SBA WATERSHED PROTECTION PROGRAM

Stormwater Monitoring Report

Prepared for:
Alameda County Water District

July 2006

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SBA WATERSHED PROTECTION PROGRAM

Stormwater Monitoring Report

I. Introduction and Purpose

This report details the findings of stormwater monitoring performed for the South Bay Aqueduct (SBA) Watershed Protection Plan project. The project is funded with a Proposition 13 Watershed Protection Grant from the California State Water Resources Control Board (SWRCB) to the Alameda County Water District (ACWD). Stormwater monitoring was conducted during the winter of 2005-2006. Background, purpose, methods, and quality assurance standards for the stormwater monitoring effort are detailed in two reports, a Stormwater Monitoring Plan and a Quality Assurance Project Plan (QAPP), prepared by ESA and their subcontractor, EOA (ESA and EOA, 2005a; 2005b). Drafts of the two reports were reviewed first by the SBA Contractors (ACWD; the Zone 7 Water Agency of the Alameda County Water Conservation and Flood Control District – Zone 7 Water Agency; and the Santa Clara Valley Water District – SCVWD), and then by the SWRCB. Both documents were approved by the SWRCB prior to the commencement of sampling.

The goals of the project and the specific objectives of the stormwater monitoring program are stated in the QAPP:

> The purpose of the project is to support the SBA Contractors and the DWR in protecting and improving water quality for the SBA. The goal is to provide the SBA Contractors and DWR with recommendations and guidance pertaining to actions and management strategies for water quality protection and improvement.
>
> The specific objectives of this water quality study are to 1) assess the significance of contaminant sources of concern by sampling selected water quality parameters, and 2) use this information within the context of the broader study to assess the effectiveness of management practices currently implemented in the drainages contributing to the SBA.
>
> (ESA and EOA, 2005a)

Because of the limited funding and time available, this stormwater monitoring effort was designed simply to provide a few snapshots of stormwater runoff and its impacts in the SBA watershed. The purpose of the stormwater monitoring was not to pinpoint particular pollution sources, nor to develop a statistically robust data set, but rather to gather data from the major input sources to the SBA in a manner that would allow for comparison and also to provide a cross-check for other data sources. In particular, the results may be used in comparison with a sanitary survey conducted by the California Department of Water Resources (2001) and subsequent drinking water source assessments (Archibald and Wallberg 2002, 2005).

II. Methodology

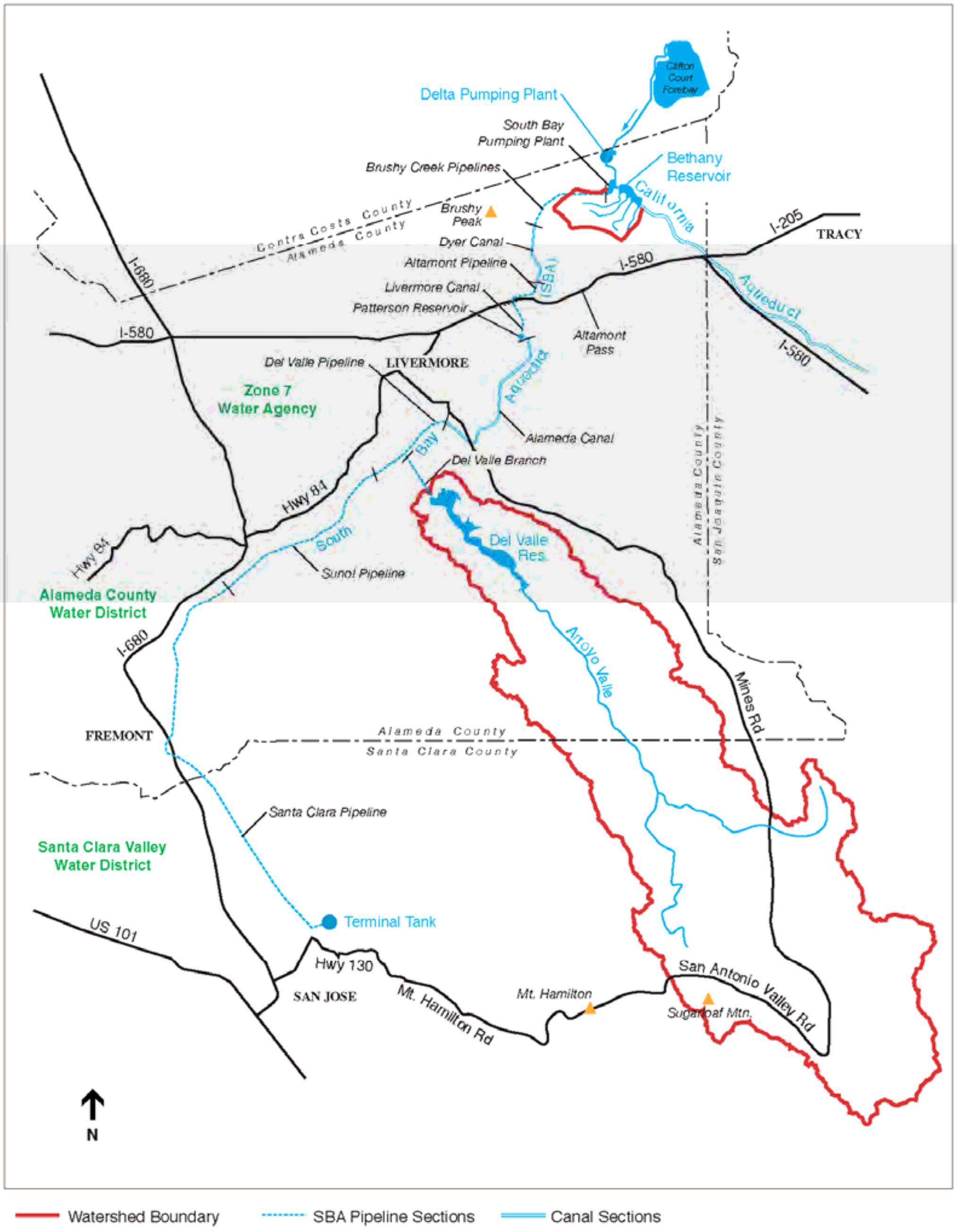
The methods and quality assurance measures used for the stormwater monitoring program, including sampling design, sampling locations, sampling methods, sample handling, laboratory and field analysis, and data management are detailed in the Stormwater Monitoring Plan and the QAPP (ESA and EOA, 2005a, 2005b). The methodology included the following:

- Establishment of 7 sampling stations representing major inputs to the SBA system (Map 1). Four stations were established on the California Aqueduct, at Bethany Reservoir, and in the South Bay Aqueduct itself (Maps 2, 3, and 4). These were:
  - CA-1, is on the California Aqueduct upstream of Bethany.
  - BR-1 is on a small stream that is tributary to Bethany Reservoir, the mouth of which is very near the South Bay Pumping Plant.
  - BR-2 is on the same tributary downstream of a small wetland and upstream of the Reservoir.
  - BR-3 is at the head of the Dyer Canal, at the outlet of the pipelines from the SBA Pumping Plant at Bethany Reservoir. An alternate site for BR-3 (designated BR-3a) was established in Bethany Reservoir at the SBA Pumping Plant, to be used in the event that the pumps were not operating at the time of sampling.
- Three additional sampling stations were established at and around Lake Del Valle Reservoir (Figure 5):
  - LDV-1 is on Arroyo Valle downstream of a large cattle ranch. The original location of LDV-1 was at the location of the U.S. Geological Survey (USGS) gaging station 11176400 (Arroyo Valle Below Lang Canyon, Near Livermore, CA); however, due to private property access issues, LDV-1 was moved downstream approximately ½ mile, to a location within the park boundary. The original (marked “old”) and revised (marked “new”) locations of LDV-1 are shown in Figure 4.
  - LDV-2 is on a small stream that drains into Lake Del Valle known as Cedar Creek.
  - LDV-3 is near the Del Valle Pumping Plant intake from Lake Del Valle. LDV-3a was established as an alternate site (the Conservation Outlet Works) that was to be used in the event DWR was withdrawing water from Lake Del Valle into the SBA system at the time of sampling.

  Grab samples were to be collected at all 7 stations during 5 stormwater runoff events, intended to capture a range of runoff conditions, including season and intensity/duration.

- Field analysis and laboratory analysis wer to be performed for 19 physical, chemical, and pathogenic water quality parameters from grab samples. Laboratory analysis was performed by the Zone 7 Water Agency Laboratory and by Biovir Laboratory.
- Quality assurance protocols for sampling, sample handling, field and laboratory analysis, and data management per the QAPP (ESA and EOA, 2005a).

SBA Watershed Lands



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Map 1

SBA Watershed Areas

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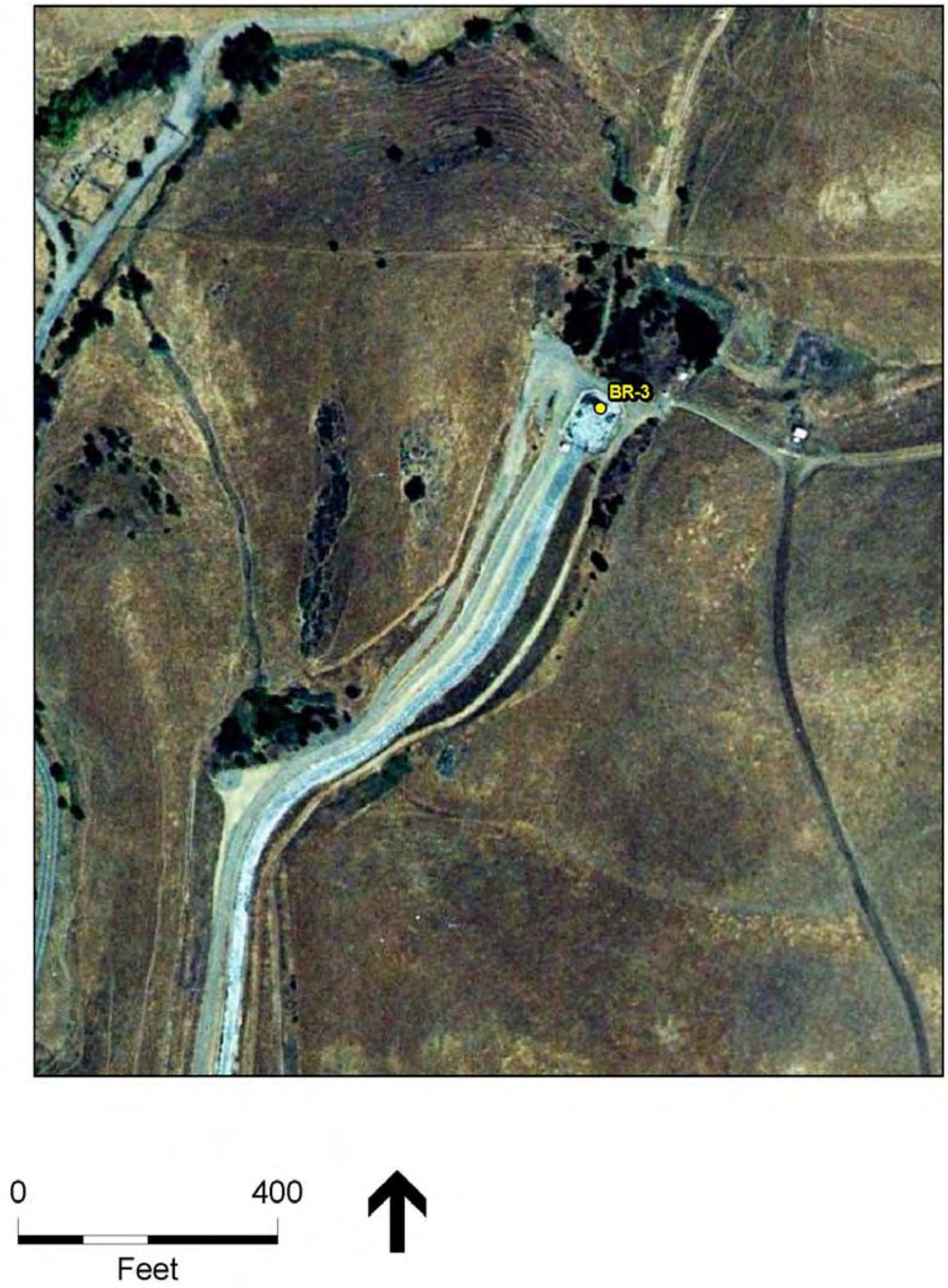
Map 2

Sampling Stations at Bethany Reservoir



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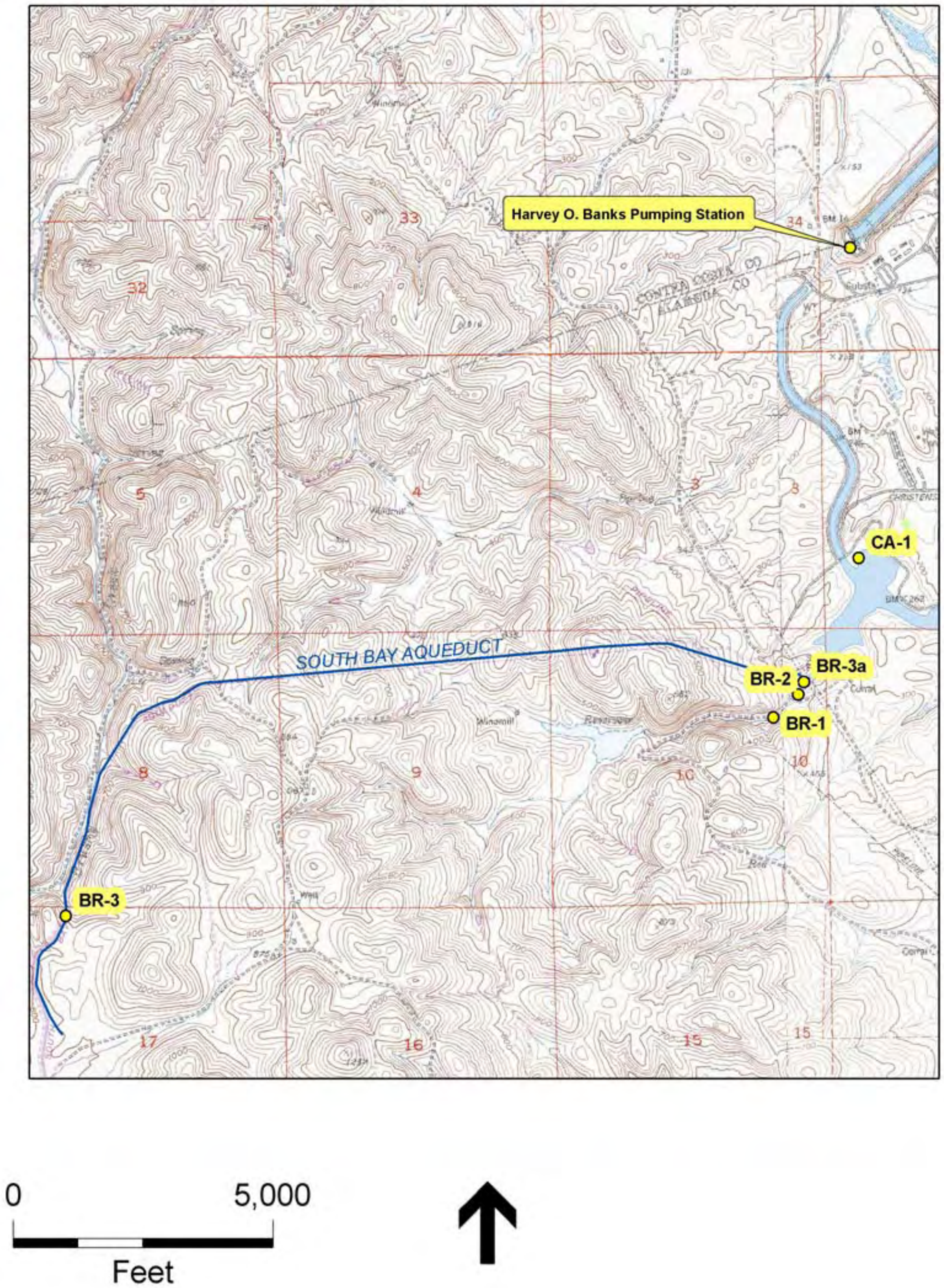
Map 3

Location of Sampling Station 3



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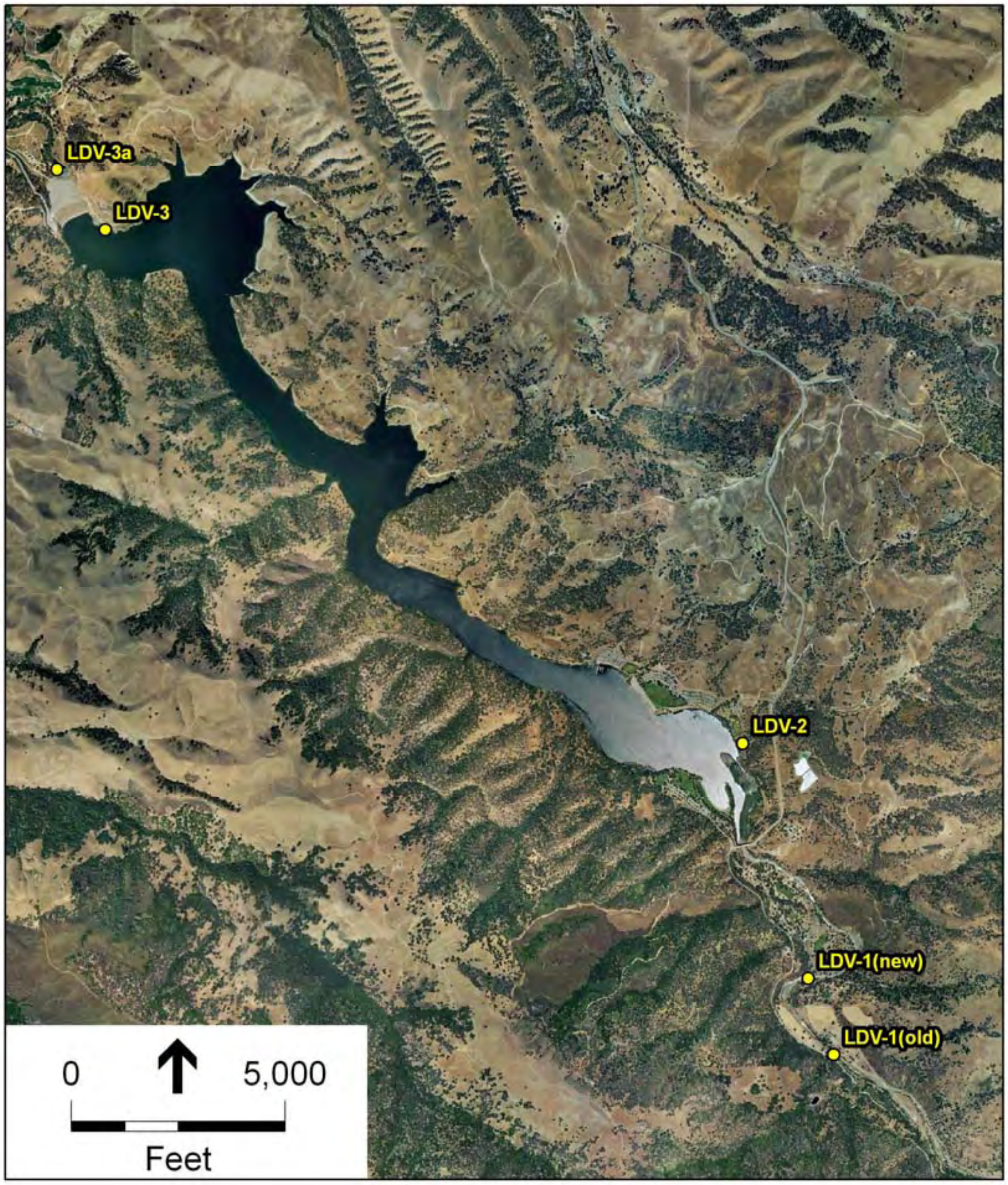
Map 4

Location of Bethany Reservoir and Aqueduct Sampling Stations



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Map 5

Location of Sampling Stations around Lake Del Valle

Divergence from Methodology

In addition to the above-noted change in the location of sampling station LDV-1, there were two other significant deviations from the methods described in the Stormwater Monitoring Plan (ESA and EOA, 2005b) and QAPP (ESA and EOA, 2005a): 1) due to malfunction of field equipment, two parameters, conductivity (also referred to as electrical conductance) and pH were analyzed by the Zone 7 laboratory, instead of in the field, for several of the sampling events; and 2) when high solids content of samples for *Giardia* and *Cryptosporidium* samples resulted in the laboratory filtering out a large volume of “pellets,” ESA instructed Biovir Laboratory to prepare only two slides per sample, due to budget constraints. After the first instance of this, the sample collection method was improved to reduce the collection of floating solids.

