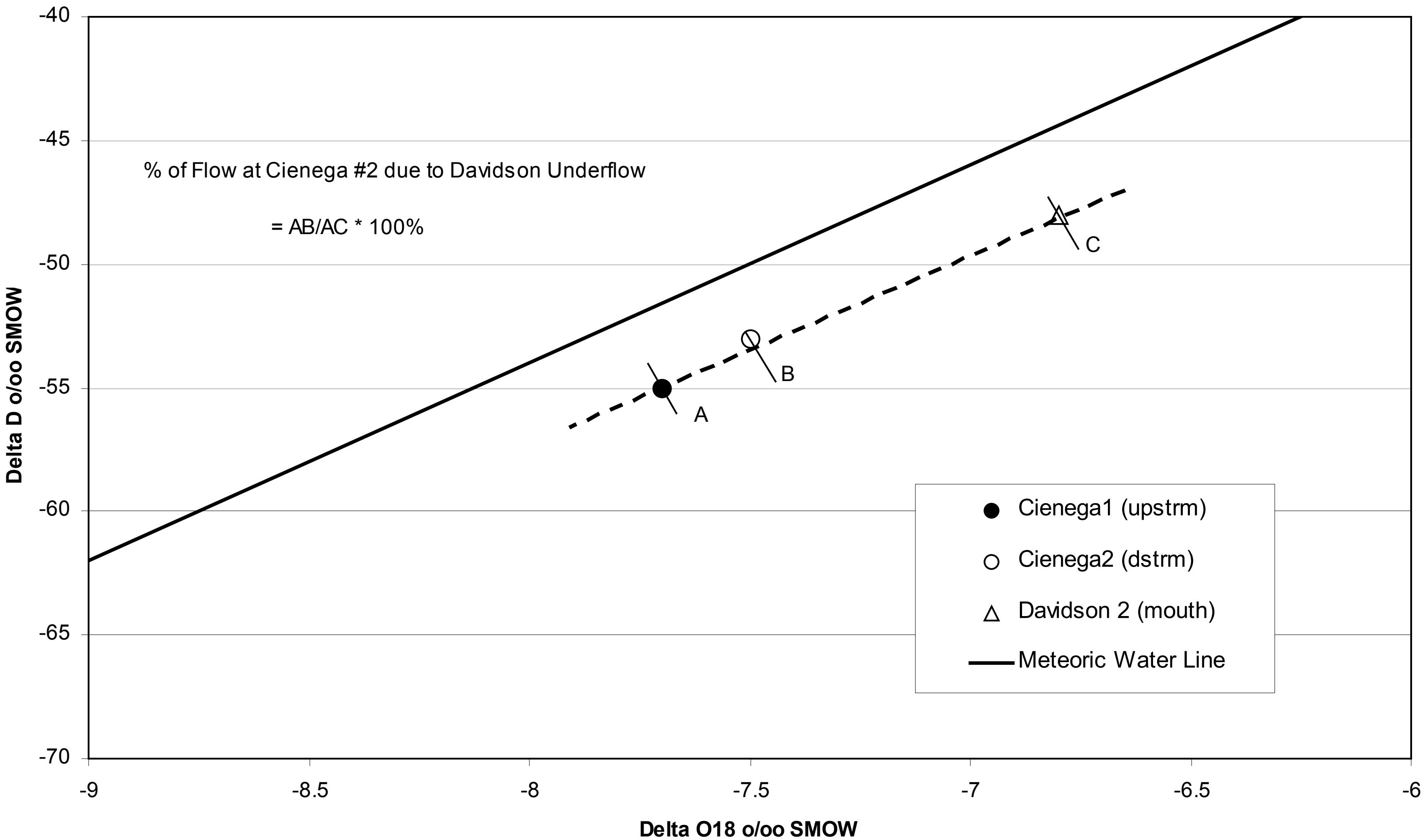


Figure 1. Sample Locations Along Davidson Canyon and Cienega Creek

Figure 2. Calculation of Davidson Contribution from Stable Isotope Data



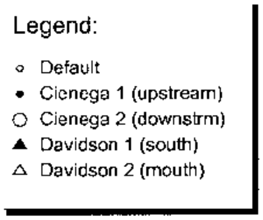
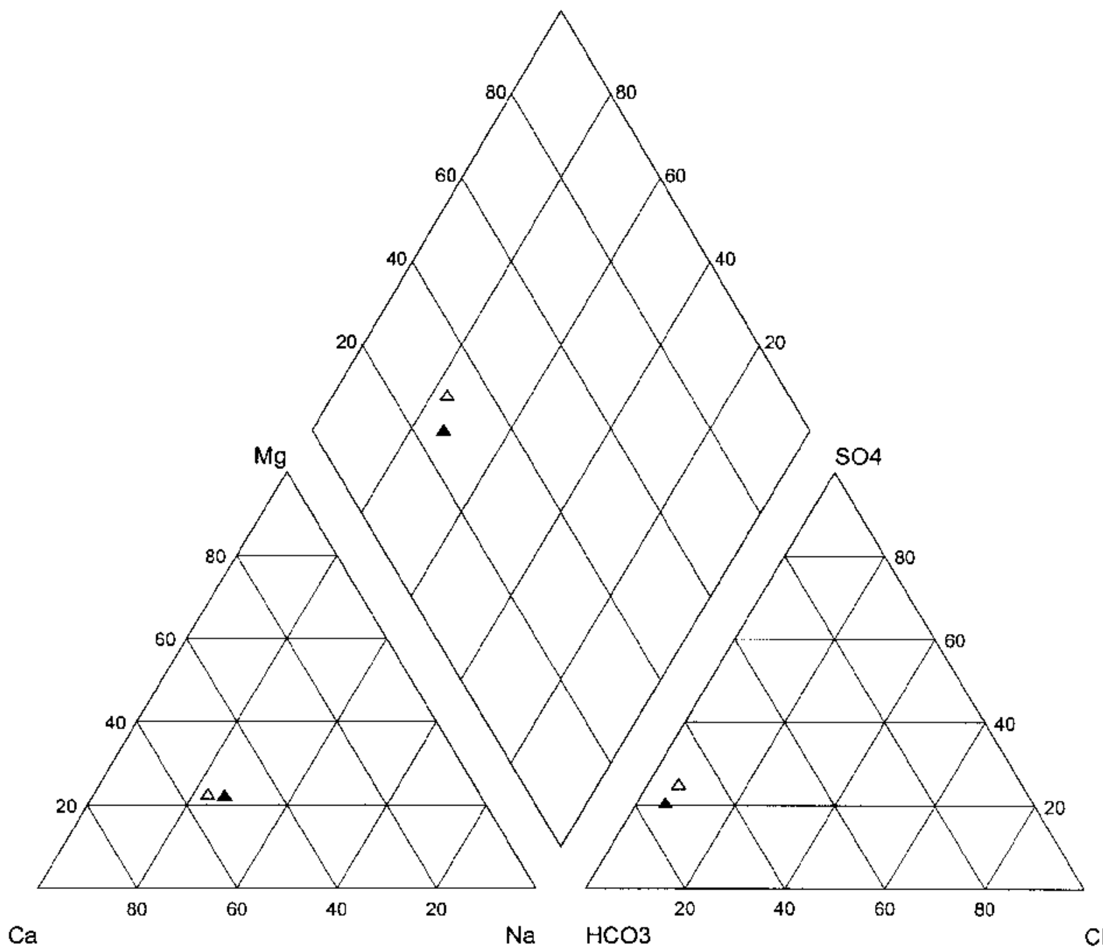