III. Results

Sampling occurred on five dates during the winter of 2005-2006, with the first event sampled on December 21, 2005, and the last on March 6, 2006 (Table A). Table A shows the sampling dates and the hydrologic conditions prevalent on the sampling dates, including the rainfall recorded at the Livermore Airport and Mount Hamilton stations up to 6:00 p.m. of the day of sampling, and the instantaneous discharge at the time of sampling at the USGS gage on Arroyo Valle and the Zone 7 Water Agency gage on Cedar Creek at station LDV-2.

The December 21, 2005 sampling event occurred early in the rainy season (Figure A), prior to the onset of winter base flows in Arroyo Valle, and prior to any recorded flows in Cedar Creek. All of the other events occurred later in the season, after the very large storm event of December 30, 2005–January 2, 2006, when base flows were already established. Figure A indicates the much more rapid response of elevated flows to storm events later in the season. For the February 28, 2006 sample date, the mean daily flow value recorded at the USGS Arroyo Valle gage was the fourth largest over the time period of October 1, 2005 through March 31, 2006 (Figure A).

As shown in Table A-1 in Appendix A, samples were collected at all stations during all 5 events with the following exceptions:

- No samples were collected at station LDV-2 on December 21, 2005, as the station was dry;
- No *Giardia*/*Cryptosporidium* samples were collected at station BR-2 on December 21, 2005 or on February 28, 2005, due to low flow conditions at the station (a 10-liter sample is required).
- pH testing was not conducted at station LDV-1 on December 21, 2005, due to equipment malfunction.
- TOC analysis was not conducted for the LDV-1 sample on February 27, 2006 as the sample was lost (broken) in the laboratory.

TABLE A
SAMPLE DATES AND CONDITIONS

Sample Date	24 Hour Rainfall Total: Livermore [A] (inches)	24 Hour Rainfall Total: Mt. Hamilton[a] (inches)	LDV-1: Arroyo Valle Flow at Time of Sample[b] (cfs)	LDV-2: Cedar Creek Flow at Time of Sample[c] (cfs)
12/21/2005	0.27	0.54	3.1	NA
2/27/2006	0.21	1.3	12.0	0.7
2/28/2006	0.44	1.3[d]	543.0	1.3
3/2/2006	0.19	0.31[d]	148.0	0.8
3/6/2006	0.54	0.48	161.0	0.9

[a] Precipitation values are the accumulated totals for the NOAA Livermore, CA station (COOP ID 04-4997) and Mt. Hamilton Station (COOP ID 04-5933-04) over the previous 24 hours ending at 18:00 PST on the given date.
[b] Value represents the instantaneous discharge reported for USGS Gage No. 111764000 for the time closest to the reported sample time (station samples every 15 minutes).
[c] Value represents the instantaneous discharge reported for the Zone 7 Cedar Creek Gage for the time closest to the reported sample time (station samples every 15 minutes).
[d] In addition to the rainfall totals shown, this station reported .5 inches of snow on February 28 and 1.3 inches of snow on March 2.

Pollutants and Characteristics

The average parameter value for each sampling location is presented in Table B. For total coliform and *E. coli*, detected values reported as greater than 2000 were assumed to be 2,000 for purposes of averaging.

Water Quality Physio-chemical Parameters

Physio-chemical measurements were made in the field. Water temperatures at Bethany Reservoir locations ranged between 9 and 19 ºC. The dissolved oxygen concentrations at all sites were greater than 10 mg/l. Specific conductance ranged between 169 and 2,950 uS/cm and pH concentrations were between 6.8 and 8.7 units. The estimated average water velocity measured at Bethany site BR-1 was 0.1 ft/sec during the March 2nd storm event.

Water temperatures at Lake Del Valle locations ranged between 10.2 to 15.2 C. The dissolved oxygen concentrations at all sites were greater than 9.4 mg/l; LDV-1 had the greatest average dissolved oxygen level of 12.98 mg/l of all sample locations. Specific conductance ranged between 223 and 1,296 uS/cm and pH concentrations were between 7.9 and 8.8 units. The average water velocity measured at LDV-1 and LDV-2 sites was 173.4 and 0.9 ft/sec respectively.

Giardia and *Cryptosporidium*

The *Giardia* and *Cryptosporidium* results for each sample location are shown in Figure B. *Cryptosporidium* was present in samples from the 3 Bethany Reservoir locations (BR-1, BR-2, and BR3), and 2 Del Valle locations (LDV-1 and LDV-2). The greatest number of

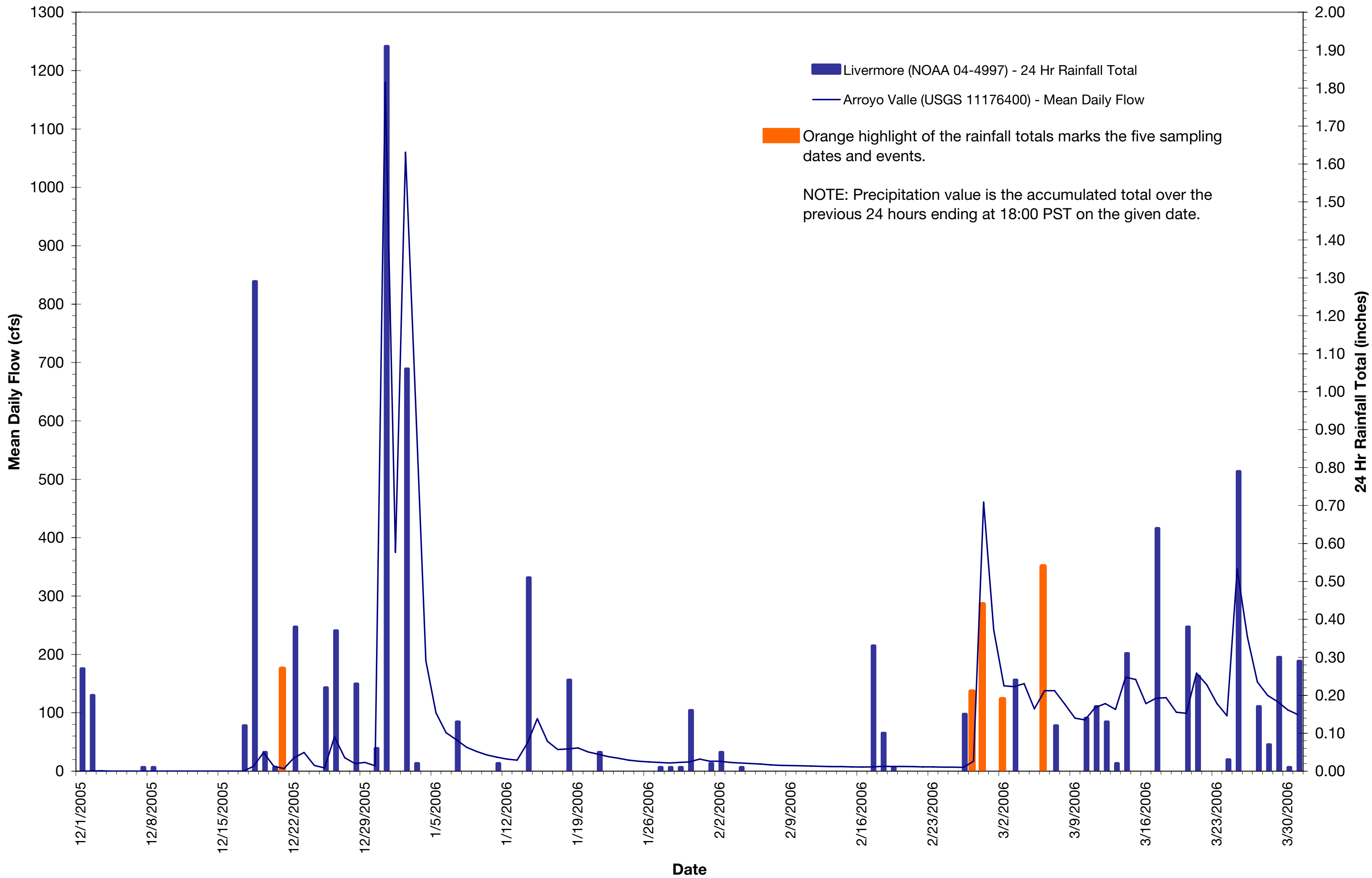

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Figure A

Livermore 24-hour Rainfall Total and Arroyo Valle Mean Daily Flow, 12/21/2005–3/30/2006

Cryptosporidium was observed at BR-1, and oocysts were observed in samples from all 5 monitoring events. No *Cryptosporidium* was found in samples from the aqueduct (CA-1) or LDV-3 from any of the 5 storm events. *Cryptosporidium* values for each location per storm sampling event are shown in Figure B-1.

Giardia was present in samples from the aqueduct (CA-1), and Bethany Reservoir (BR-1, BR-2, and BR3), and Del Valle (LDV-1). The greatest number of *Giardia* was observed at BR-1, with oocysts observed in samples from all 5 monitoring events. *Giardia* values for each location per storm sampling event are shown in Figure B-2.

Chemical Parameters

Water quality samples were collected at 7 sites during 5 sampling events. Samples were analyzed for nutrients and anions, suspended sediment concentrations, bromide, total organic carbon, turbidity and total dissolved solids.

Bromide

Bromide concentrations ranged from 0.08 to 1.98 mg/l. Bromide was above the CALFED bromide target of 0.050 mg/l at the aqueduct location (CA-1), all Bethany locations (BR-1, BR-2, BR-3), and LDV-2. A majority of the samples were over the bromide target. BR-1 and BR-2 presented the greatest bromide concentrations for all 5 storm events. Measured bromide results for the stormwater events are shown in Figure C.

Total Organic Carbon

TOC concentrations ranged from 3.2 to 11.2 mg/l. All samples collected were above the CALFED TOC target of 3 mg/l at all locations. There was no TOC data for LDV-2 for the 12/21/05 sampling event, as the station was dry; or -1 on for LDV-1 for the February 27 sampling event due to a broken sample in the laboratory. The two Lake Del Valle tributary locations (LDV-1 and LDV-2) exhibited the highest TOC concentrations, with averages of 6.10 and 9.94, respectively. Measured total organic carbon concentrations for the stormwater sampling events are shown in Figure D.

Turbidity

Turbidity concentrations ranged from 1.2 to 273 ntu. Turbidity was elevated during the February sampling events at BR-2 and LDV-1. Measured turbidity results for the 5 stormwater sampling events are shown in Figure E.

Total Dissolved Solids

TDS levels ranged from 138 to 1,720 mg/l. BR-1 and BR-2 had consistently high TDS levels for all storm events. LDV-2 had the highest TDS levels for the Lake Del Valle locations. TDS results for the 5 stormwater sampling events are shown in Figure F.

Nutrients

Nitrate-nitrogen levels ranged from <0.10 to 2.11 mg/l. The Bethany locations (BR-1 BR-2 and BR-3) had consistently higher nitrate, nitrite, and ammonia levels than Lake Del Valle locations. Nitrite-nitrogen ranged from <0.01 to 0.31 mg/l, and phosphate-P levels ranged from <0.05 to 0.06 mg/l. Ammonia-nitrogen concentrations ranged from <0.05 to 0.18 mg/l. Sulfate concentrations ranged from 22 to 280 mg/l. Figures G and H-1 through H-4 show the concentrations of the nutrient parameters for each location and storm event.

Sodium

Sodium concentrations ranged from 12 mg/l to 445 mg/l. BR-1 and BR-2 presented the greatest sodium concentrations for all 5 storm events. Measured sodium results for the stormwater events are shown in Figure I.

Potassium

Potassium concentrations ranged from 1.4 mg/l to 4.5 mg/l. BR-1, BR-2, and LDV-2 had elevated potassium concentrations for all 5 storm events. Measured potassium results for the stormwater events are shown in Figure J.

Fluoride

Fluoride concentrations ranged from 0.07 mg/l to 1.13 mg/l. BR-1 and BR-2 presented the greatest fluoride concentrations for all 5 storm events. Measured fluoride results for the stormwater events are shown in Figure K.

Total Alkalinity

Total alkalinity levels ranged from 52 mg/l to 476 mg/l. BR-1 and BR-2 presented the greatest alkalinity concentrations during all 5 storm events. LDV-2 showed the greatest alkalinity levels for the Lake Del Valle sites. Measured alkalinity results for the stormwater events are shown in Figure L.

Total Hardness

Total hardness ranged from 78 mg/l to 612 mg/l. BR-1 and BR-2 presented the greatest water hardness values for all 5 storm events. LDV-2 showed the highest hardness for the Lake Del Valle sites. Measured hardness results for the stormwater events are shown in Figure M.

Water Quality Generals

Water temperature ranged from 10 to 15 °C. Dissolved oxygen ranged from 6 to 13 mg/l, and specific conductance levels ranged from 169 to 2,950 uS/cm. the specific conductance levels at BR-1, BR-2, and LDV-2 were above the WQO and SMCL of 900 uS/cm. Salinity ranged from 0.0 to 1.5 ppt. The Bethany locations (BR-1 BR-2 and BR-3) had consistently higher salinity and specific conductance levels than Lake Del Valle locations. The water pH ranged from 6.8 to 8.8 pH units, and all values were above the water quality objective of 6.5 units for minimum pH.

Figures N-1 through N-5 show the concentrations of the water quality general parameters for each location and storm event.

Bacteriological Parameters

Surface water samples were collected during the 5 sampling events from the 7 monitoring locations. Samples were analyzed for total coliform and *E.coli*. Total coliform concentrations ranged from 16 to >2,000 MPN/100 ml. All BR-1 samples exhibited coliform > 2,000 MPN/100 ml. The highest coliform levels (>2,000 MPN/100 mL at four locations) were observed during the early part of the storm season (December 21, 2005 sampling event). Total coliform and *E. coli* concentrations were highest at Lake Del Valle during the February 28, 2006 sampling event. Total coliform results are presented in Figure O-1.

E. coli concentrations ranged from 1 to > 2,000 MPN/100 ml. The highest E. coli levels (>2,000 MPN/100 mL at three locations) were observed during the early part of the storm season (December 21, 2005 sampling event). The February 28, 2006 sampling event was notable for the highest *E. coli* concentrations found in the Lake Del Valle tributary locations (LDV-1 and LDV-2). *E. coli* results are presented in Figure O-2.

Correlations

Turbidity and Conductance vs. Discharge

Turbidity and specific conductance at LDV-1 were plotted and analyzed to show the relationship with stream flow for Arroyo Valle (Figure P). A direct correlation between turbidity and stream discharge, and inverse correlation with conductance were determined. As observed, high turbidity and low conductance occurred with increasing flows.

Total Coliform vs. Discharge

A direct correlation between total coliform and stream discharge at LDV-1 was evident as shown in Figure Q.

Giardia and *Cryptosporidium* vs. Discharge

The relationship of *Giardia* and *Cryptosporidium* levels at BR-1 compared to the magnitude of flow discharges for the various storm events in the nearby Arroyo Valle drainage are shown in Figure R.

TABLE B
AVERAGE PARAMETER VALUES

Parameter	Units	Field/Lab Analysis (F/L)	Average Parameter Value per Sample Location[a]						
			CA-1	**BR-1**	**BR-2**	**BR-3**	**LDV-1**	**LDV-2**	**LDV-3**
Air Temperature	°C	F	13.5	13.4	14.7	17.0	19.5	18.0	17.2
Water Temperature	°C	F	12.0	12.1	11.7	11.8	11.6	13.1	12.0
pH	pH units	F/L	7.9	8.2	8.5	8.1	8.5	8.5	8.4
Dissolved Oxygen (DO)	mg/L	F	9.15	9.24	10.02	10.40	**11.37**	10.34	10.41
Specific Conductance	uS/cm	F/L	332	2,135	**2,662**	408	397	1,078	336
Salinity	ppt	F	0.1	**0.8**	0.7	0.1	0.2	0.5	0.1
Turbidity	NTU	F	22.5	16.2	**81.1**	10.5	75.2	13.9	24.0
Total Alkalinity	mg/L	L	64	387	**431**	67	171	308	152
Total Hardness	mg/L	L	91	**569**	**569**	92	206	329	175
Total Dissolved Solids (TDS)	mg/L	L	204	**1,625**	1,608	219	249	716	214
Total Organic Carbon (TOC)	mg/L	L	3.67	4.82	5.16	3.77	6.10	**9.94**	4.94
Ammonia (NH_3)	mg/L	L	0.09	**0.13**	0.08	0.08	ND	ND	ND
Bromide (Br)	mg/L	L	0.17	**1.84**	1.79	0.18	ND	0.23	ND
Fluoride (F)	mg/L	L	0.07	0.80	**0.90**	ND	0.09	0.21	0.12
Nitrite (NO_2)	mg/L	L	0.01	**0.31**	ND	0.01	ND	ND	ND
Nitrate (NO_3)	mg/L	L	0.80	**0.91**	0.72	0.83	0.20	0.11	0.18
Potassium (K)	mg/L	L	2.20	3.50	3.40	2.20	1.70	**3.90**	1.80
Phosphate (PO_4), Total	mg/L	L	0.05	ND	ND	ND	ND	0.05	ND
Sodium (Na)	mg/L	L	39	394	**401**	39	19	141	35
Sulfate (SO_4)	mg/L	L	34	**239**	228	35	47	206	32
Total Coliform [b]	MPN/100mL	L	1,012	**2,000**	1,602	732	906	1,825	61
Escherichia coli [b]	MPN/100mL	L	560	**998**	623	117	327	615	10

[a] Values in bold type indicate highest average value among all sample locations for the given parameter.
[b] Detected values reported as ">2,000" were assumed to be 2,000 for purposes of averaging.

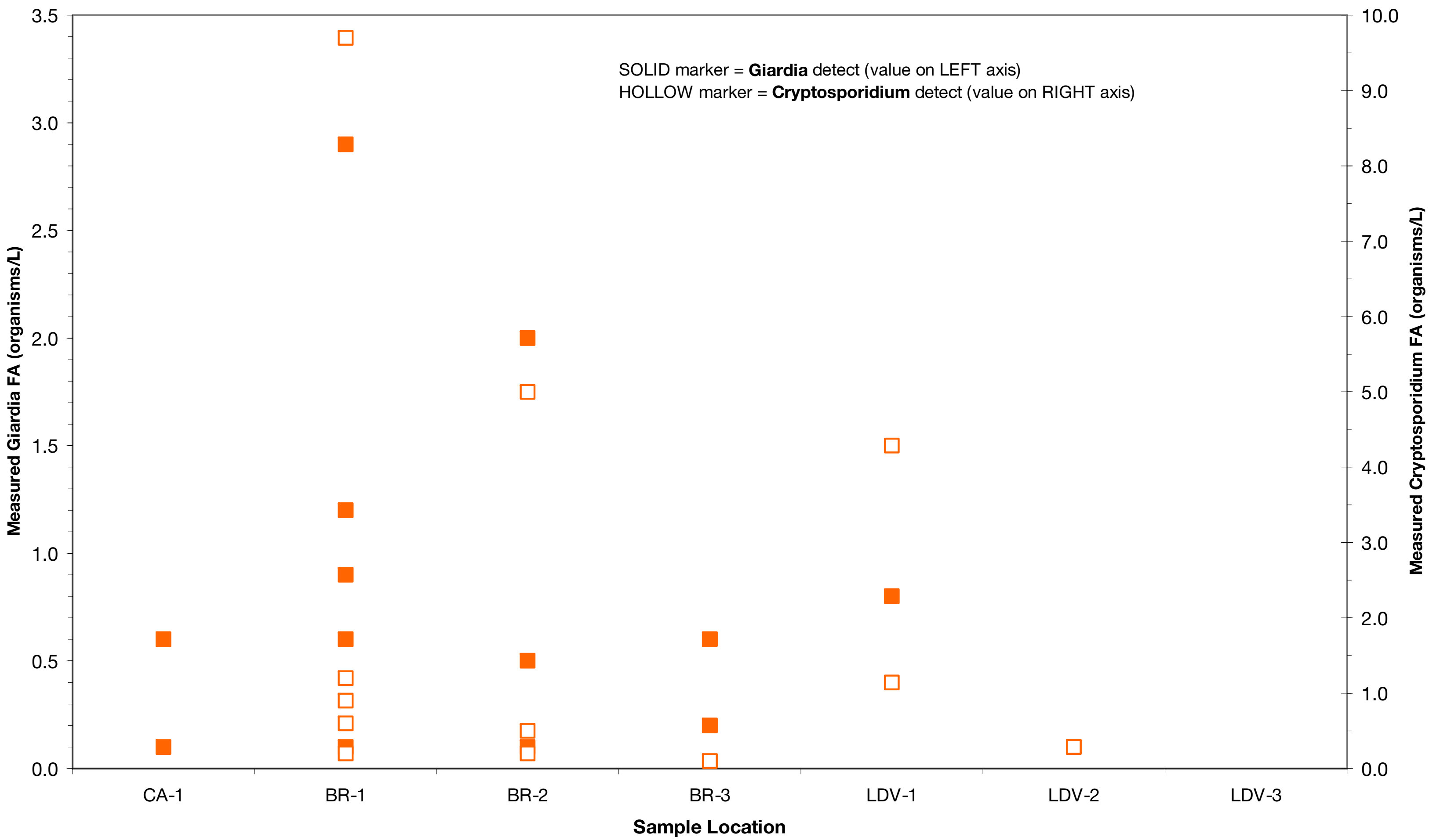

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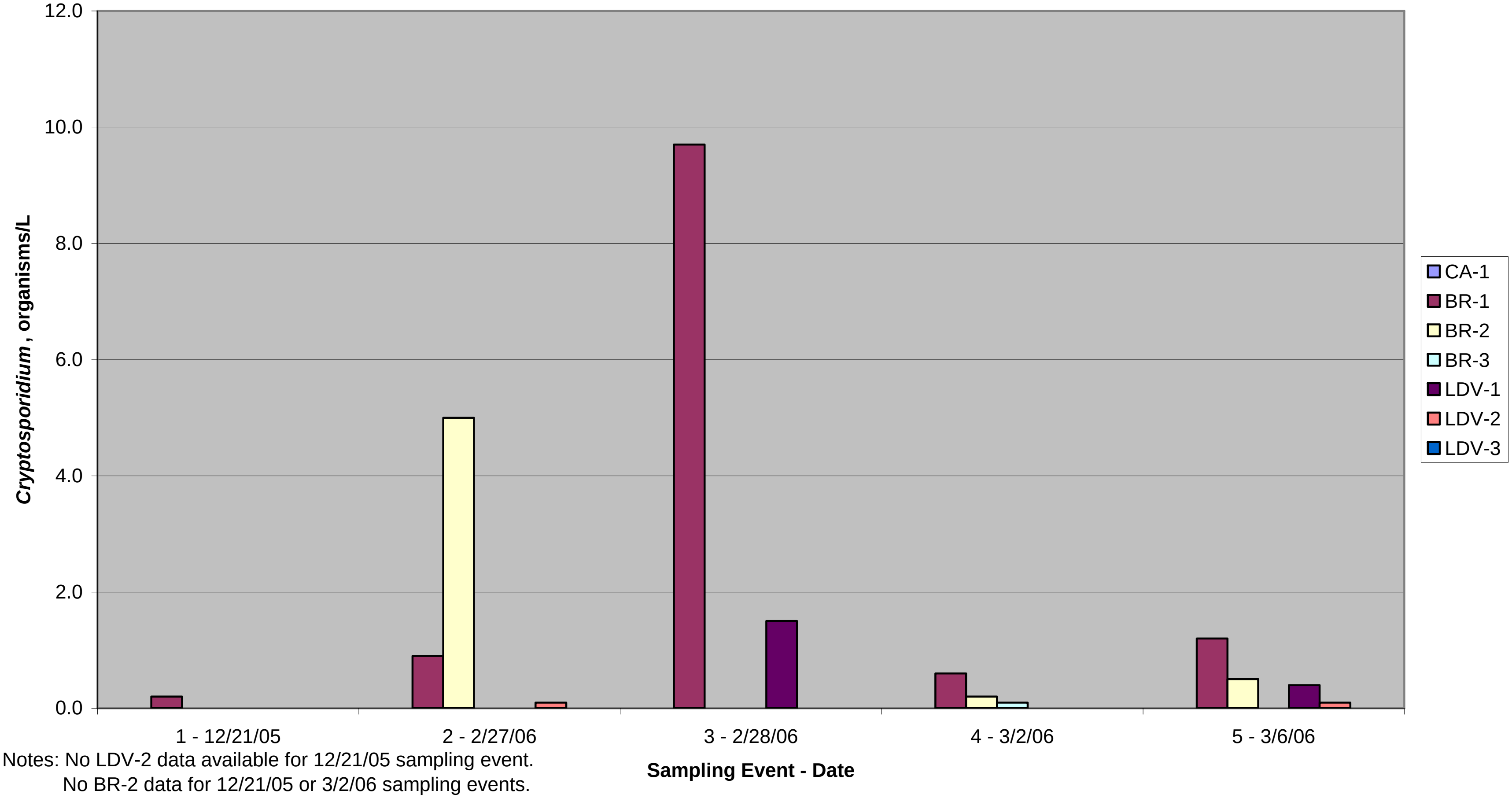
Figure B

Giardia and *Cryptosporidium*



Notes: No LDV-2 data available for 12/21/05 sampling event.
No BR-2 data for 12/21/05 or 3/2/06 sampling events.

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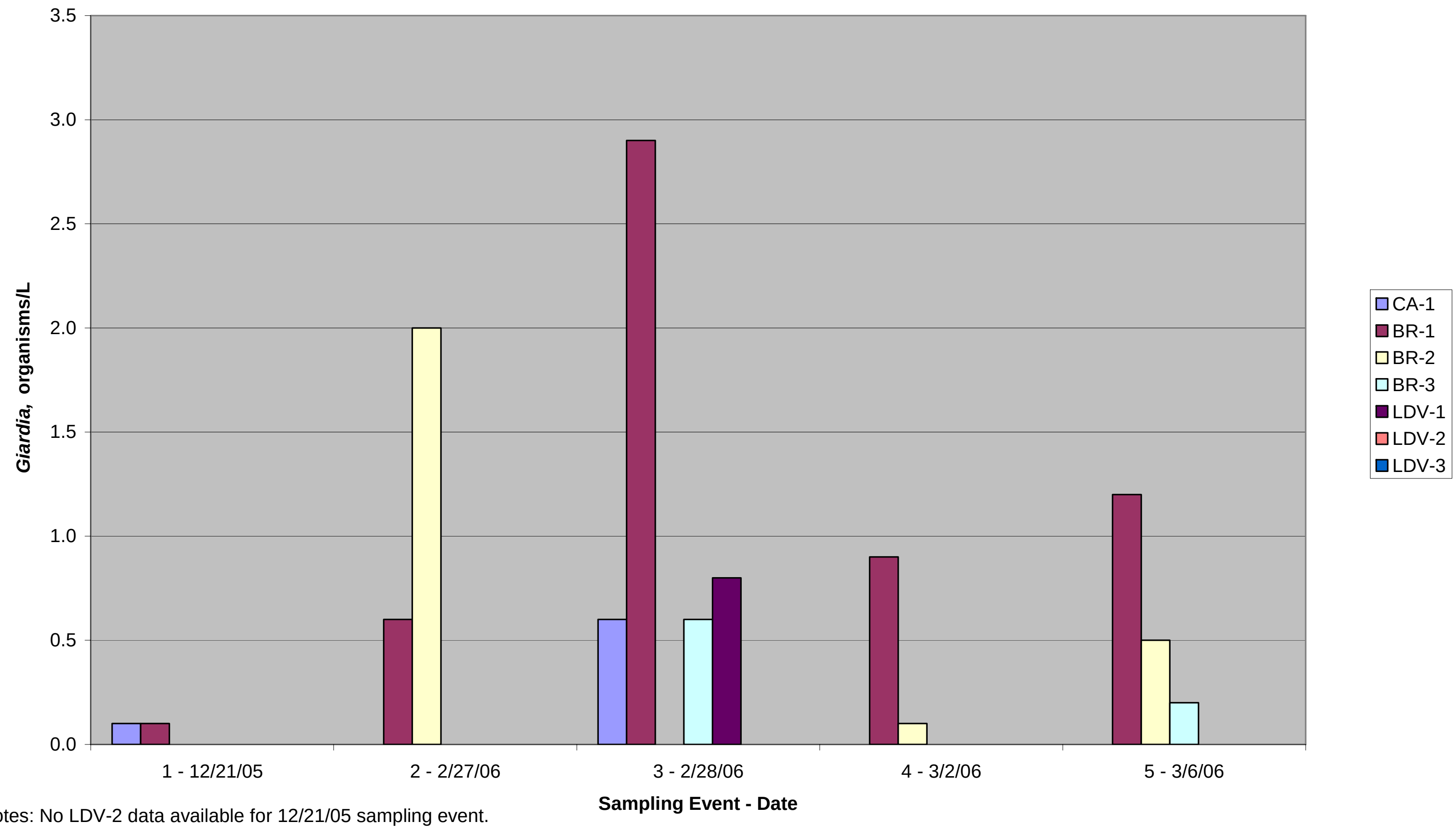
Figure B-1

Cryptosporidium



Notes: No LDV-2 data available for 12/21/05 sampling event.
No BR-2 data for 12/21/05 or 3/2/06 sampling events.

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Figure B-2

Giardia

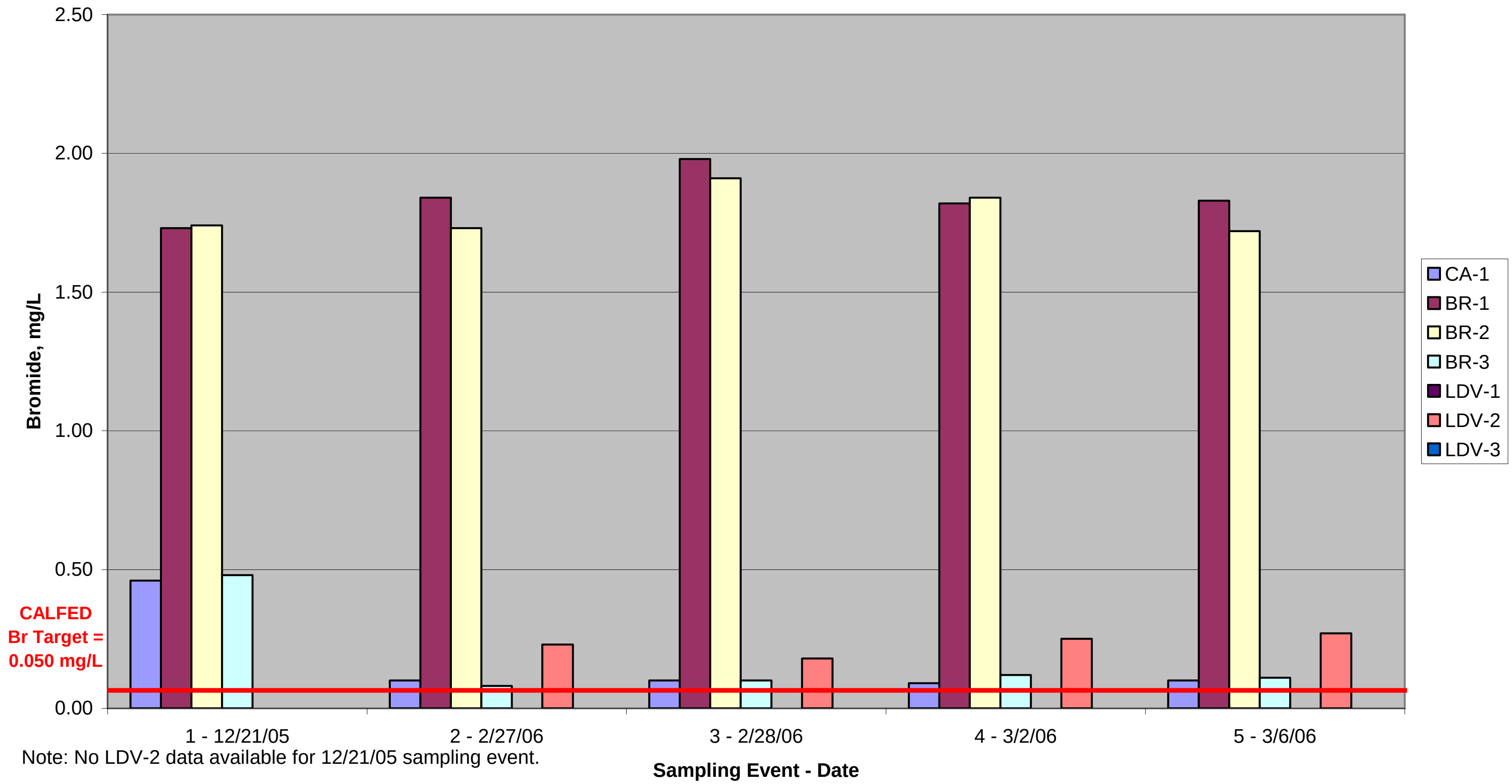

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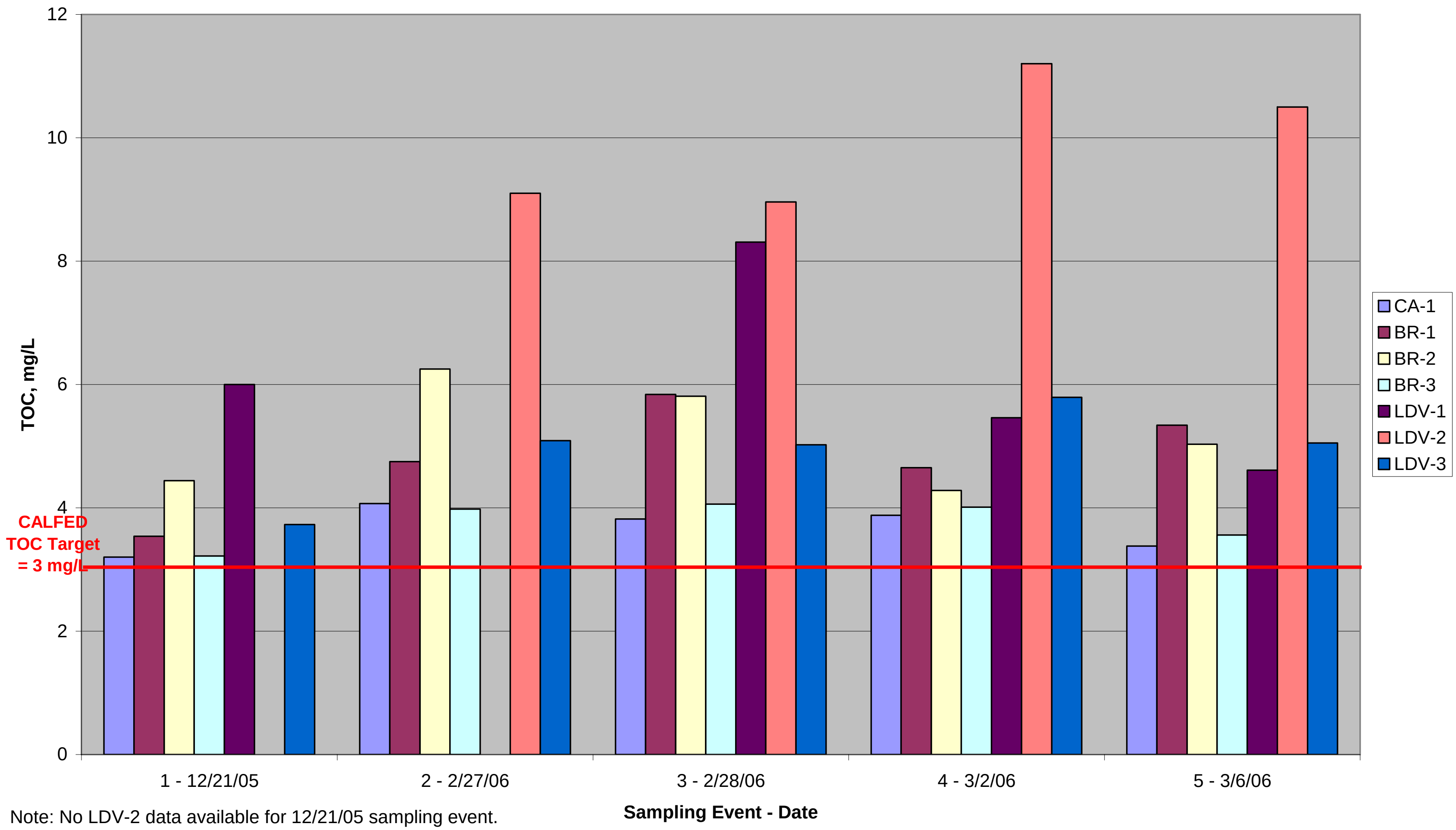
Figure C

Bromide



Note: No LDV-2 data available for 12/21/05 sampling event.

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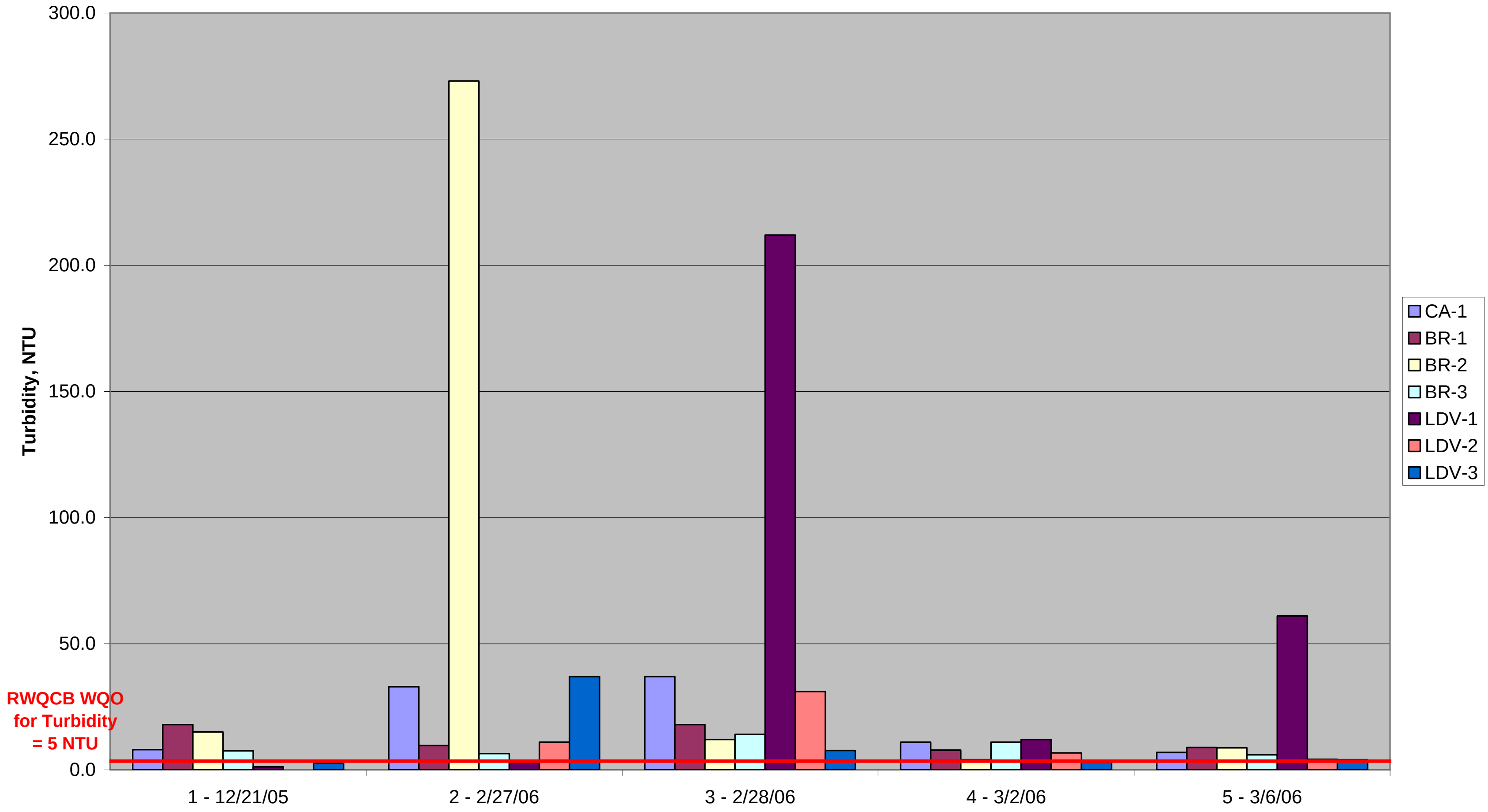
Figure D

Total Organic Carbon



Note: No LDV-2 data available for 12/21/05 sampling event.