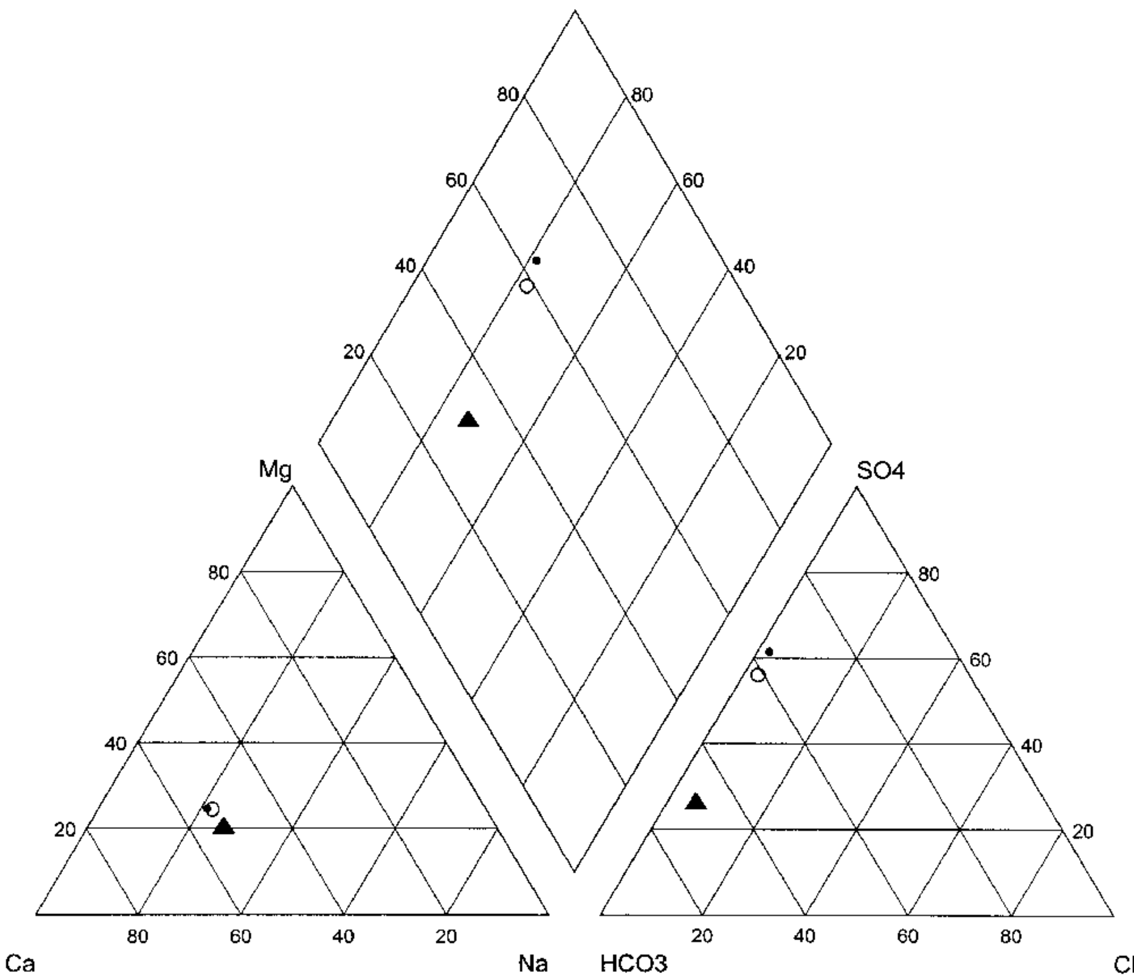
Figure 3. Davidson Samples June 4, 2002



Legend:

- ○ Default
- • Cienega 1 (upstream)
- ○ Cienega 2 (downstrm)
- ▲ Davidson 1 (south)
- △ Davidson 2 (mouth)

Figure 4. Cienega/Davidson Samples 8/2/02



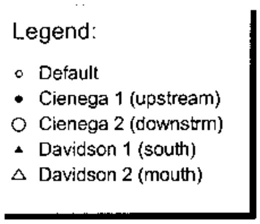
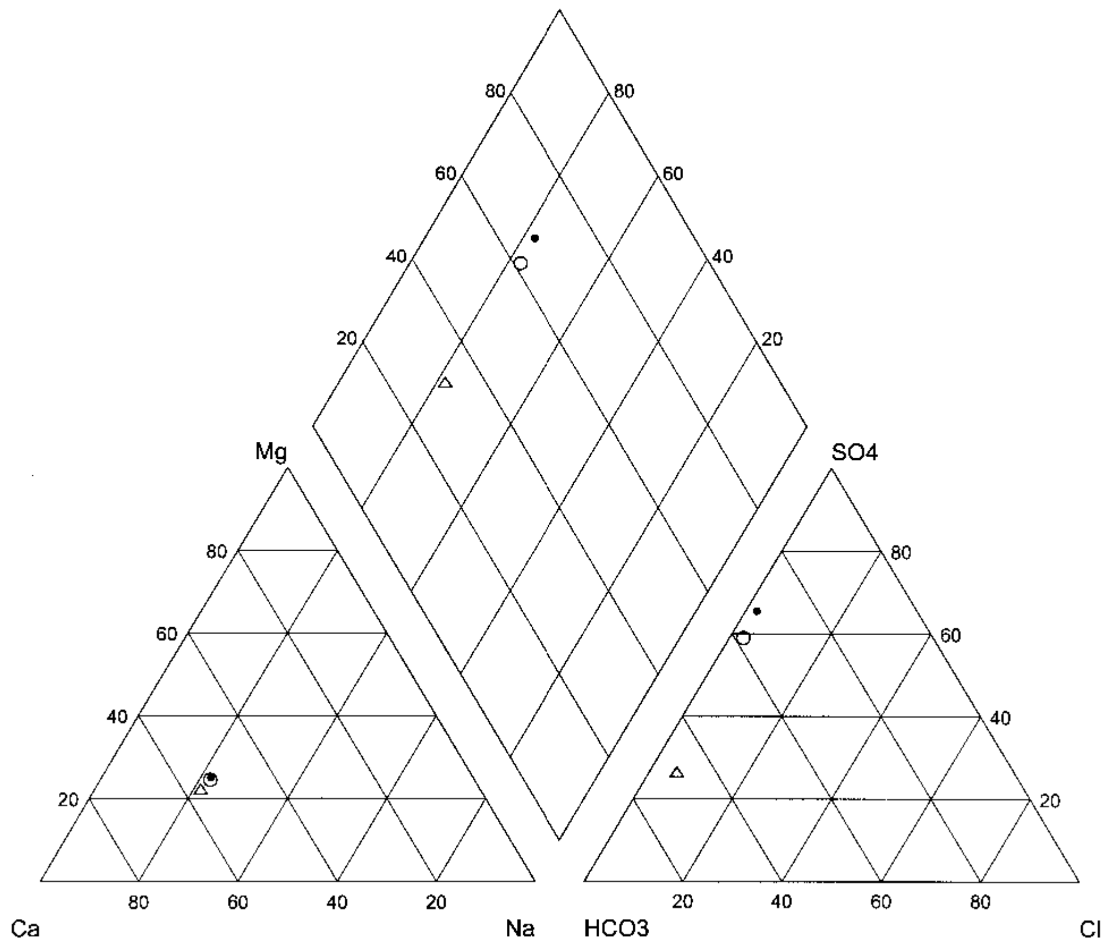