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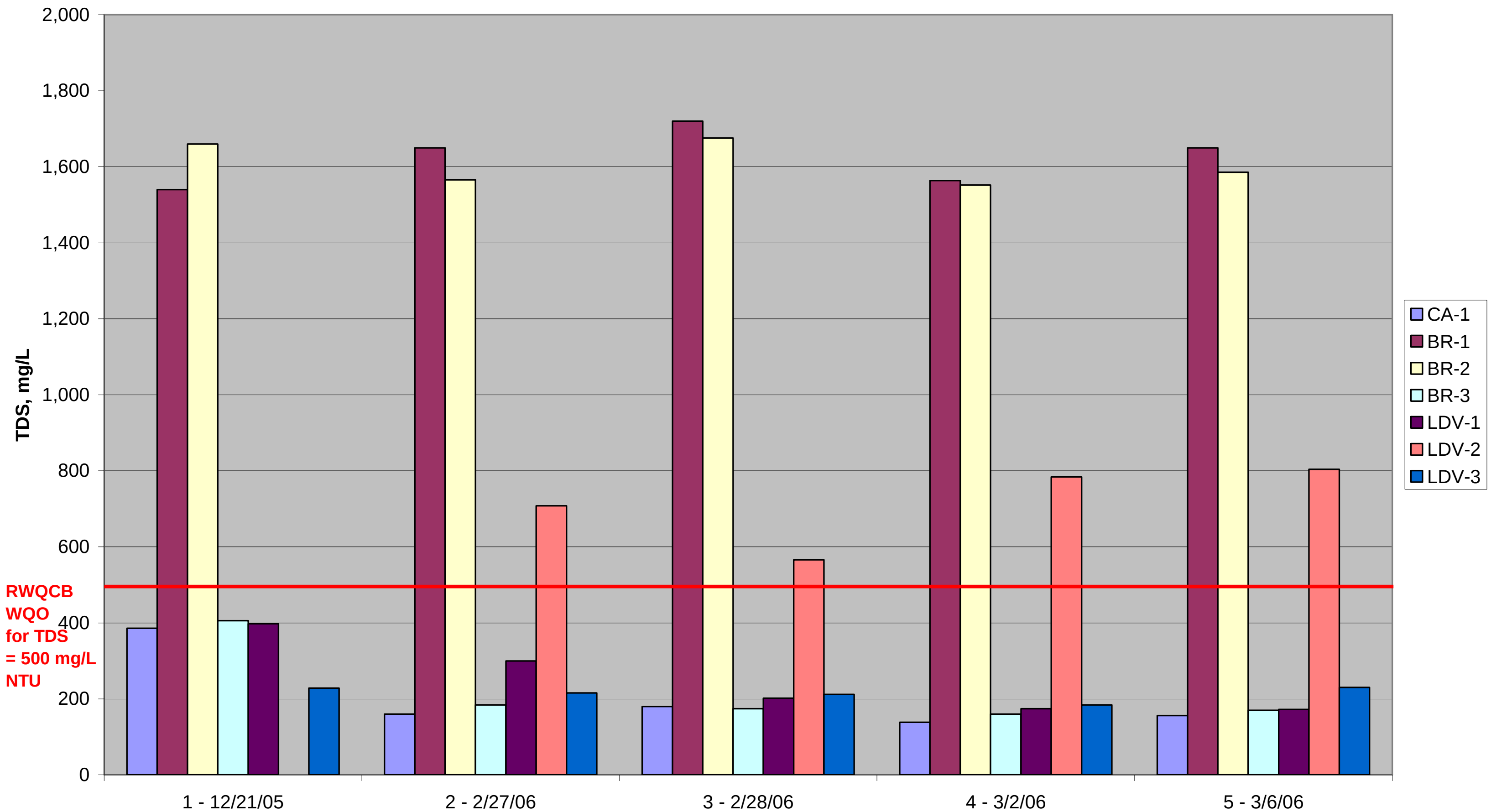
Figure E

Turbidity



Note: No LDV-2 data available for 12/21/05 sampling event.

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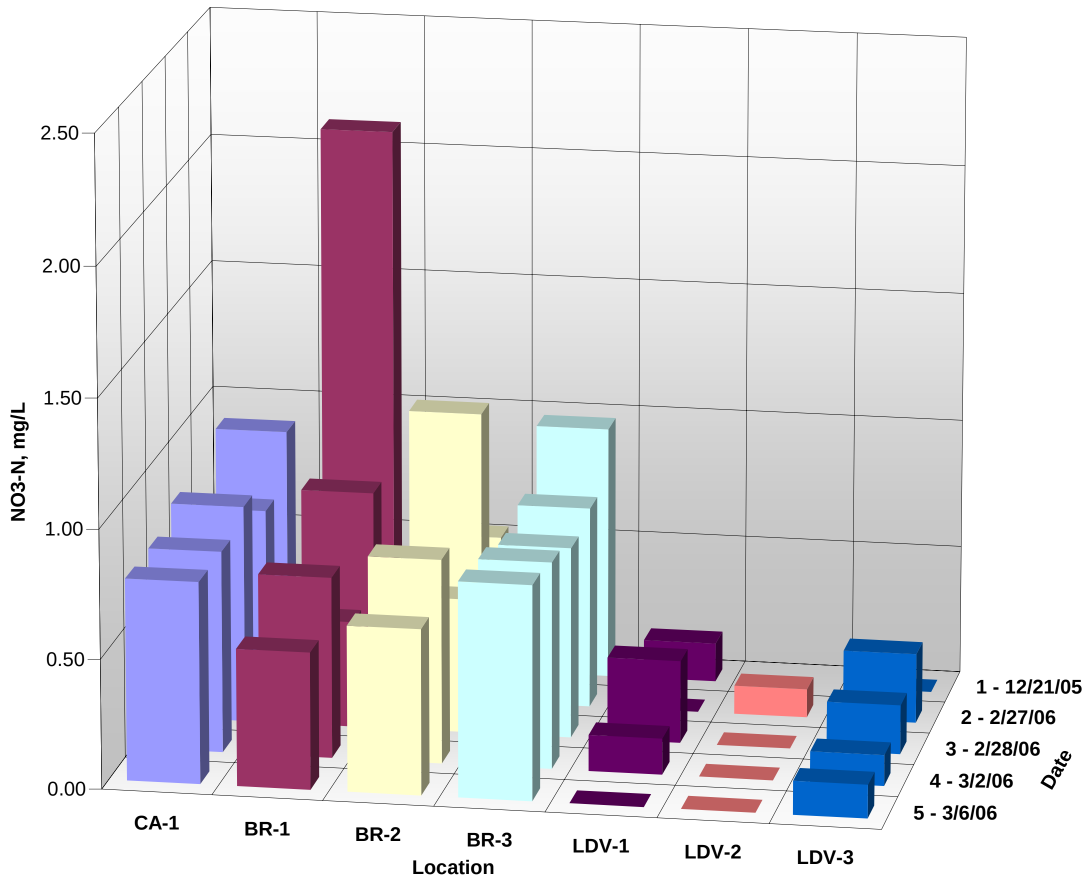
Figure F

Total Dissolved Solids (TDS)