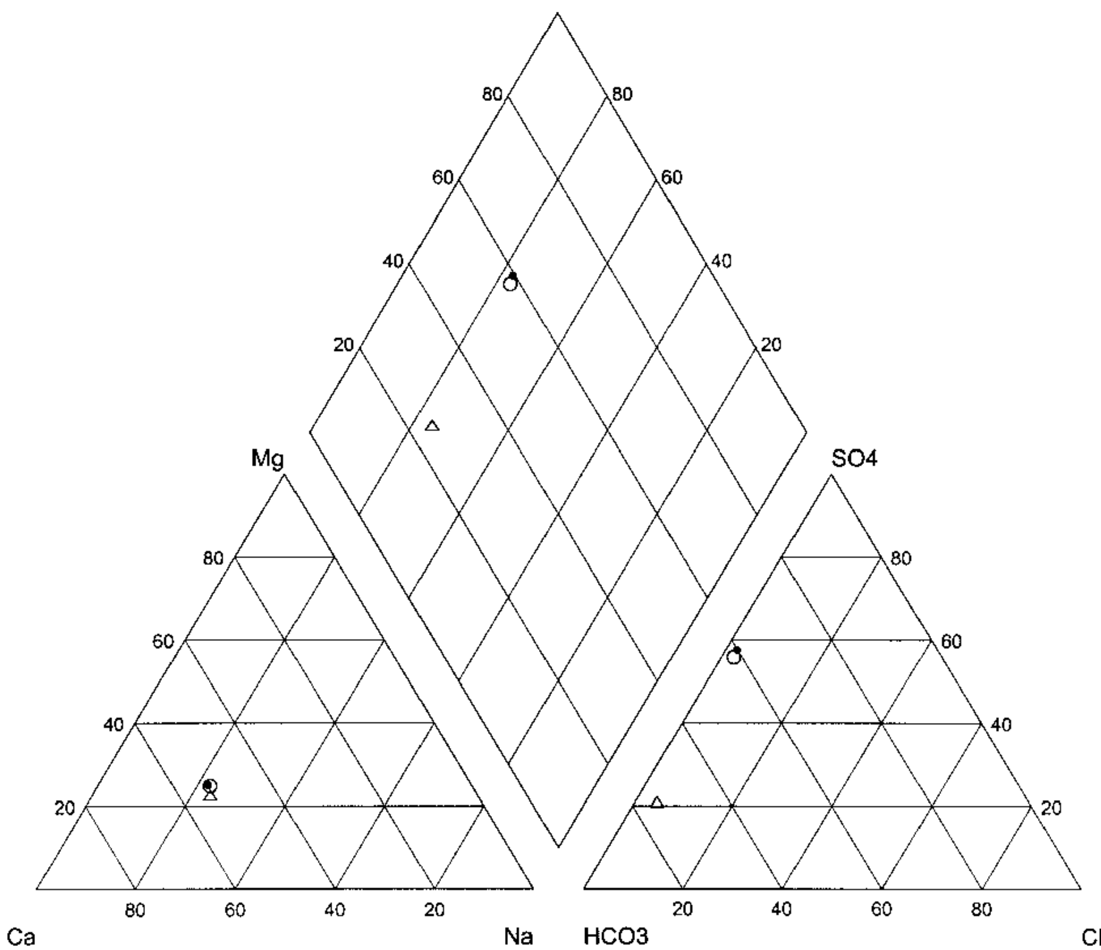
Figure 5. Cienega/Davidson Samples 10/2/02



Legend:

- ○ Default
- • Cienega 1 (upstream)
- ○ Cienega 2 (downstrm)
- ▲ Davidson 1 (south)
- △ Davidson 2 (mouth)

Figure 6. Cienega/Davidson Samples 1/3/03



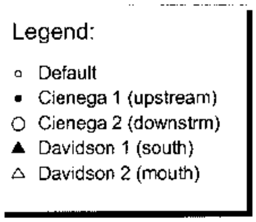
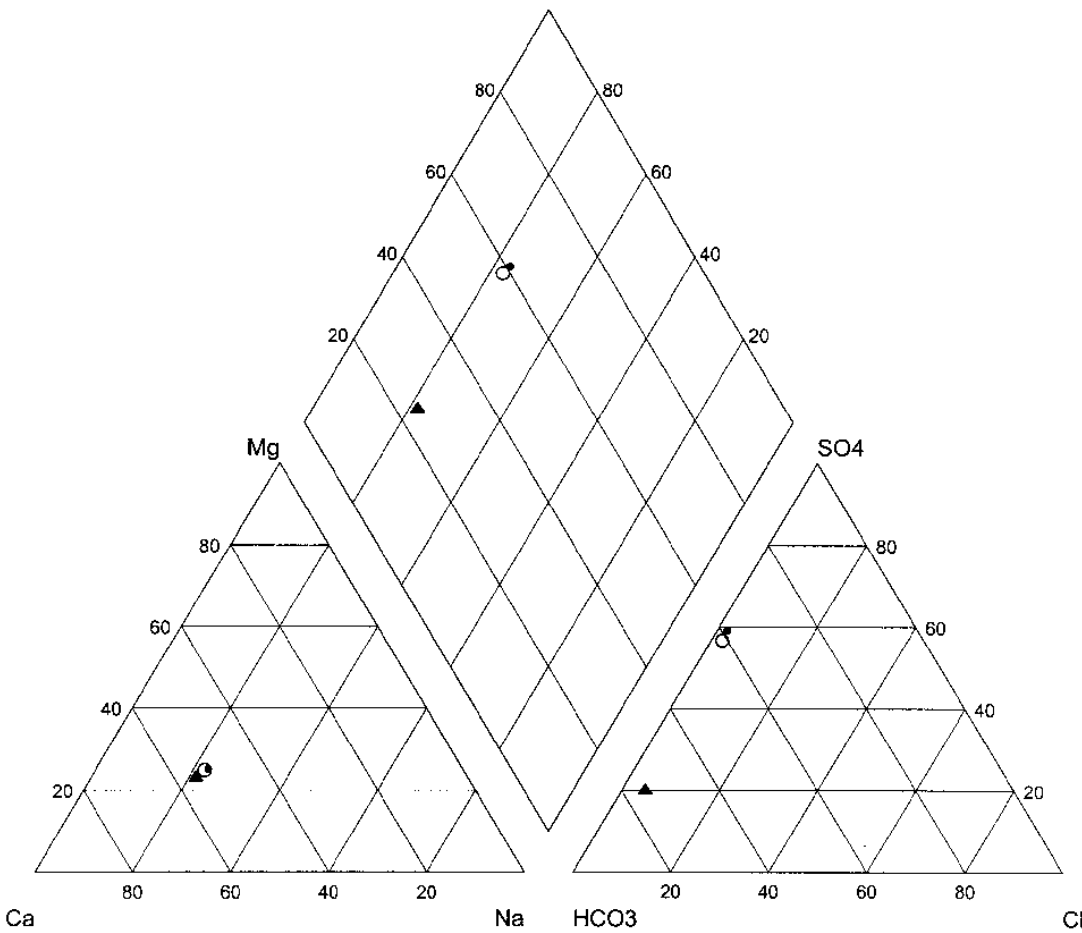


Figure 7. Cienega/Davidson Samples 5/8/03



Legend:
- ○ Default
- ● Cienega 1 (upstream)
- ○ Cienega 2 (downstrm)
- ▲ Davidson 1 (south)
- △ Davidson 2 (mouth)

Figure 8. Piper Plot for All Samples

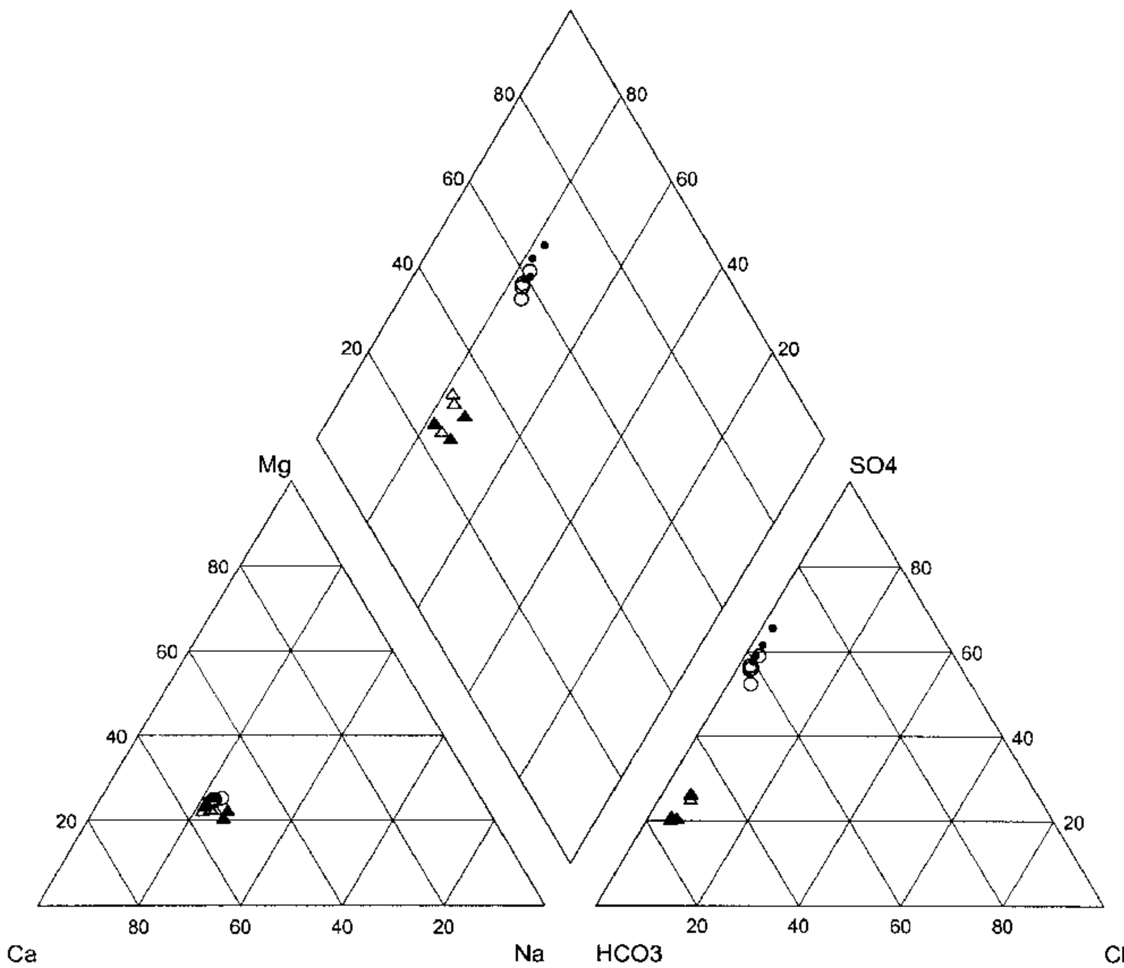


Figure 9 . Cienega/Davidson Stable Isotope Sampling Results
June 2002

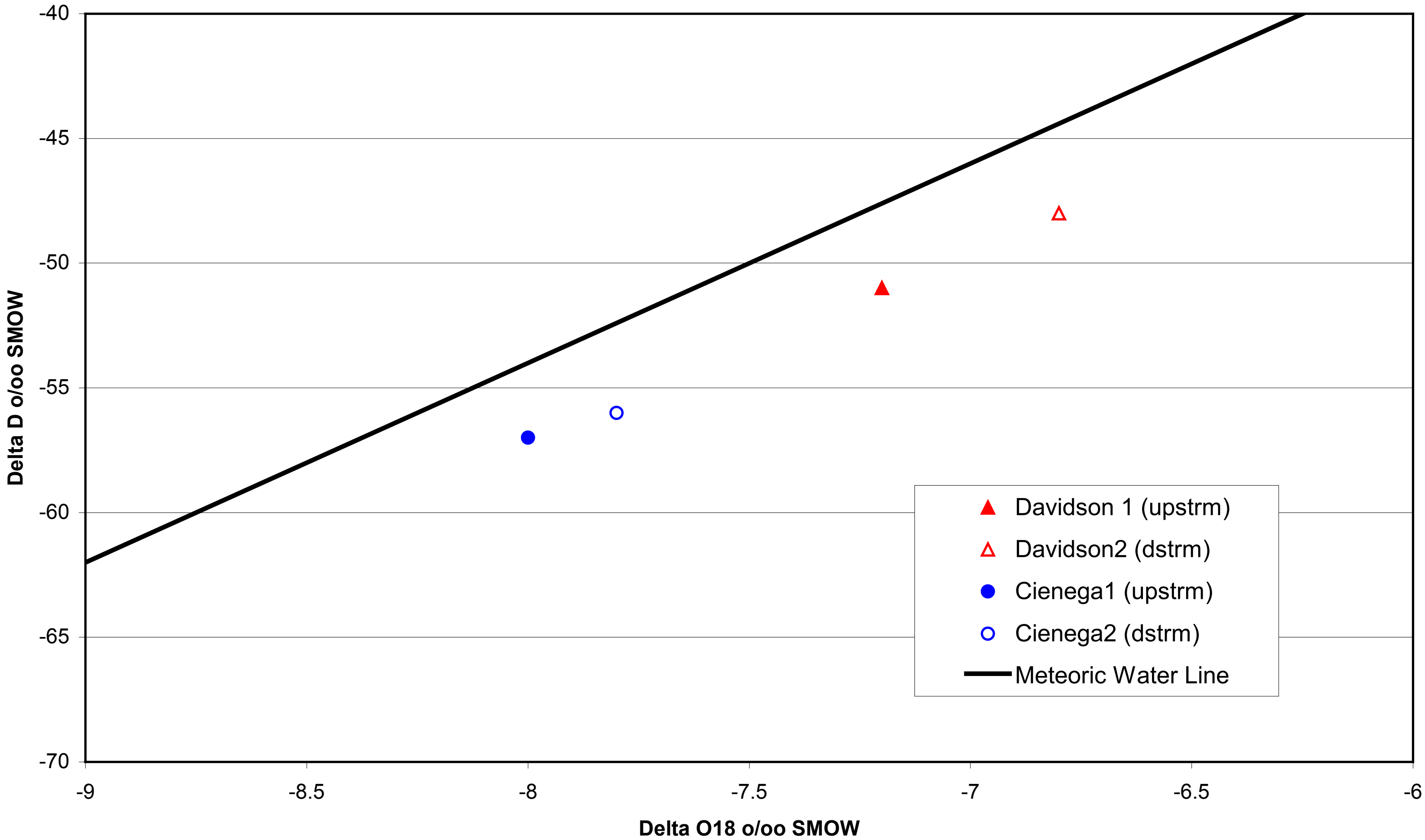