Note: No LDV-2 data available for 12/21/05

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Figure G

Nitrate: 3-D View

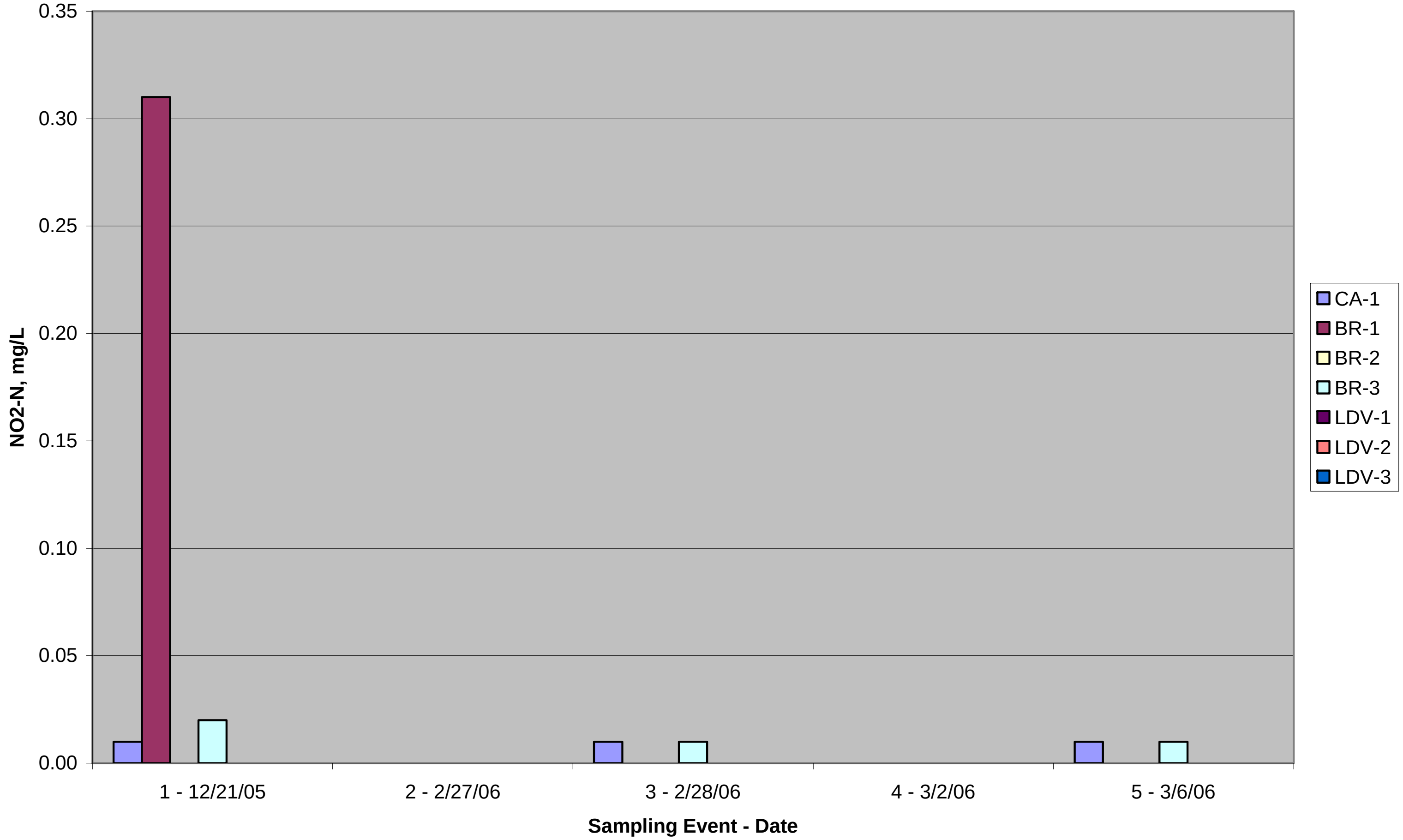

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Figure H-1

Nitrite

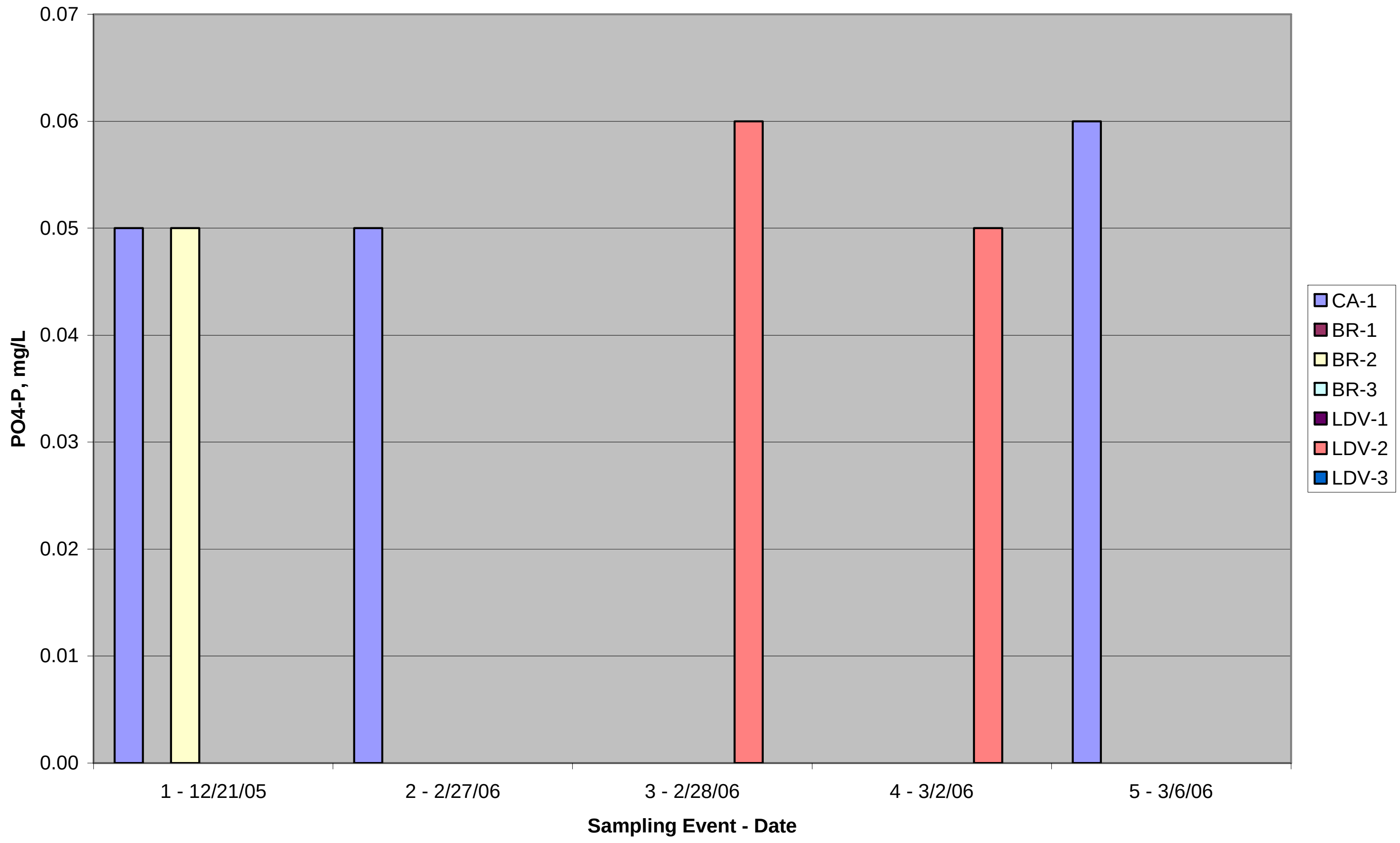

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Figure H-2

Phosphate

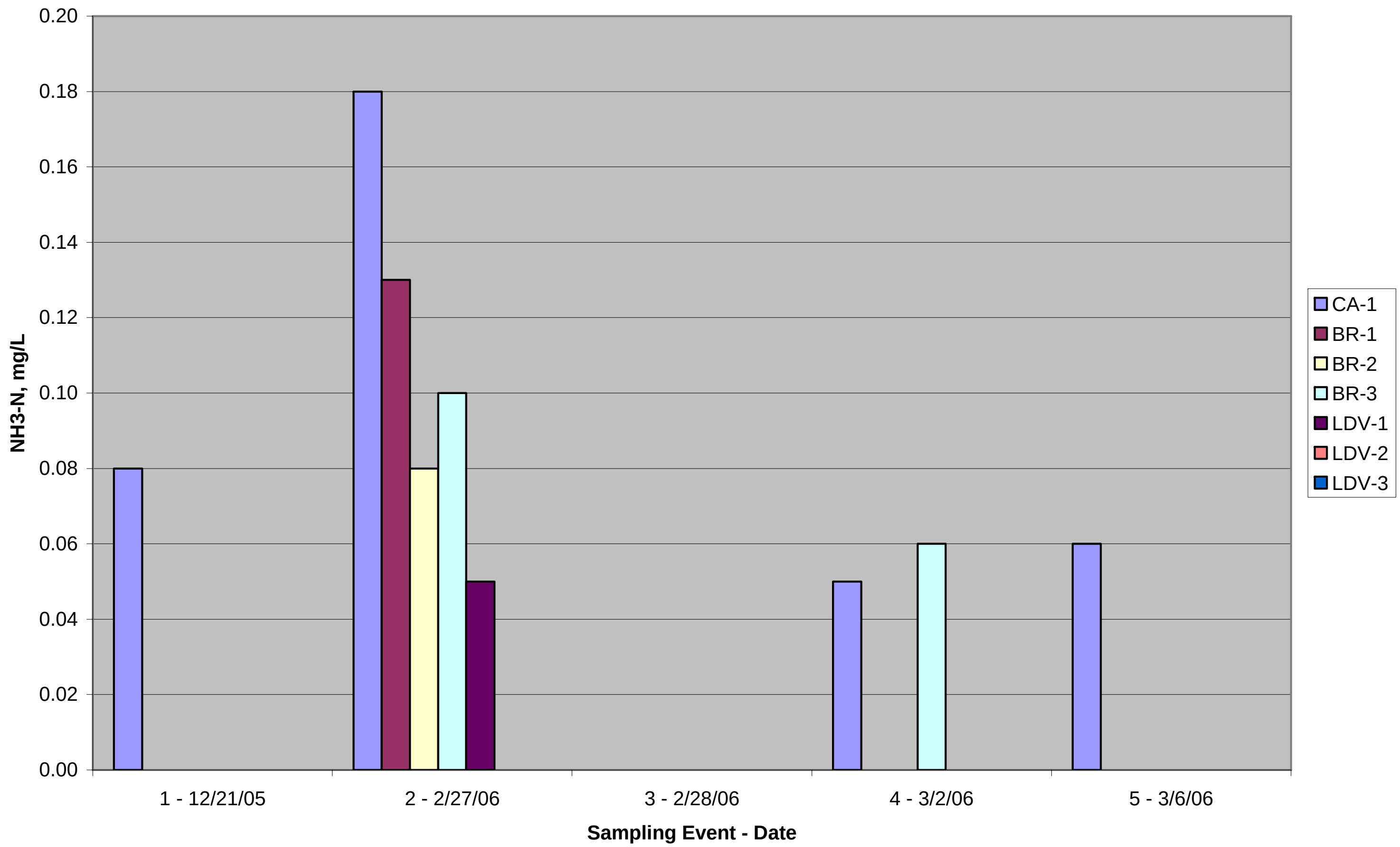

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Figure H-3

Ammonia

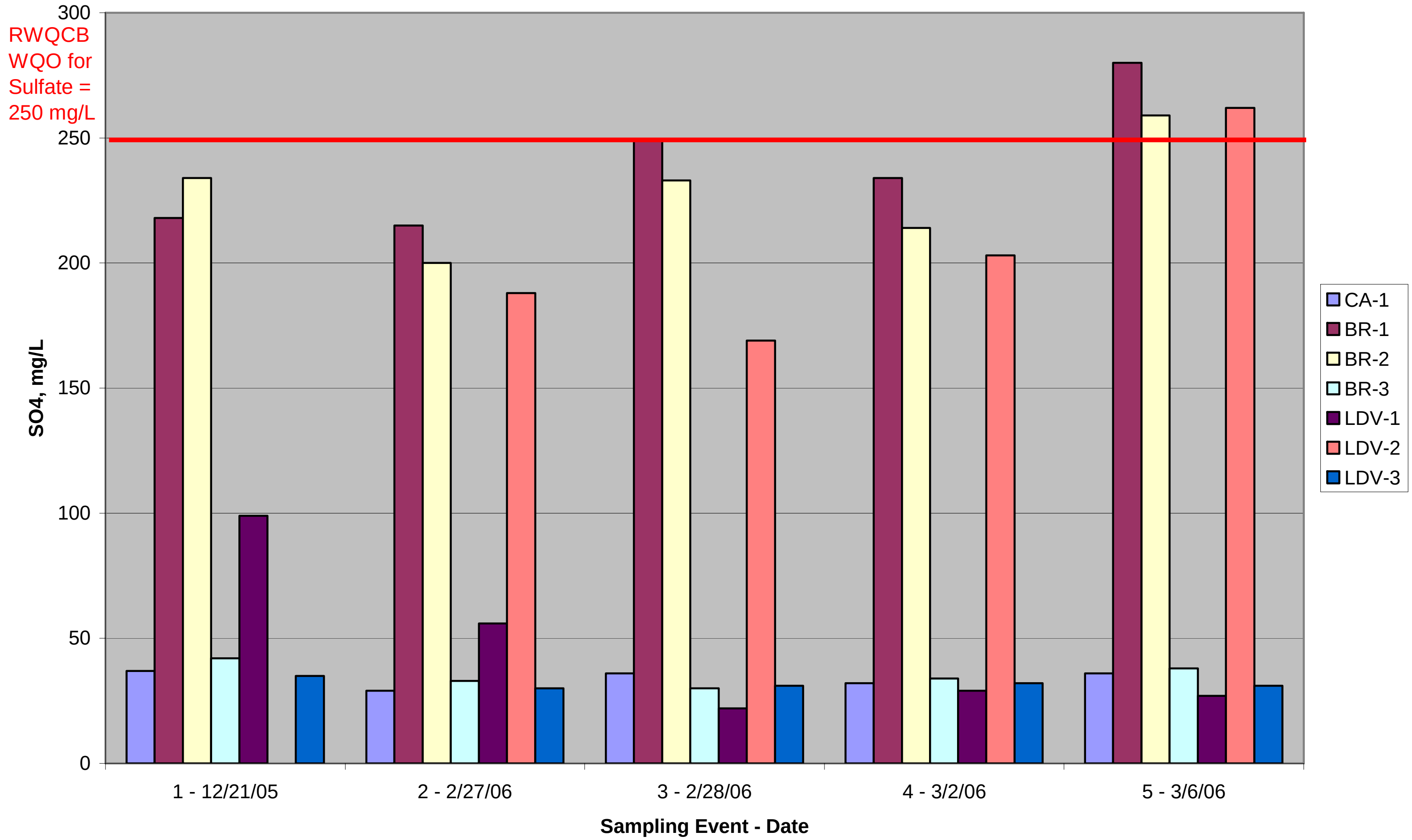

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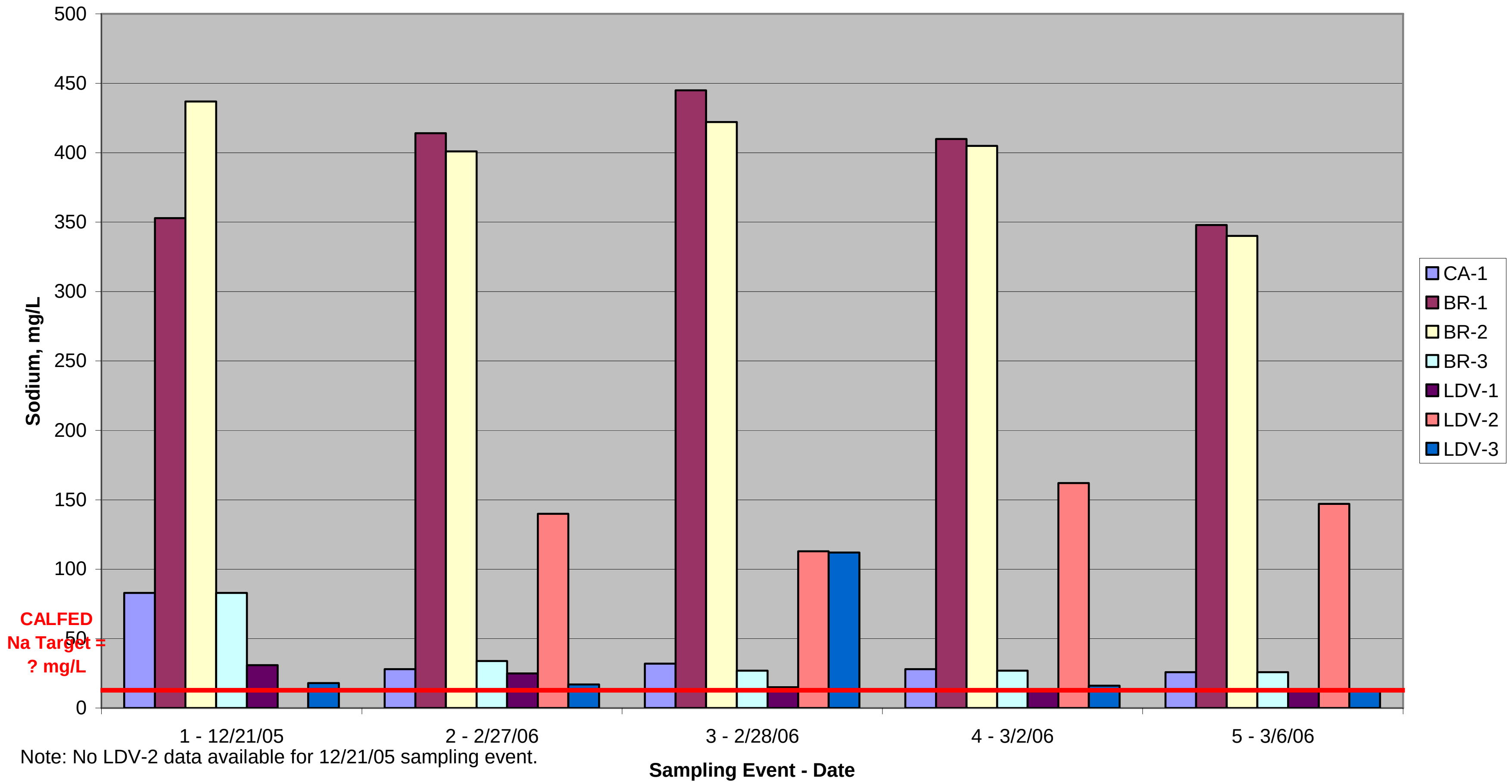
Figure H-4

Sulfate



Note: No LDV-2 data available for 12/21/05 sampling event.

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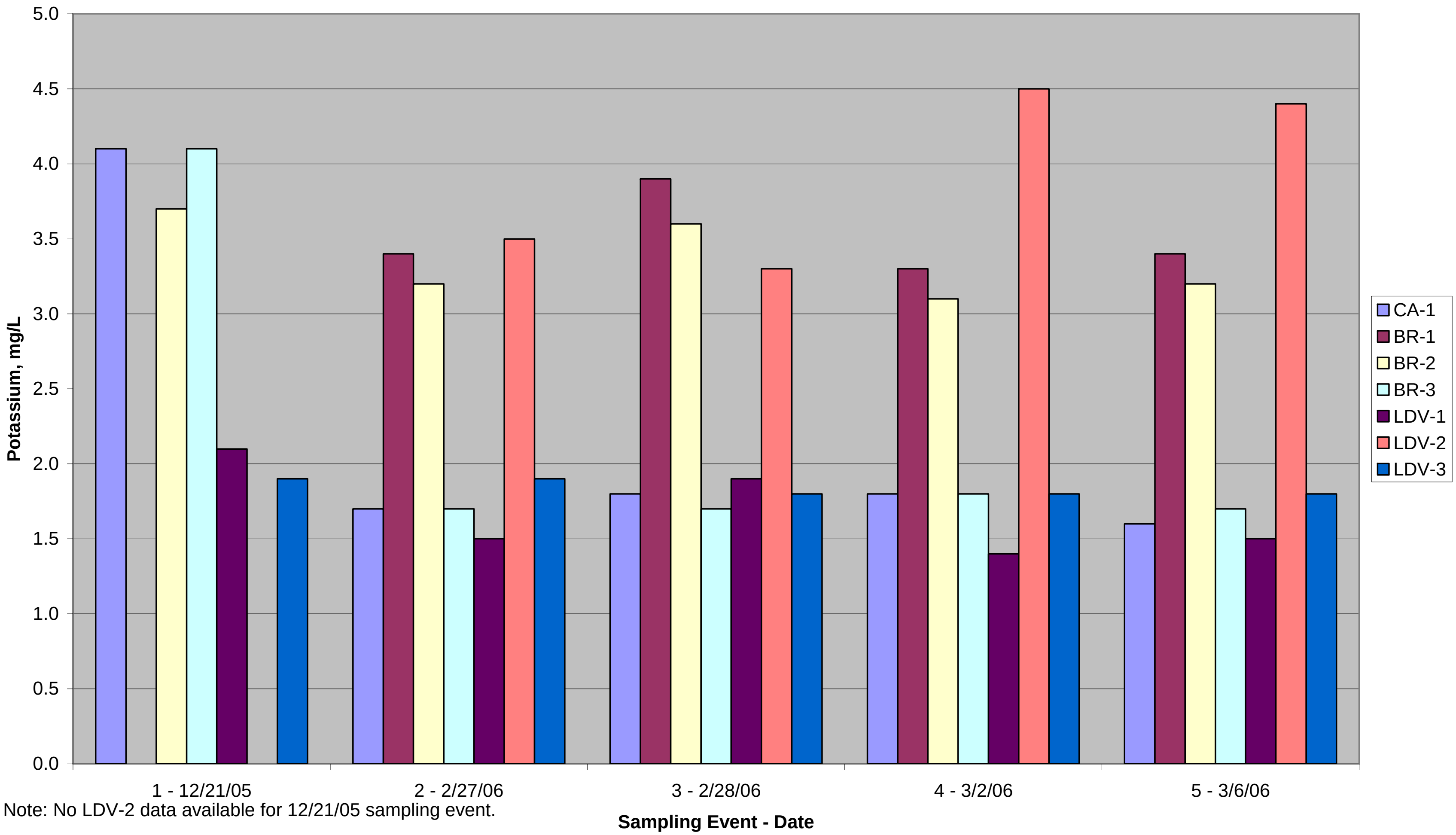
Figure I
Sodium



Note: No LDV-2 data available for 12/21/05 sampling event.

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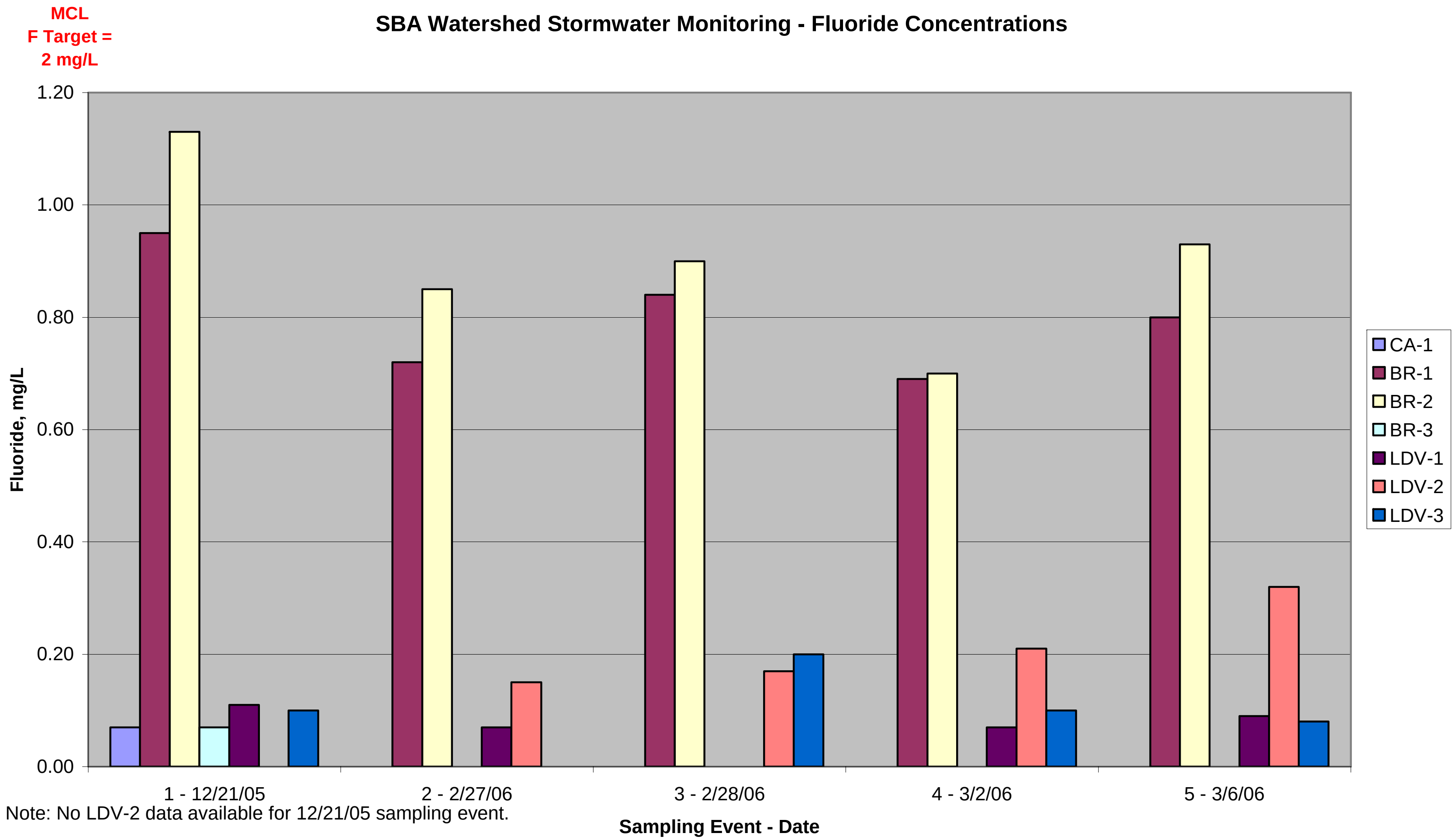
Figure J

Potassium



Note: No LDV-2 data available for 12/21/05 sampling event.

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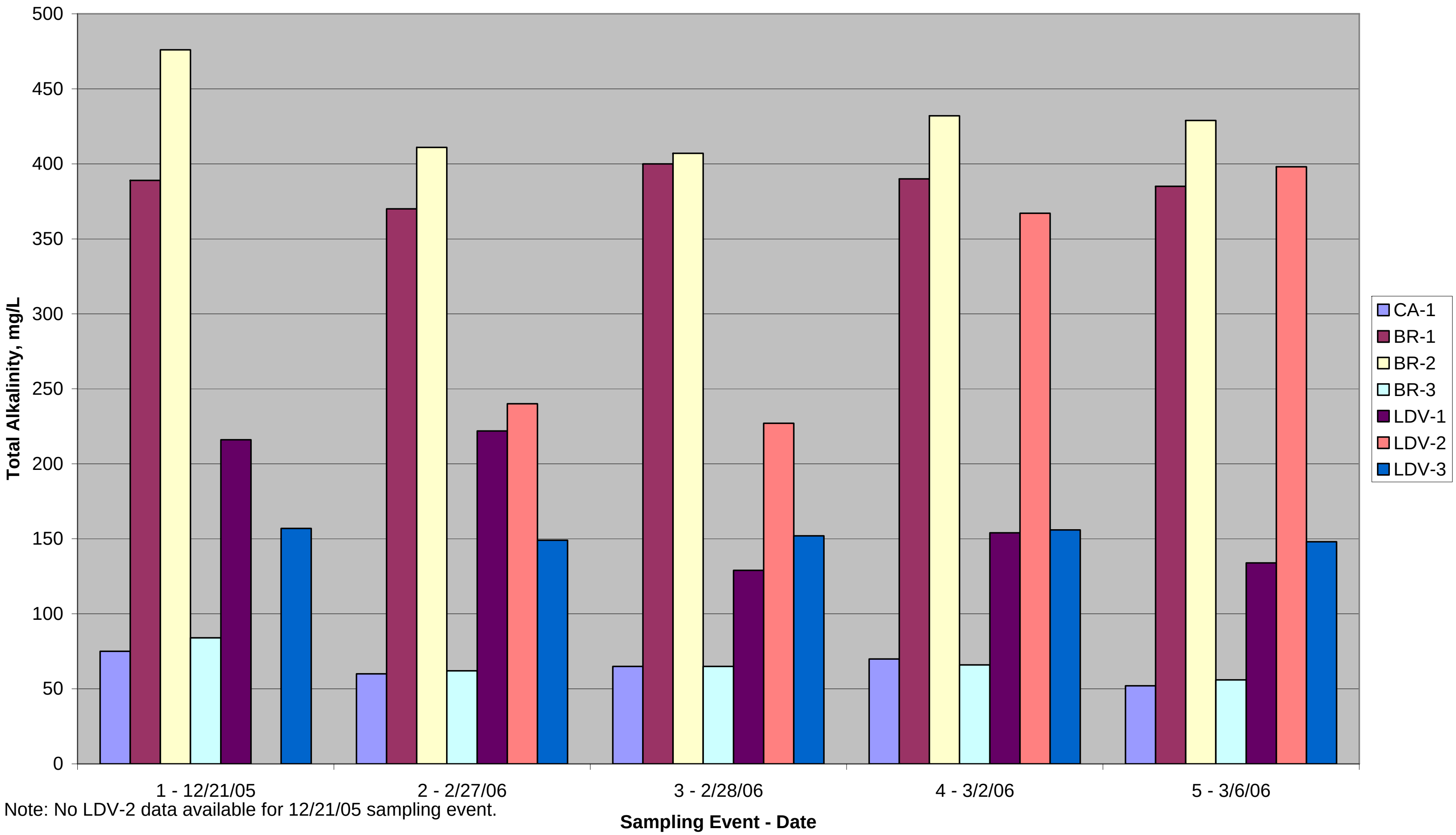
Figure K
Fluoride



Note: No LDV-2 data available for 12/21/05 sampling event.

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Figure L
Total Alkalinity

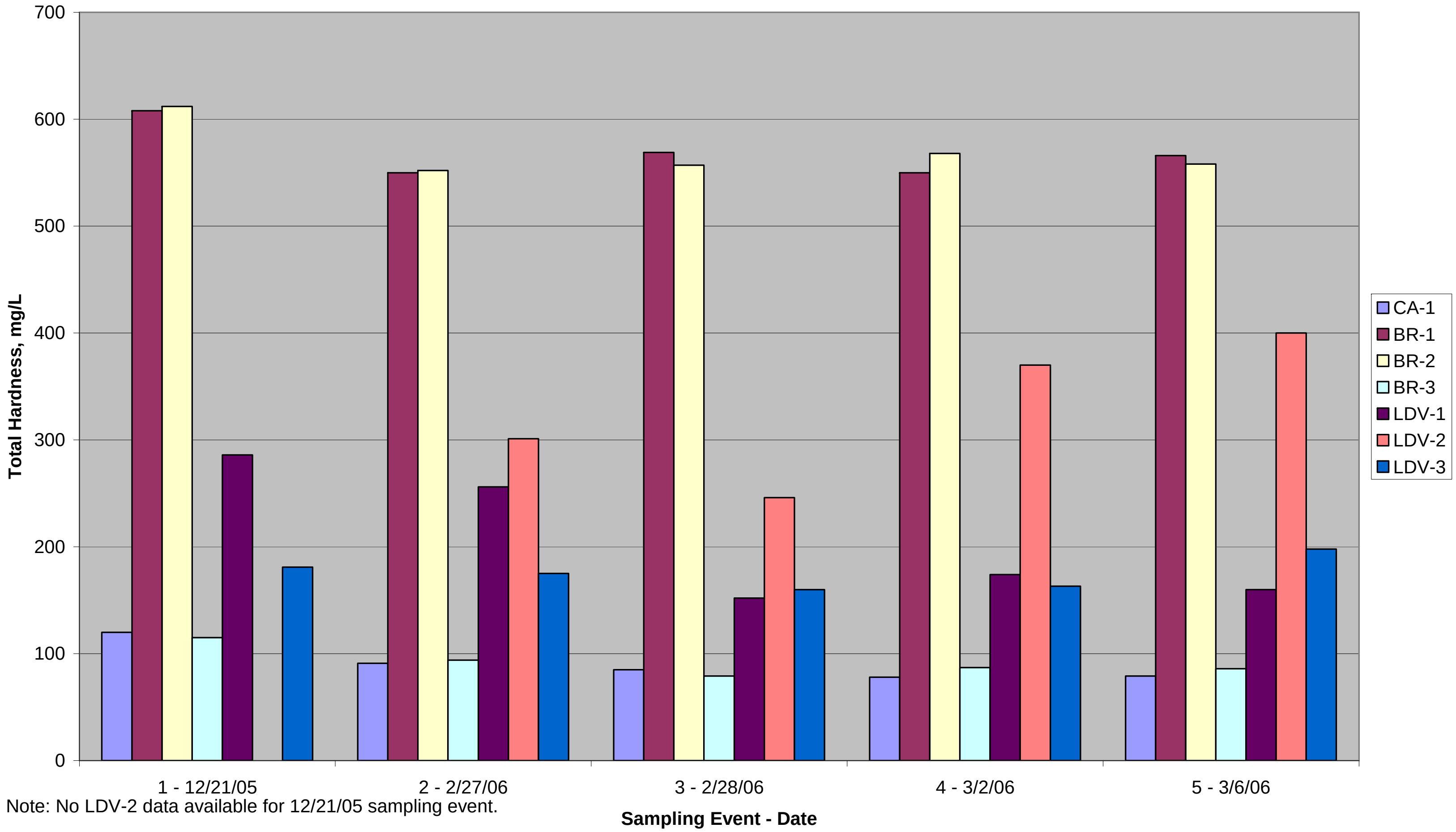

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Figure M
Total Hardness

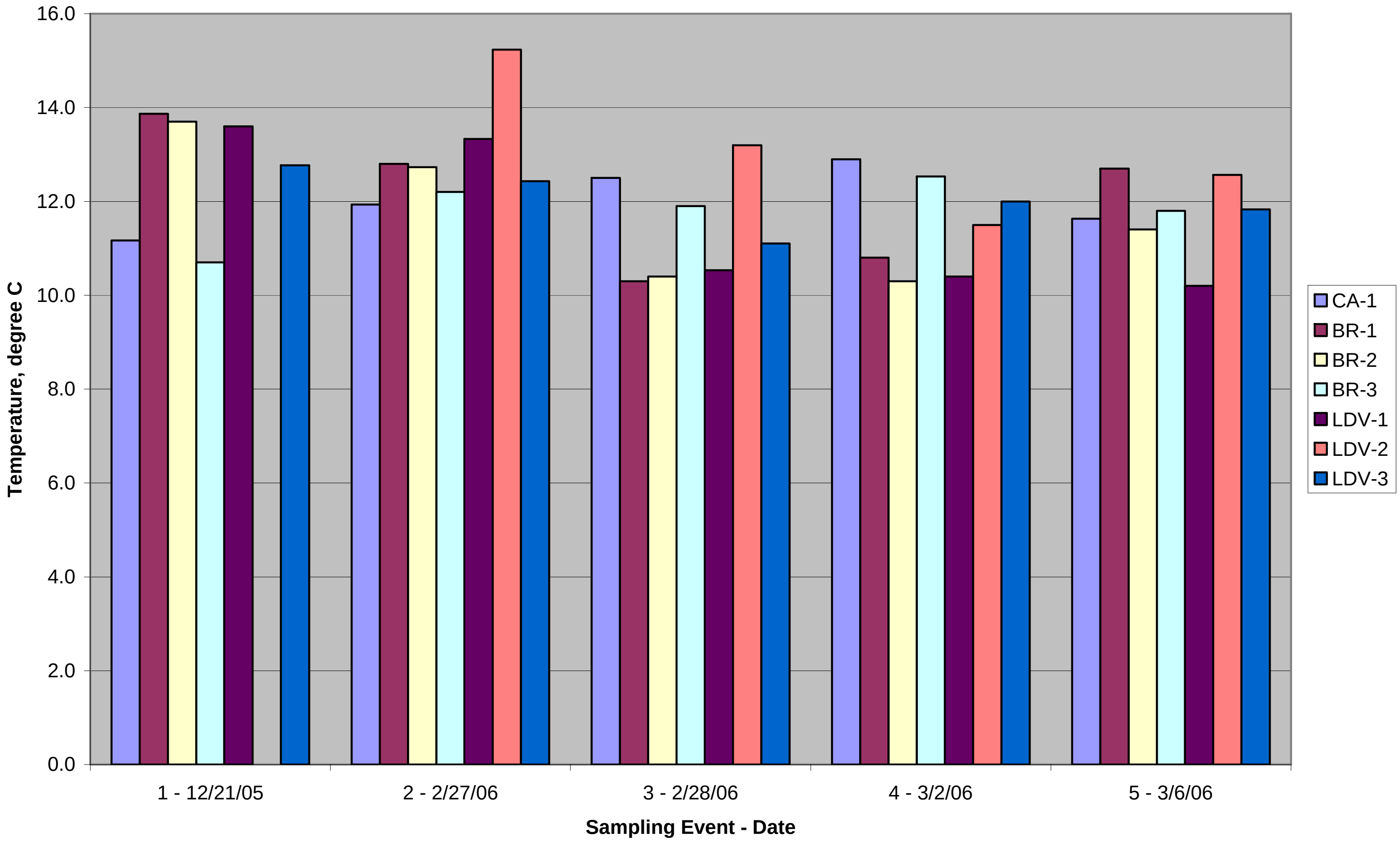

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Figure N-1

Water Temperature

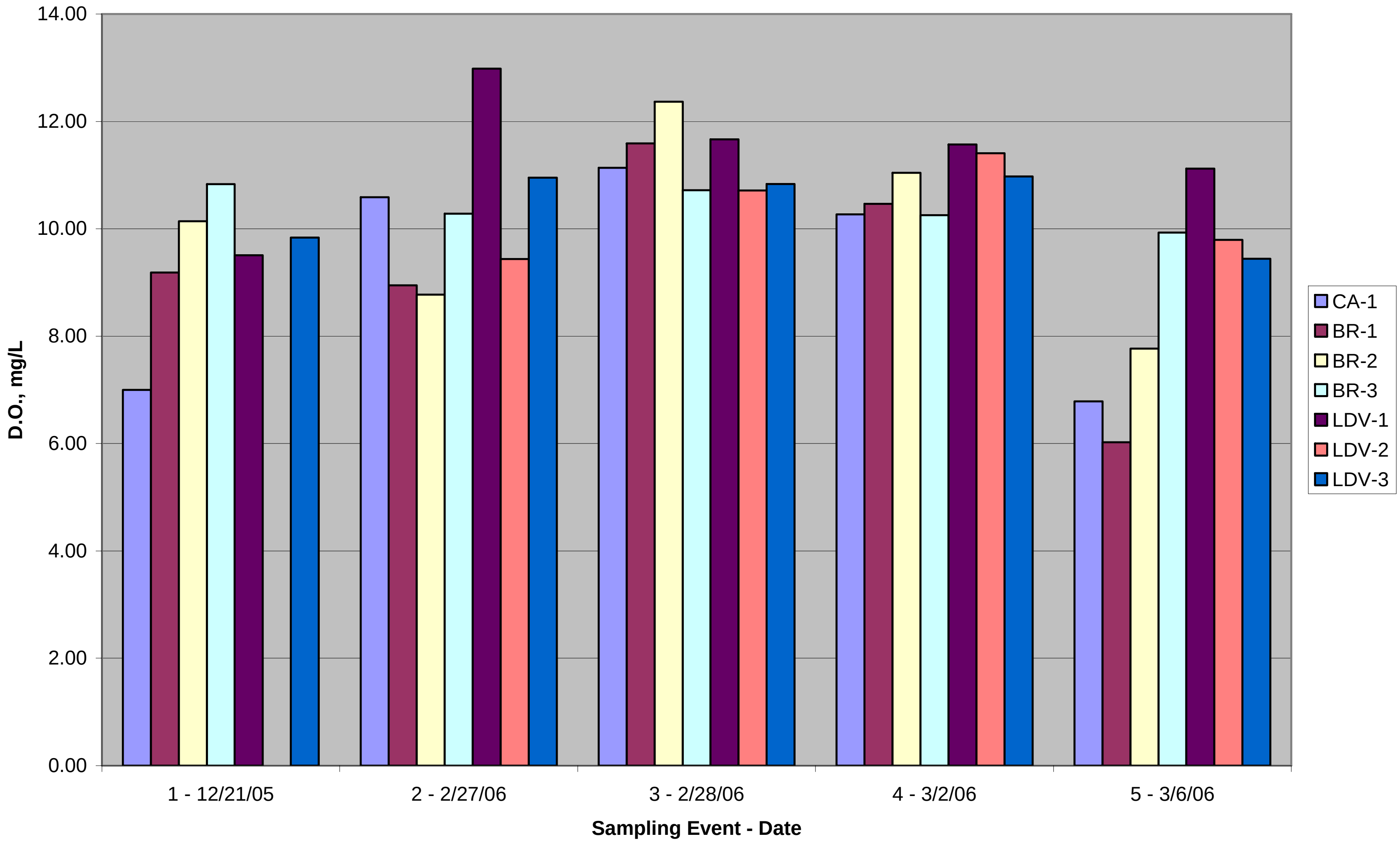

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Figure N-2

Dissolved Oxygen

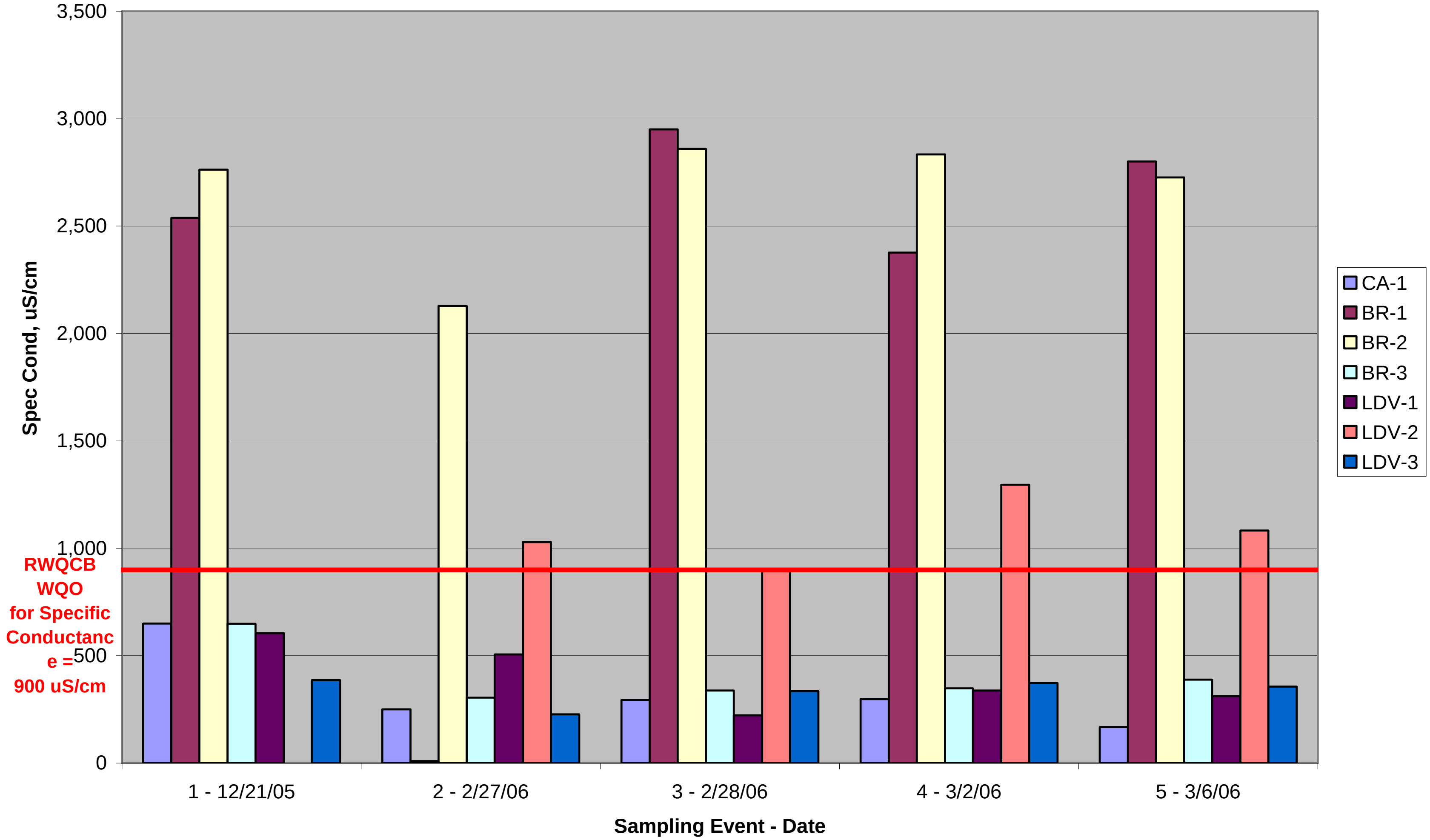

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Figure N-3

Specific Conductance

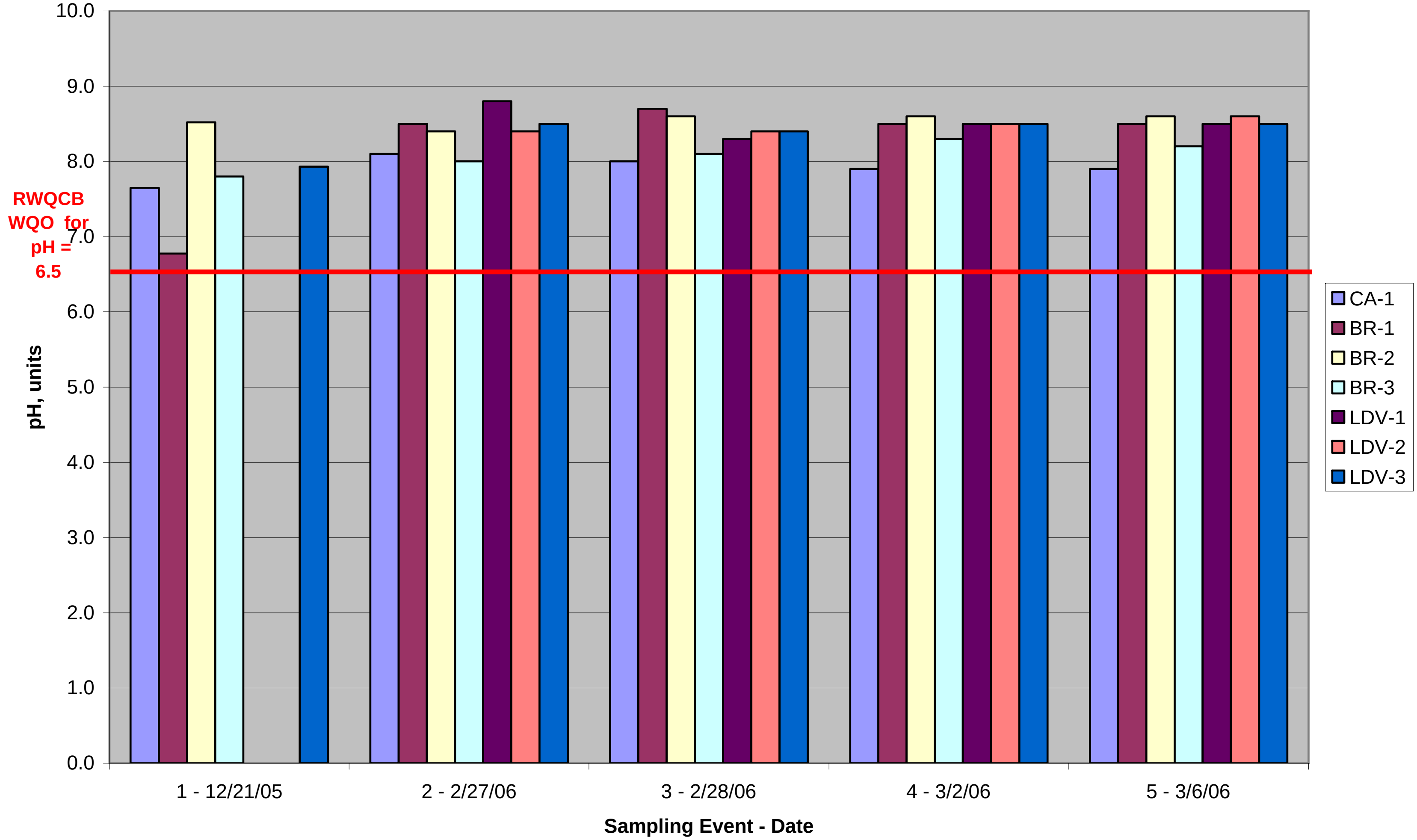

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Figure N-4

pH

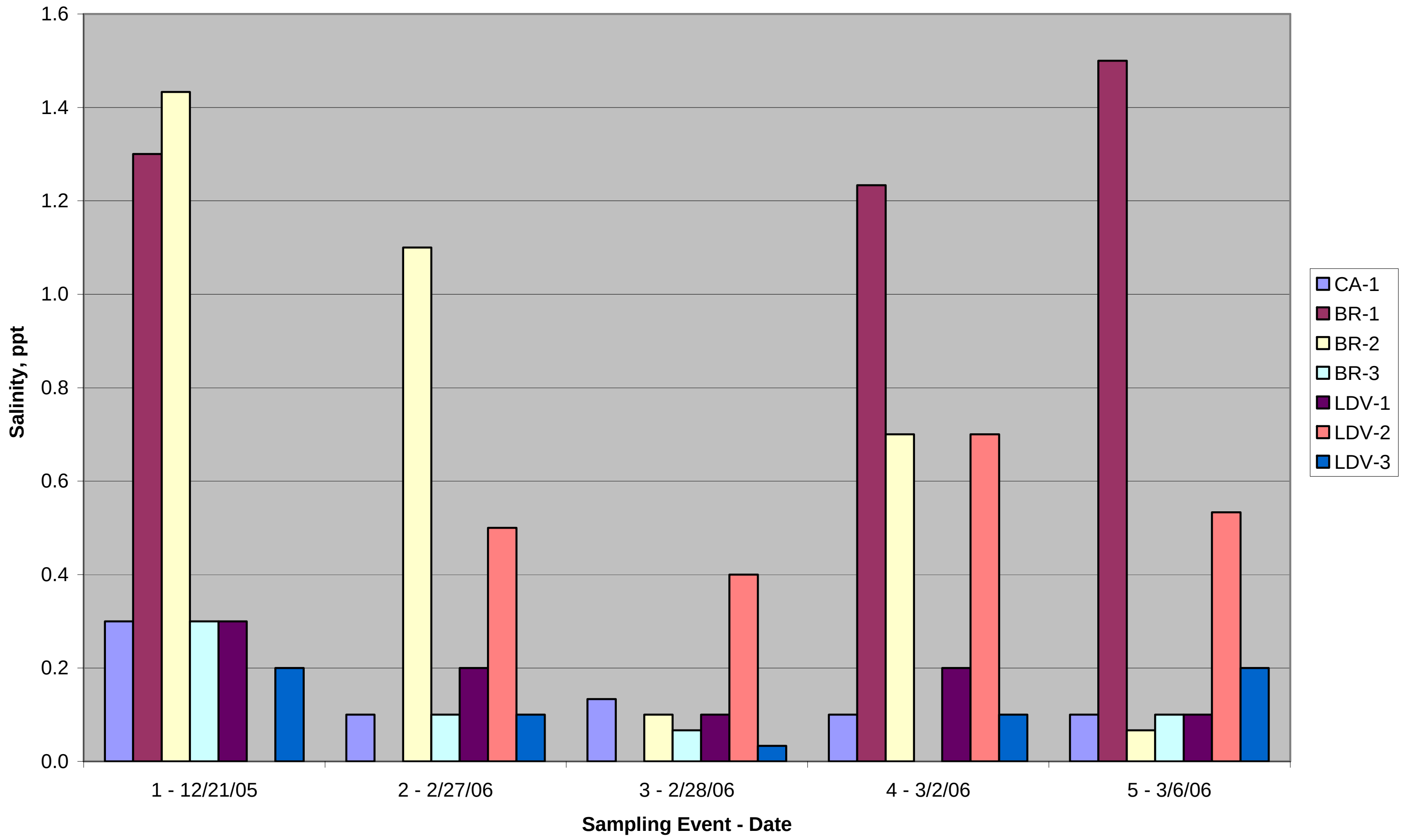