Figure 10. Cienega/Davidson Stable Isotope Sampling Results August 2002

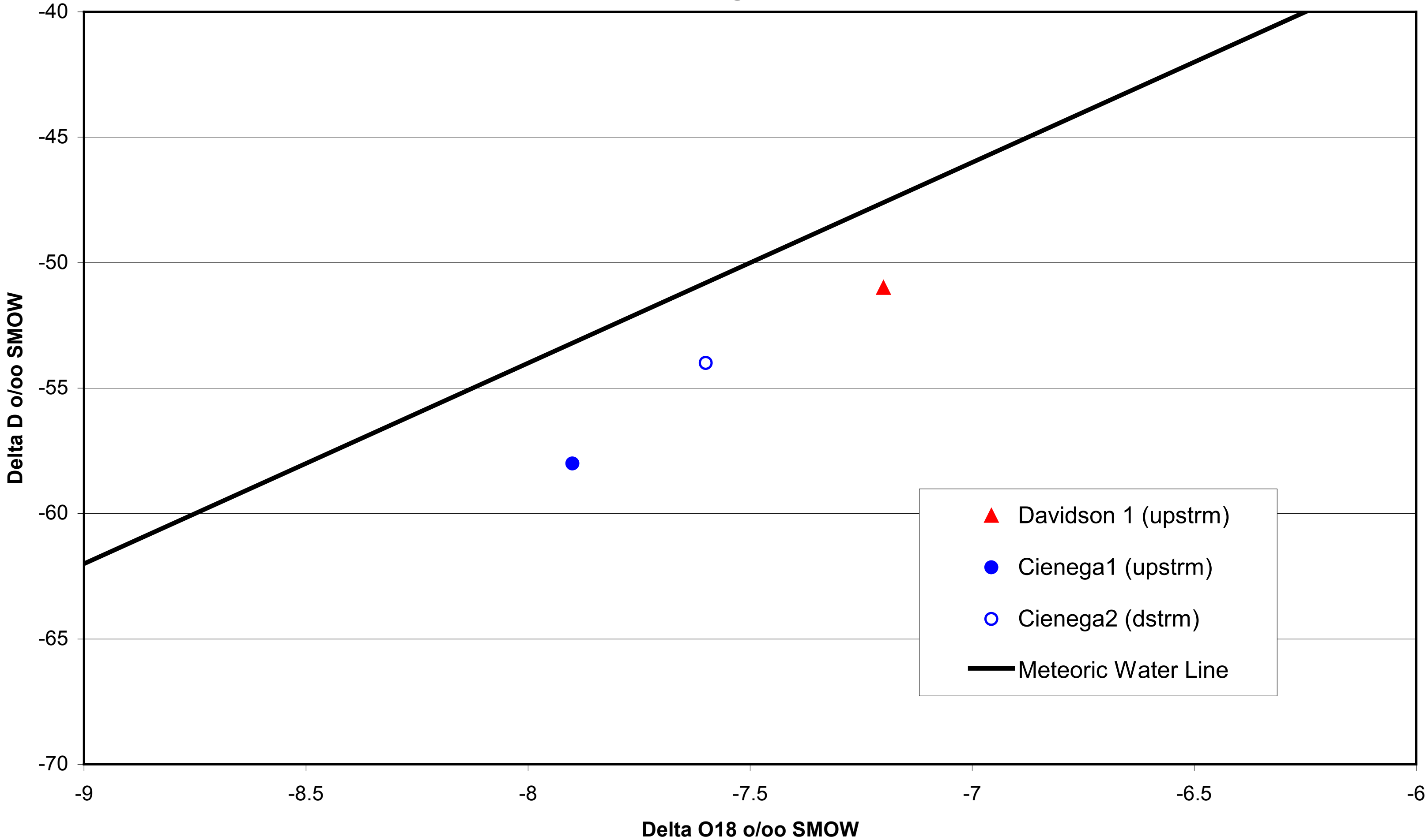


Figure 11. Cienega/Davidson Stable Isotope Sampling Results
October 2002

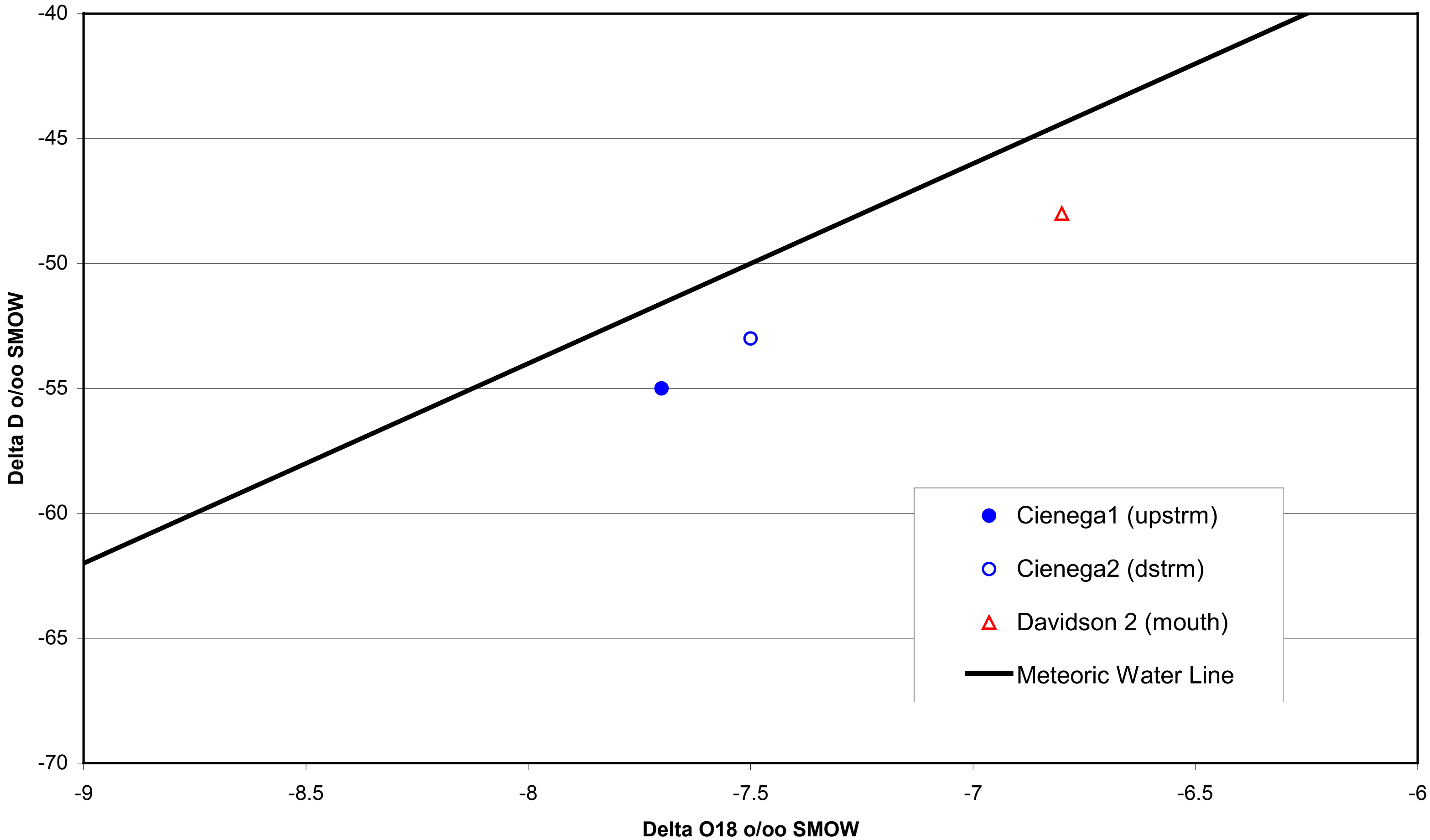


Figure 12. Cienega/Davidson Stable Isotope Sampling Results
January 2003

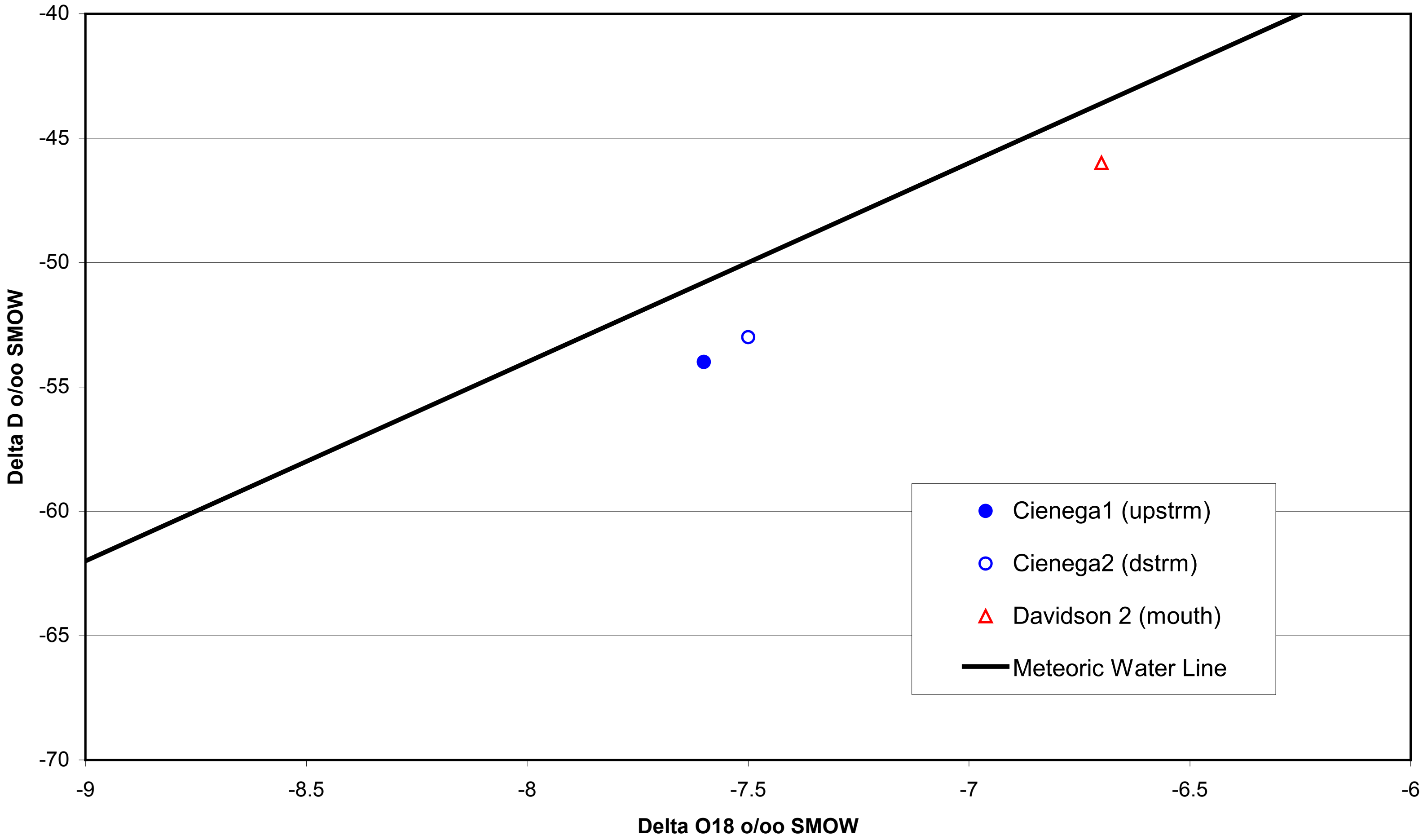


Figure 13. Cienega/Davidson Stable Isotope Sampling Results