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Figure N-5

Salinity

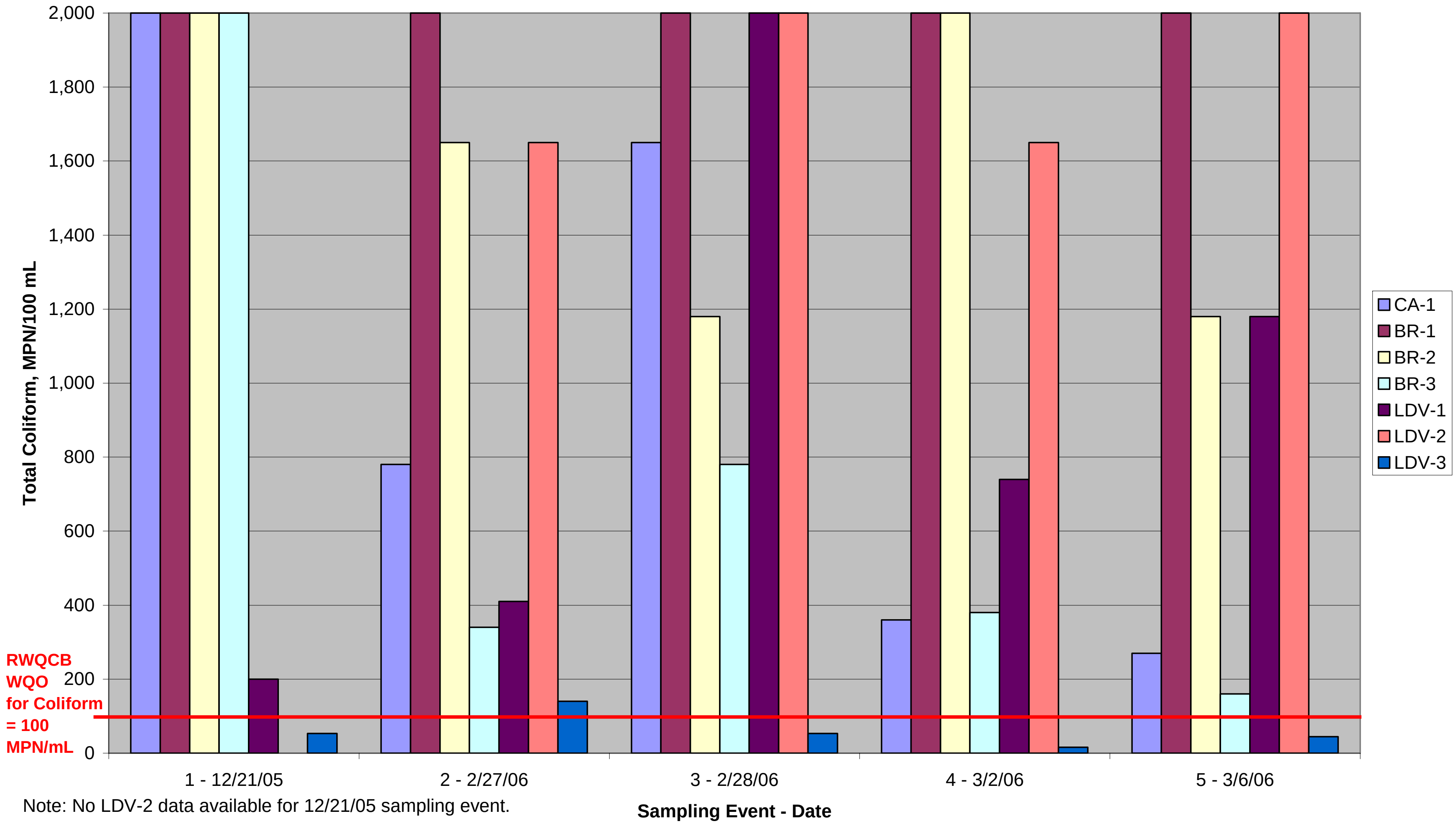

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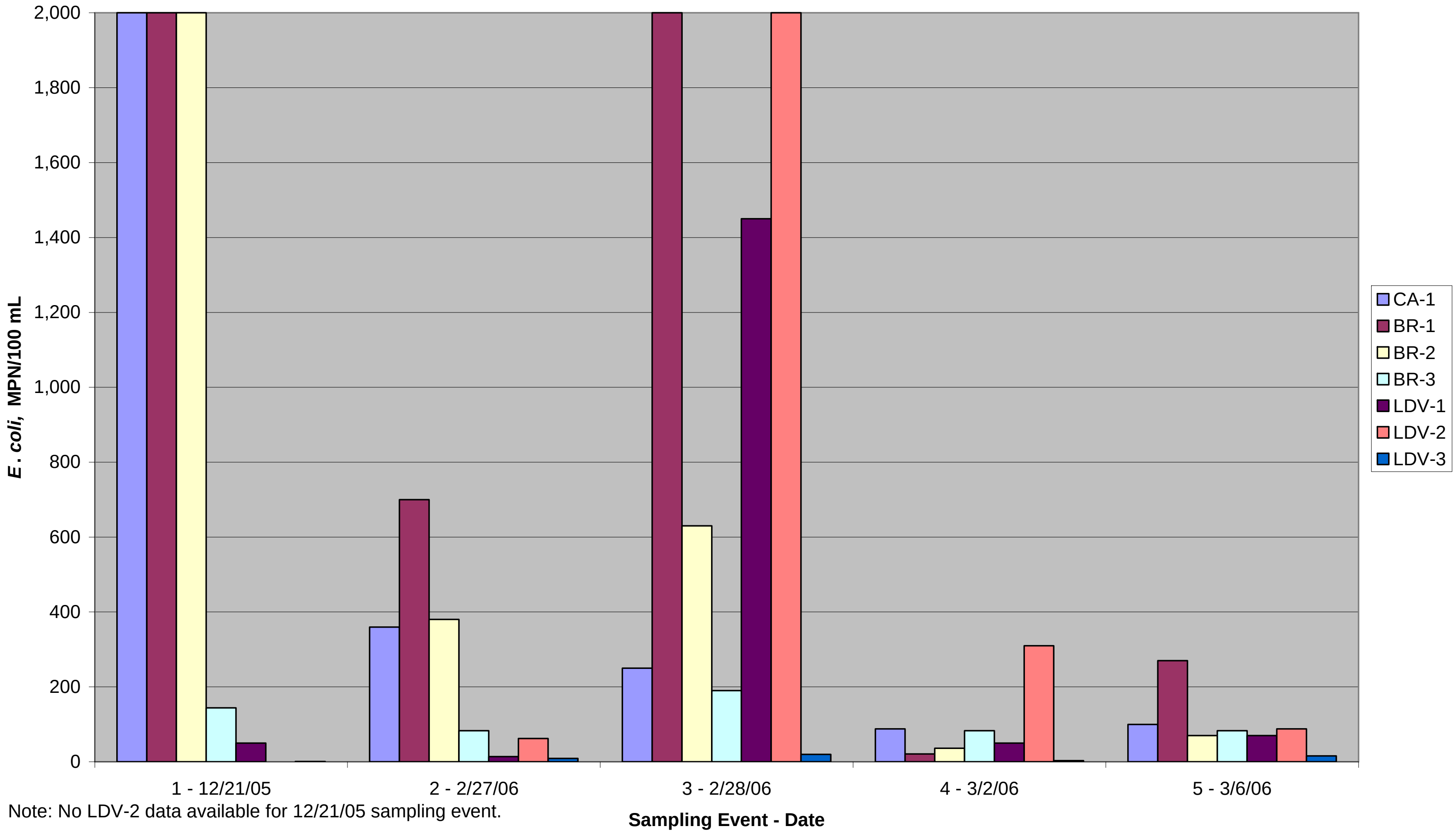
Figure O-1

Total Coliform Results



Note: No LDV-2 data available for 12/21/05 sampling event.

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Figure O-2

E. coli

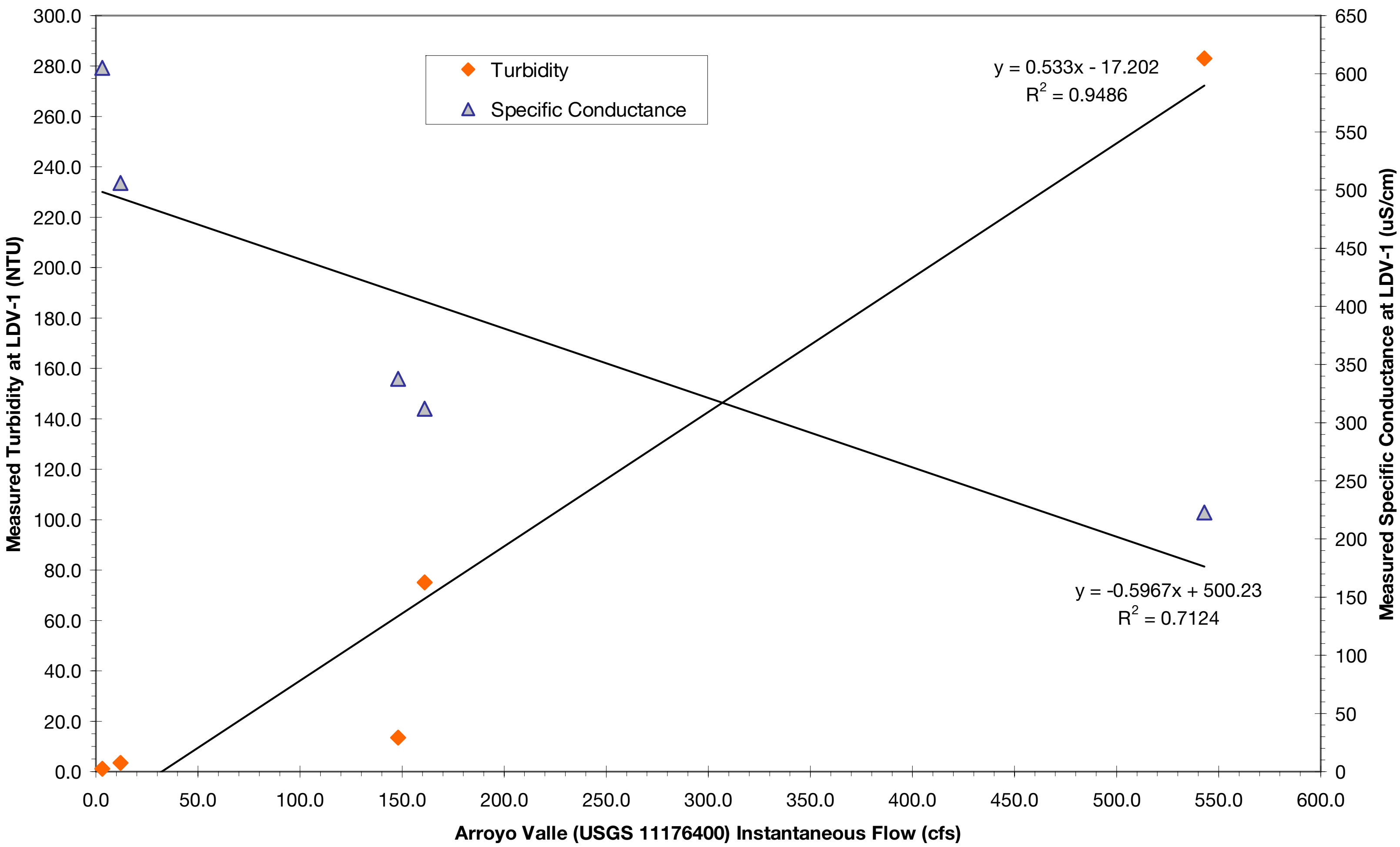

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Figure P

Turbidity and Specific Conductance versus Stream Discharge

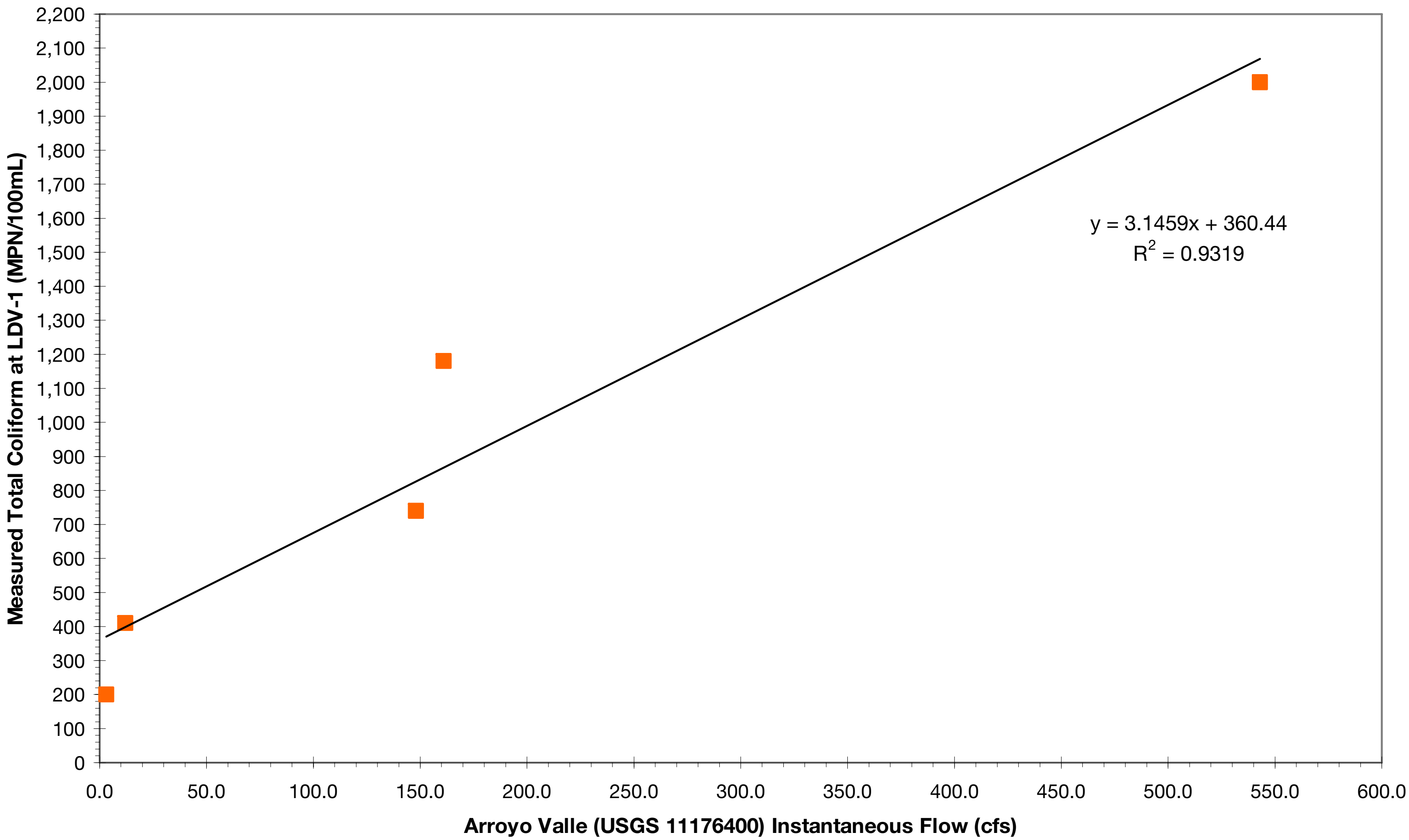

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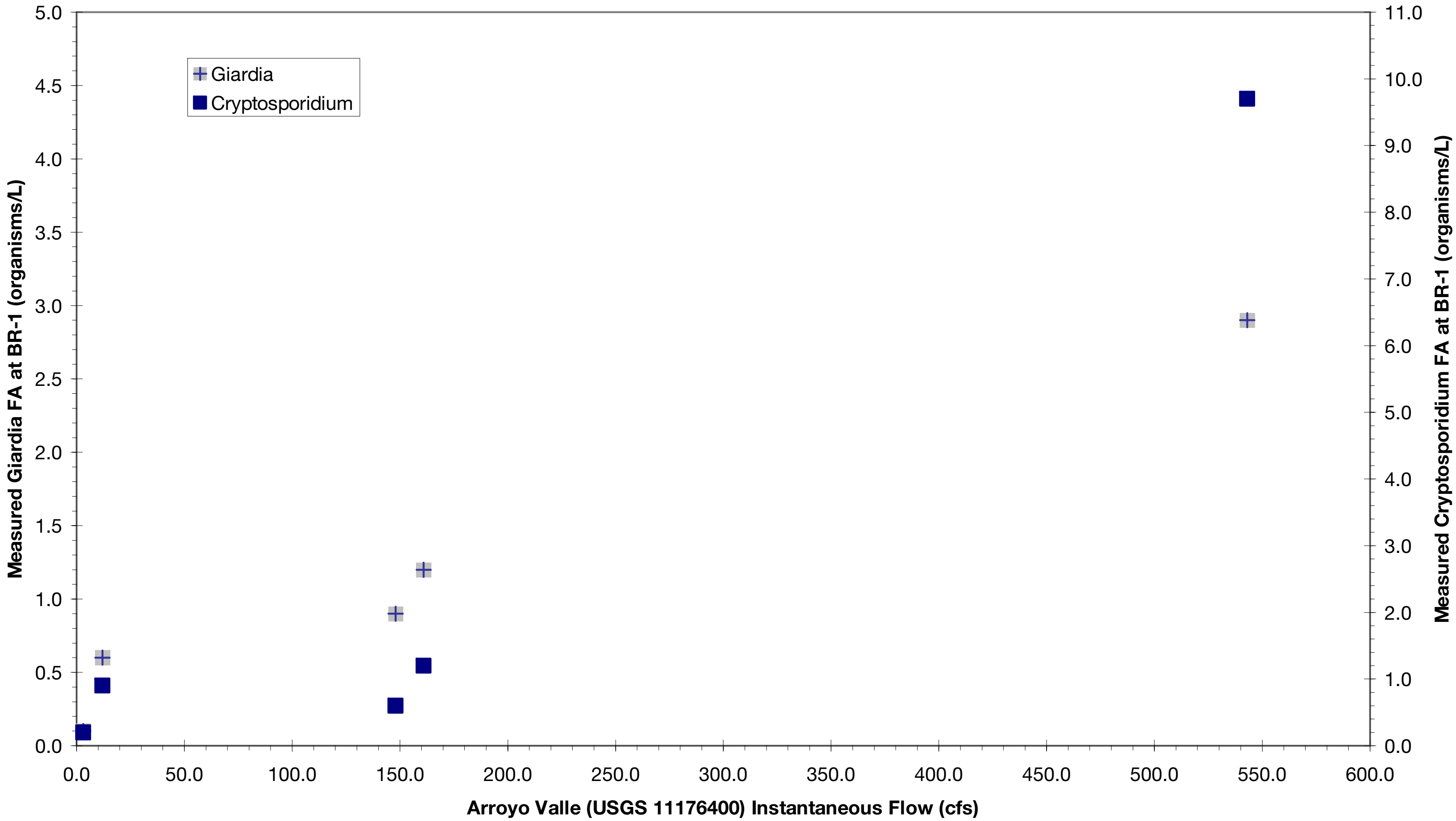
Figure Q