May 2003

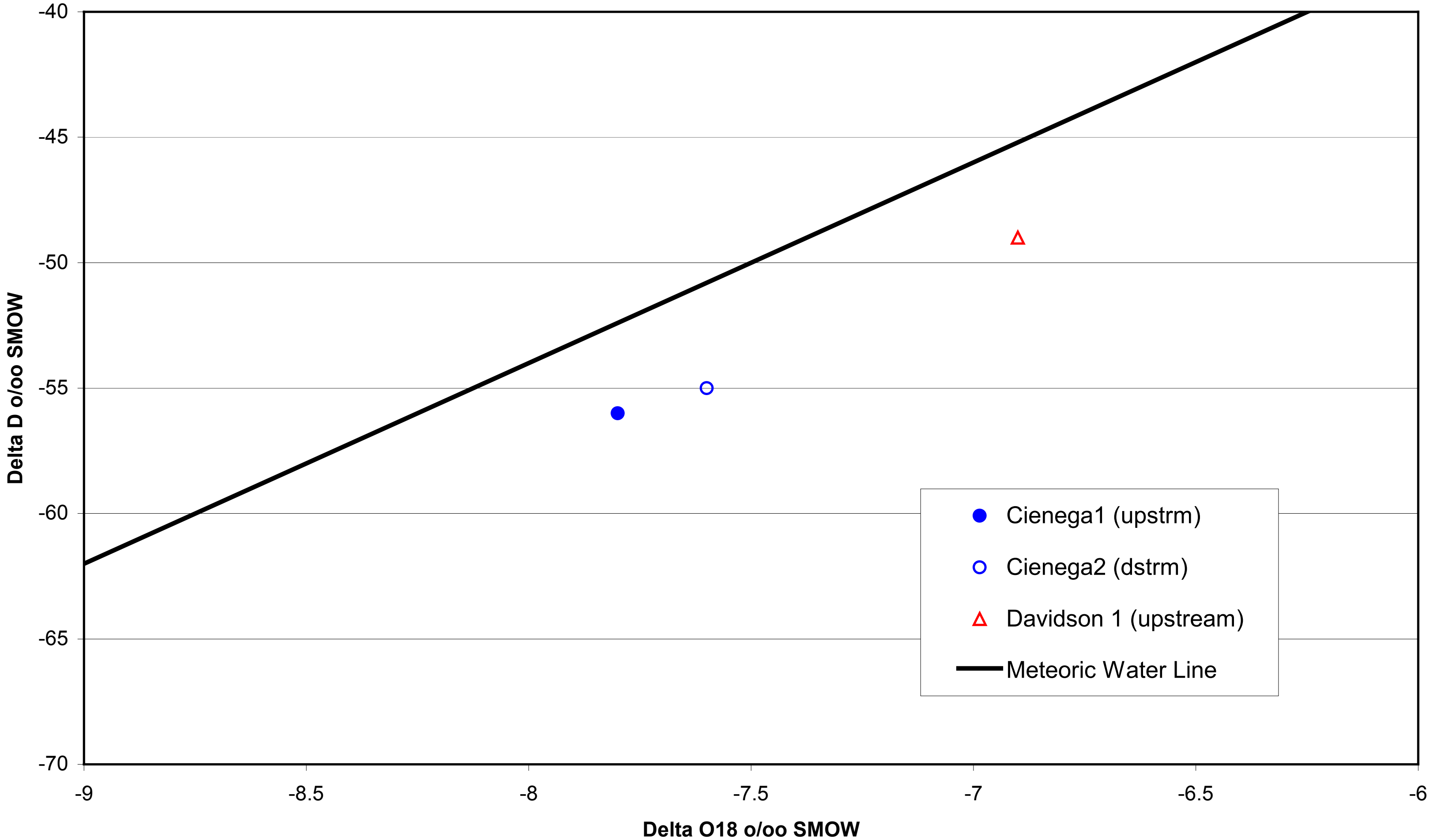


Figure 14. Cienega/Davidson Combined Stable Isotope Sampling Results

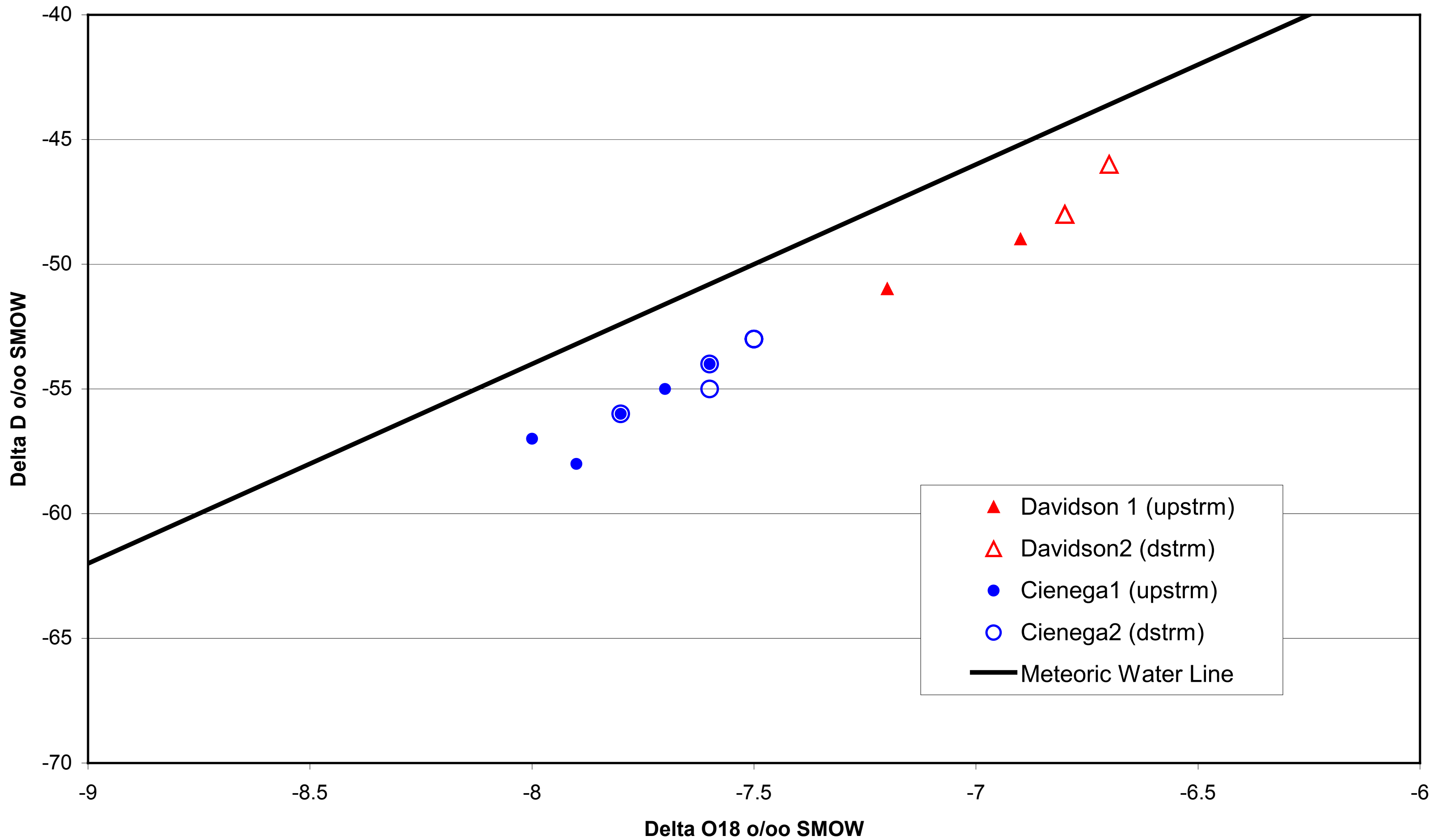


Figure 15. Cienega/Davidson Delta D Values

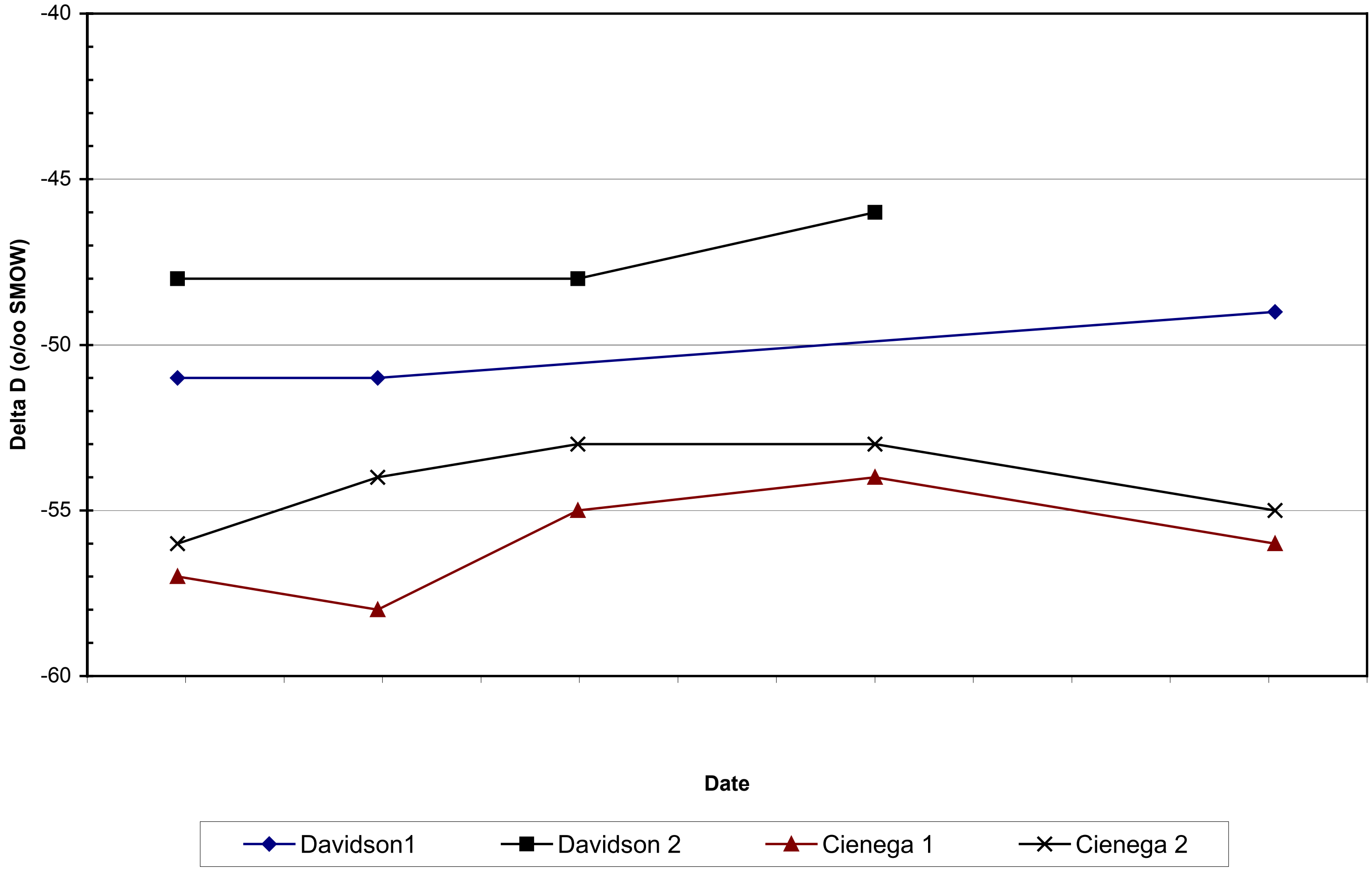
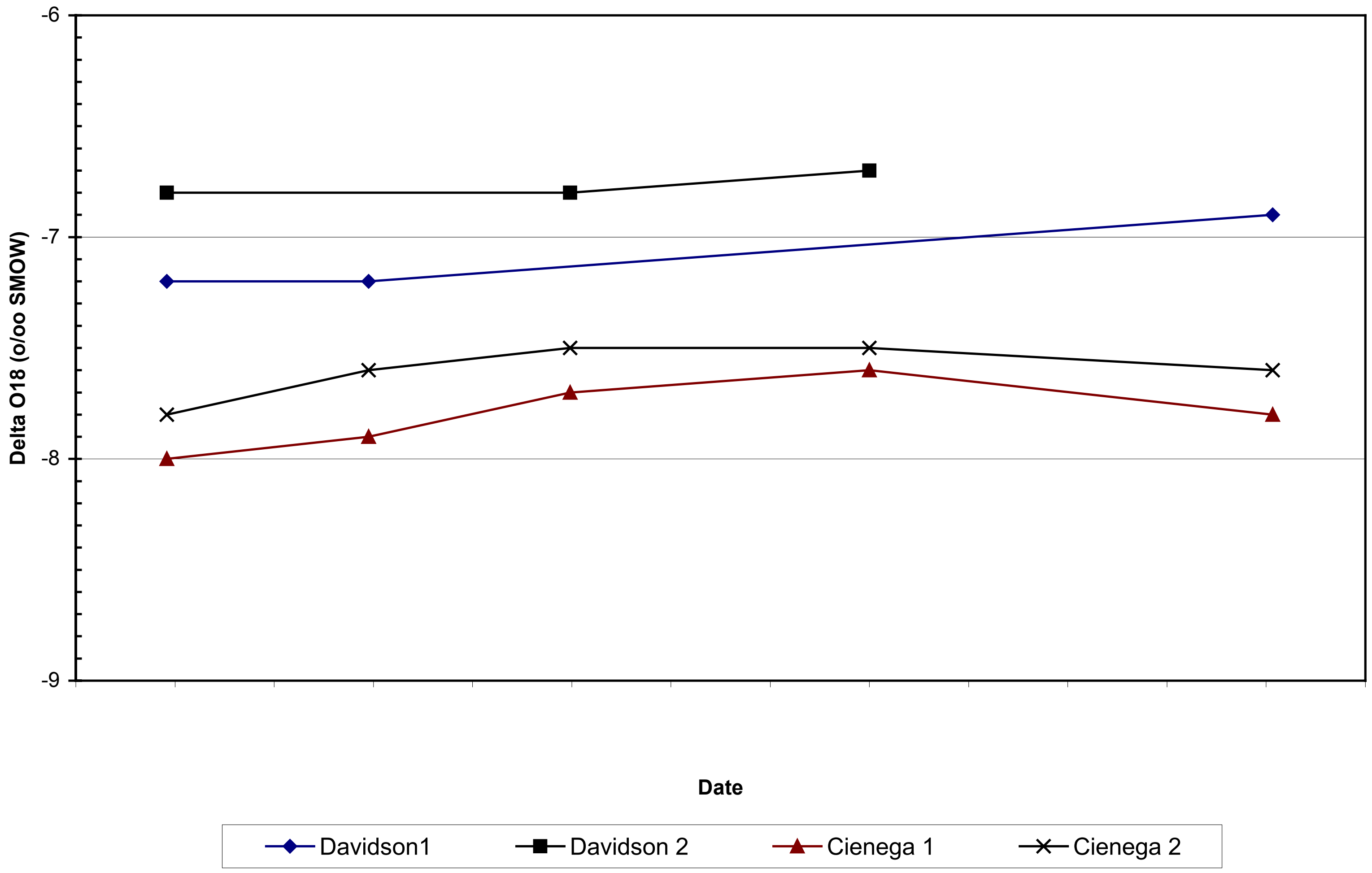


Figure 16. Cienega/Davidson Delta O18 Values



Appendix A. Stable Isotope Duplicate Sampling Results for Clearwater Renewable Resource Facility Stable Isotope Study

Stable Isotope Duplicate Sampling Results*

Sample Date	Lab No.	Delta O-18 o/oo SMOW	Delta D o/oo SMOW
7/30/02	W11472	-8.3	-57
7/30/02	W11473	-82	-58
10/15/02	W12309	-8.2	-61
10/15/02	W12310	-8.2	-60
12/17/02	W13216	-8.2	-58
12/17/02	W13217	-8.3	-58
1/16/03	W13442	-9.6	-77
1/16/03	W13443	-9.5	-79
7/21/03	W15531	-10.0	-84
7/21/03	W15532	-9.9	-83

* Data from Clearwater Renewable Resource Facility Stable Isotope Study

Appendix B. Turner Laboratories Analysis Reports
(Note: Appendix B is only available in hardcopy formats of the report)

Appendix C. Laboratory of Isotope Geochemistry Analysis Reports

(Note: Appendix C is only available in hardcopy formats of the report)