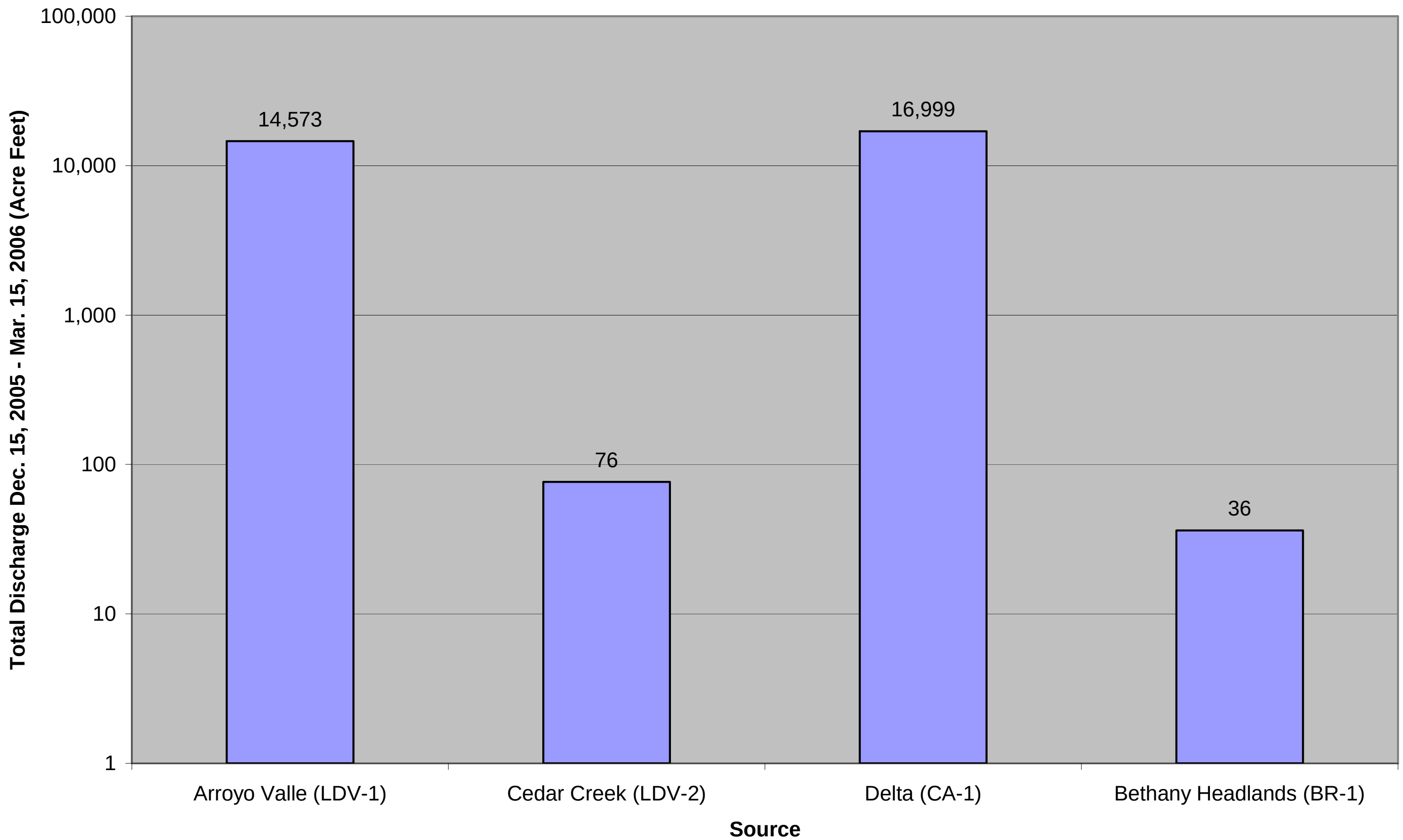
Total Coliform versus Stream Discharge



SBA Watershed Management Program Development Stormwater Monitoring Program . 205076

Figure R

Giardia and *Cryptosporidium* versus Stream Discharge

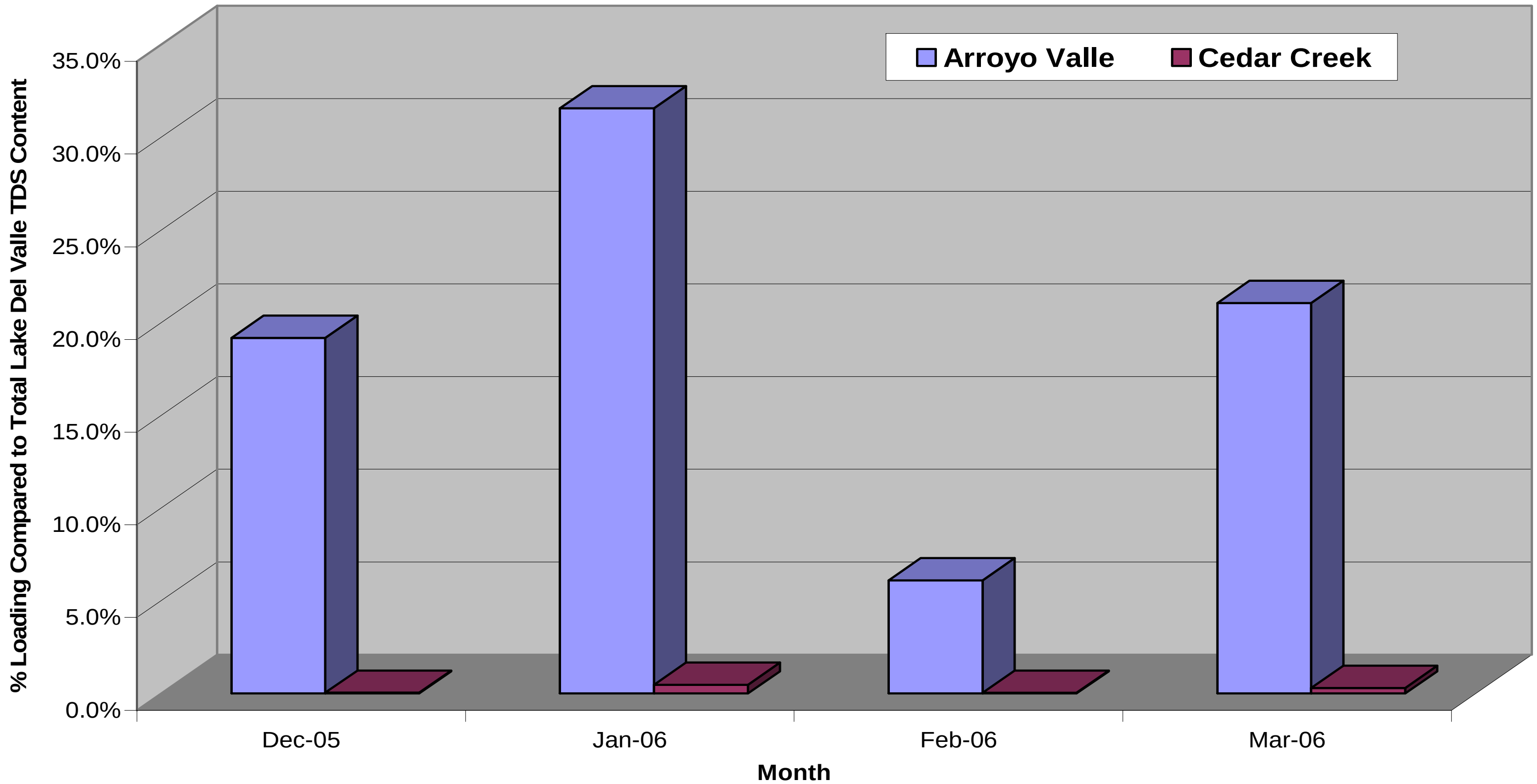


SBA Watershed Management Program Development Stormwater Monitoring Program . 205076

Figure S

Relative Contribution of Water Volume to the SBA from Monitored Sources

NOTE: Assumes that all water in Lake Del Valle is considered "in the SBA system" even though not all of the water in the lake ends up in the SBA as drinking water supply.



SBA Watershed Management Program Development Stormwater Monitoring Program . 205076

Figure T

Calculated TDS Loading at Lake Del Valle

IV. Discussion

Based on the results of the stormwater monitoring, the following observations can be made:

- Sample locations BR-1 and BR-2 had markedly poorer water quality compared to the other five stations. One or both of these stations had the highest average value for the following parameters: specific conductance, salinity, turbidity, total alkalinity, total hardness, total dissolved solids, ammonia, nitrate, nitrite, sodium, sulfate, total coliform, *Escherichia coli*, and *Giardia* and *Cryptosporidium* organisms.
- All but one location (LDV-3) recorded hits for *Giardia* or *Cryptosporidium*.
- At LDV-1, instantaneous flow values for the USGS (11176400) Arroyo Valle gage showed strong positive correlations with measured turbidity and total coliform values, while measured specific conductance values showed a fairly strong negative correlation with instantaneous flow.
- The sample events of March 2, 2006 and March 6, 2006 illustrate that the value of water quality parameters are often a function of sampling time relative to the storm cycle. For example, at LDV-1, the flow values at the time of sampling were similar, 148 cfs and 161 cfs, respectively, yet the turbidity value on the latter date was almost six times greater. In reviewing the daily flow hydrograph for Arroyo Valle, the March 2 event was sampling the falling limb of the storm hydrograph while the March 6 event was sampling the rising limb of the storm hydrograph, when more sediment is typically transported for a given flow.
- Flow was not directly measured at station BR-1. However, the *Giardia* and *Cryptosporidium* values show a fairly strong positive correlation with the instantaneous flow values for the Arroyo Valle gage, which is used as a surrogate for local flow measurements.
- The first sampling event (on December 21, 2005) for locations CA-1, BR-1, BR-2, and BR-3 all resulted in relatively high total coliform and *Escherichia coli* values (i.e., most > 2,000 MPN/100 mL). One possible explanation for this is that there was an accumulation of these constituents during the dry season, they remained immobilized in the early fall, and the first sampling event occurred prior to the local system being flushed (or diluted) with storm runoff.
- The Bethany Headlands drainage, as sampled at BR-1 and BR-2, exhibited high levels of alkalinity, TDS (especially SO_4^{2-} and Na^+), hardness, coliform, TOC, and pathogens, but not high levels of nutrients. It was observed that this stream did not respond markedly to moderate rainfall, but maintained a steady, low flow, suggesting that springs may contribute much of the flow. Some of the elevated parameters may be due to local geology, rather than stormwater runoff. Cattle have access to the entire drainage, including the stream channel, without restriction, which may explain the elevated levels of pathogens and the presence of parasitic oocysts.
- Placing sampling stations above and below the small wetland in the Bethany Headlands drainage (stations BR-1 and BR-2) was intended to reveal any effect of the wetland on water quality. Results are inconclusive. This may be partly due to difficulties in obtaining samples at BR-2, due to the very shallow depth of flow in the concrete flume at the sampling station, and the presence of large amounts of floating matter and algae in the water at this location.
- There was little difference between water quality sampled from the California Aqueduct (CA-1) and the SBA (BR-3), indicating that there was minimal impact from Bethany Reservoir and its associated runoff during the stormwater monitoring events. Nevertheless,

the presence of *Cryptosporidium* and *Giardia* oocysts at BR-1 and BR-2 are cause for concern, and should be addressed.

- Cedar Creek (station LDV-2) appears to contribute water with high EC/TDS (especially SO_4^{2-} and Na^+), alkalinity, TOC, hardness, and coliform. Water quality in this small stream is generally worse than in the much larger Arroyo Valle. The Cedar Creek watershed is small and contains several land uses that might affect water quality negatively, including roads, campgrounds, on-stream ponds, cattle grazing, and rural residential developments.
- With the exception of the small amount of water coming into the SBA from the Bethany Headlands drainage, SBA source water generally is very low in *Giardia* and *Cryptosporidium* levels.

Pollutant Loading

With a maximum of five data points from each of seven stations over the course of one rainy season, the data gleaned from the stormwater monitoring effort, and particularly the statistical relationships between constituent levels and water volume, are not sufficiently robust to enable calculation of seasonal pollutant loading rates with an acceptable degree of accuracy. However, monitoring results and the available information on the relative rates of flow of the several monitored inputs to the SBA do enable a qualitative discussion of pollutant loading.

Figure S shows the relative discharges or water volumes from the monitored sources to the SBA system. Note that the Y-axis uses a logarithmic scale. The calculated discharges for each of the four monitored sources shown in the chart – Arroyo Valle (LDV-1), Cedar Creek (LDV-2), the California Aqueduct (CA-1), and Bethany Headlands (BR-1) are the total in acre feet for the period December 15, 2005 – March 15, 2006. The Arroyo Valle and Cedar Creek discharges are calculated from the daily mean flow for each station reported by the USGS for gage 11176400, just upstream of station LDV-1 and by Zone 7 for LDV-2. For Bethany Headlands, a constant discharge of 0.2 cubic feet per second (cfs) was assumed based on estimates of flow at the time of sample collection. For CA-1, the average monthly pumping rate at the SBA Pumping Plant for each month (December –March), as reported by the Department of Water Resources (Thompson, 2006),[1] was used as a basis for calculating the total amount of water pumped into the SBA from Bethany Reservoir; the amount shown in Figure S for this source reflects the calculated total minus the contribution from Bethany Headlands, reflecting an assumption that the SBA pumps intake all of the discharge from Bethany Headlands, and the remainder from the California Aqueduct. In other words:, for the Delta/CA 1 figure:

eqn.1) $$\mathbf{V_{SBA(i)} = (Q_{AVE\ (i)} \times days/month_i \times acre\text{-}feet/ft3 \times sec/day) - Q_{BH(i)}}$$

where, $V_{SBA(i)}$ = Contribution of California Aqueduct to SBA for month i, (acre-ft)

[1] The reported monthly average pumping rates for the SBA Pumping Plant were:

December, 2005:	122 cfs
January, 2006:	94 cfs
February, 2006:	97 cfs
March, 2006:	59 cfs

Q_{AVE} = SBA Monthly Average Flow Rate for month i, (ft3/sec)

$Q_{BH,(i)}$ = Bethany Headlands Discharge for month i, (acre-ft/$month_i$)

i = month, Dec 2005 – March 2006

Figure S demonstrates that, during the period of monitoring, the California Aqueduct contributed about the same volume of water to the SBA system as Arroyo Valle. Note that this assumes that all water in Lake Del Valle is considered "in the SBA system," though not all of the water in the lake ends up in the SBA as drinking water supply. At Lake Del Valle, Arroyo Valle contributed about three orders of magnitude more volume than Cedar Creek; and at Bethany Reservoir, the California Aqueduct contributed about three orders of magnitude greater volume than the Bethany Headlands drainage. In a general sense, pollutant levels in Cedar Creek would have to be 1,000 times as high as pollutant levels in Arroyo Valle for Cedar Creek to contribute about the same load of pollutants. Assuming that there are about six other small drainages that flow directly into Lake Del Valle, and that each of these produces about the same discharge as Cedar Creek, the combined discharge of these streams would still be about two orders of magnitude less than Arroyo Valle, and pollutant levels would have to be on the order of 100 times greater than Arroyo Valle's to contribute a roughly equal pollutant load.

At Bethany Reservoir, the discrepancies in scale are similar, but the Bethany Headlands drainage is the only notable contributor to the SBA other than the California Aqueduct. Pollutant levels in the Bethany Headlands Drainage would have to be on the order of 1,000 times greater than those in the California Aqueduct to contribute a similar pollutant load.

In fact, while most of the monitored pollutants in Cedar Creek are somewhat higher than those in Arroyo Valle, the average difference between them does not approach one order of magnitude, with the exception of sodium and sulfate (see Table B). At Bethany Reservoir, most of the monitored pollutant levels are about one order of magnitude higher at BR-1 than at CA-1 (Table B). Generally, then, it may be stated that Cedar Creek and other small streams draining directly into Lake Del Valle contribute about $1/100^{th}$ of the pollutant load that Arroyo Valle contributes; and the Bethany Headlands drainage contributes about 1/100 of the pollutant load to the SBA at its point of origin. *Giardia* and *Cryptosporidium* organisms were detected in greater concentration at BR-1 and BR-2 than in the California Aqueduct. Because of inconsistencies in both concentrations and detects, these data do not lend themselves to similar comparisons.

As a quantitative illustration, Figure T shows calculated loading rates of total dissolved solids (TDS) into Lake Del Vale from Arroyo Valle (LDV-1) and Cedar Creek (LDV-2), expressed as a percentage of the total calculated amount of TDS present in lake water (based on monitoring results at LDV-3) for each month during the monitoring period. Table B and Figure F indicate that the average level of TDS at LDV-2 was about three times that at LDV-1; nevertheless, Figure T shows the TDS contribution from Arroyo Valle was much greater than that from Cedar Creek.

V. Conclusions

Samples taken from Lake Del Valle near the SBA intake confirm that the lake water is a much higher quality source than the Delta, and also demonstrate the benefits of dilution, distance from inputs to the intake, and retention time in the lake in reducing pollutant loads. This is perhaps best demonstrated by the substantially lower levels of bacteriological parameters in lake samples, several no-detects for chemical and nutrient parameters, and the non-detection of parasites. It would appear that current management of Lake Del Valle and its immediate watershed are effective in protecting water quality.However, the results of the SBA 2005-2006 stormwater monitoring also consistently show that all monitored sources and stations regularly exceeded at least some water quality standards or objectives for municipal drinking water supply. While the monitoring locations represent raw or untreated water supplies, the finding indicates the continuing need not just to protect but also to improve water quality from the watershed areas that contribute to the SBA, including the Lake Del Valle watershed, the Bethany Headlands watershed, and the Sacramento-San Joaquin Delta.

The monitoring results show that water quality is much poorer from the Bethany Headlands drainage than from any other monitored source. Of particular concern is the consistent finding of *Giardia* and *Cryptosporidium* organisms in samples taken from the Bethany Headlands stations, and the proximity of the mouth of this drainage to the SBA Pumping Plant. While the volume of water contributed by this small drainage is dwarfed by that of the California Aqueduct, the issue of parasitic organisms consistently present in source water should be addressed, particularly since the Bethany Headlands drainage area is relatively small and therefore manageable.

At Lake Del Valle, the generally poorer quality of the water found in Cedar Creek compared to Arroyo Valle may be reflective of the relatively intensive, mixed land uses found in the small Cedar Creek watershed, the lack of dilution, and perhaps also the natural geology of the area. As with the Bethany Headlands drainage, however, the contribution of Cedar Creek – and the several similar small drainages flowing directly into Lake Del Valle – is much less than Arroyo Valle.

Some pollutant levels in Arroyo Valle itself correlate well with discharge, suggesting that stormwater runoff is a major source of pollutants carried by this stream. While overall the quality of water from Arroyo Valle is the highest among the monitored flowing sources, the monitoring results point to the need for conservation of the existing low-density and low-intensity land uses in the Arroyo Valle watershed that have contributed to the protection of water quality in this area. Working with landowners and resource conservation agencies to support land management practices that protect the water quality in the area is perhaps the best approach for protecting this watershed from any future degradation. .

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