FINAL REVISED ANALYSES OF MAJOR AND TRACE ELEMENTS FROM ACID MINE WATERS IN THE LEVIATHAN MINE DRAINAGE BASIN, CALIFORNIA AND NEVADA--OCTOBER 1981 TO OCTOBER 1982

By James W. Ball and D. Kirk Nordstrom

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CONVERSION FACTORS AND ABBREVIATIONS

For the use of readers who prefer to use inch-pound units, rather than the metric (International System) units used in this report, the following conversion factors may be used:

Multiply metric unit	By	To obtain inch-pound unit
m^3/s (cubic meters per second)	35.31	ft^3/s (cubic feet per second)
L (liter)	0.2642	gal (gallon)
μg (microgram)	3.520×10^{-8}	oz (ounce)
mg (milligram)	3.520×10^{-5}	oz (ounce)
g (gram)	0.03520	oz (ounce)

Temperature in degrees Fahrenheit (°F) as follows:
degree Fahrenheit (°F) = 1.8 x degree Celsius (°C) + 32

Explanation of abbreviations:

M (Molar, moles per liter)
N (Normal, equivalents per liter)
mg/L (milligrams per liter)
nm (nanometers)
$\mu g/L$ (micrograms per liter)

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ABSTRACT

The U.S. Geological Survey collected hydrologic and water-quality data from the Leviathan/Bryant Creek drainage basin, California and Nevada, during 1981-82. Sixty-seven water samples collected from 45 sites in the basin at three different times were initially analyzed for 37 major and trace constituents using direct-current-argon-plasma emission spectrometry, flame, hydride generation and graphite furnace atomic absorption spectrometry, UV-Visible colorimetry, and ion chromatography. The previously published set of analytical data (Ball, J. W., and Nordstrom, D. K., 1985, Major and trace-element analyses of acid mine waters in the Leviathan Mine drainage basin, California/Nevada--October, 1981 to October, 1982: U.S. Geological Survey Water-Resources Investigations Report 85-4169, 46 p.) provided immediate information needed to initiate water-quality improvement of the Leviathan/Bryant Creek drainage system. An additional scientific motivation was to model the attenuation of major and trace elements during downstream transport with the best available techniques of surface-water-flow measurement and analytical and physical chemistry. Overall accuracy and precision of the chemical analyses were significantly improved by additional determinations using the more stable inductively-coupled-plasma and the more sensitive Zeeman graphite furnace atomic absorption spectrometric techniques. These additional determinations are considered essential for reliable calculations with geochemical equilibrium modeling programs and for evaluating the discharge measurements.

This additional analysis and evaluation has resulted in (1) revision of concentrations for Al, As, Ba, Cd, Ca, Cr, Co, Cu, Pb, Mg, Mn, Ni, K, SiO_2, Na, Sr, SO_4, V and Zn; (2) generation of concentration values to replace trace-metal values previously below the detection limit; (3) many duplicate analyses for the major constituents; and (4) revision of selected sulfate determinations based on more accurate metal concentration estimates and constraints of charge balance and stream flows determined by a concurrent tracer injection study. Inductively-coupled-plasma spectrometry was used to determine concentration values for Al, As, Ba, Be, B, Cd, Ca, Cr, Co, Cu, Fe, Pb, Mg, Mn, Mo, Ni, K, SiO_2, Na, Sr, V and Zn for comparison with their direct-current-plasma counterparts. Elements determined by Zeeman graphite furnace atomic absorption spectrometry to extend the detection limits to levels below those obtainable by inductively-coupled-plasma or direct-current-plasma spectrometry were Al, As, Cd, Cr, Co, Cu, Pb, Mn, Ni, V and Zn. Some of the samples were analyzed for Na and K by flame atomic absorption spectrometry and the results compared with inductively-coupled-plasma and the previous direct-current-plasma data. We have extensively compared our earlier direct-current-plasma results with our inductively-coupled-plasma, graphite furnace atomic absorption spectrometry and flame atomic absorption spectrometry results. The revisions resulting from these comparisons have yielded a more complete, accurate, and precise data set.

INTRODUCTION

The inactive Leviathan open-pit sulfur mine is located near Markleeville in Alpine County, California (fig. 1). In the early 1980s, this mine and its drainage basin became subject to a pollution abatement project undertaken by the California Regional Water Quality Control Board. As a part of this project, the U.S. Geological Survey collected basic hydrologic and water-quality data for the drainage basin (Hammermeister and Walmsley, 1985). One aspect of the program involved the collection of 63 samples of the water to provide detailed data on trace-element contaminants in the basin and to study downdrainage attenuation of the contaminants under different flow conditions (Ball and Nordstrom, 1985).

Meaningful interpretation of geochemical modeling calculations mandates the highest accuracy in analytical data. This necessitated careful evaluation and revision of the original data of Ball and Nordstrom (1985). Since publication of the initial set of data, all samples collected in June 1982 and October 1982 have been analyzed by multi-element ICP (inductively-coupled-plasma) spectrometry. In addition, analysis by Zeeman GFAAS (graphite furnace atomic absorption spectrometry) of samples having trace-metal concentrations below the detection limits obtainable by ICP or DCP (direct-current-plasma) spectrometry has been completed. Detection limits using plasma techniques are typically two to 400 times those obtainable using the Zeeman GFAAS technique.

Sulfate usually comprises more than 95 percent of the anions in solution in this watershed. Several evaluation techniques were used to revise the SO_4 data presented in this report. Element ratios at confluence points in the watershed sampled were compared. If the values could be adjusted to concomitantly improve: 1) the SO_4 to conductance relation; 2) the metal/SO_4 ratios; 3) the adherence to a mixing line calculated between selected representative end members; and 4) charge balance, the new values were adopted. It is important that all four of the independently calculated relations had to be improved by the change before a new value was adopted.

PURPOSE AND SCOPE

The purpose of this report is to document the final revised values from this analytical comparison and evaluation so that chemical equilibrium modeling can proceed. The full report justifying the choice of final values and determinations and comparing the capabilities of the different techniques is in preparation (Ball and Nordstrom, written commun., September 1989).

This report presents the results of these additional analyses, together with brief statements of the reasons for selecting values. For a description of the sampling area and discussions of the sample collection and preservation methods and the analytical methods used to obtain the original set of analytical data, the reader is referred to Ball and Nordstrom (1985). All data values are tabulated in this report, but the discussion will focus only on the evaluated and revised data.

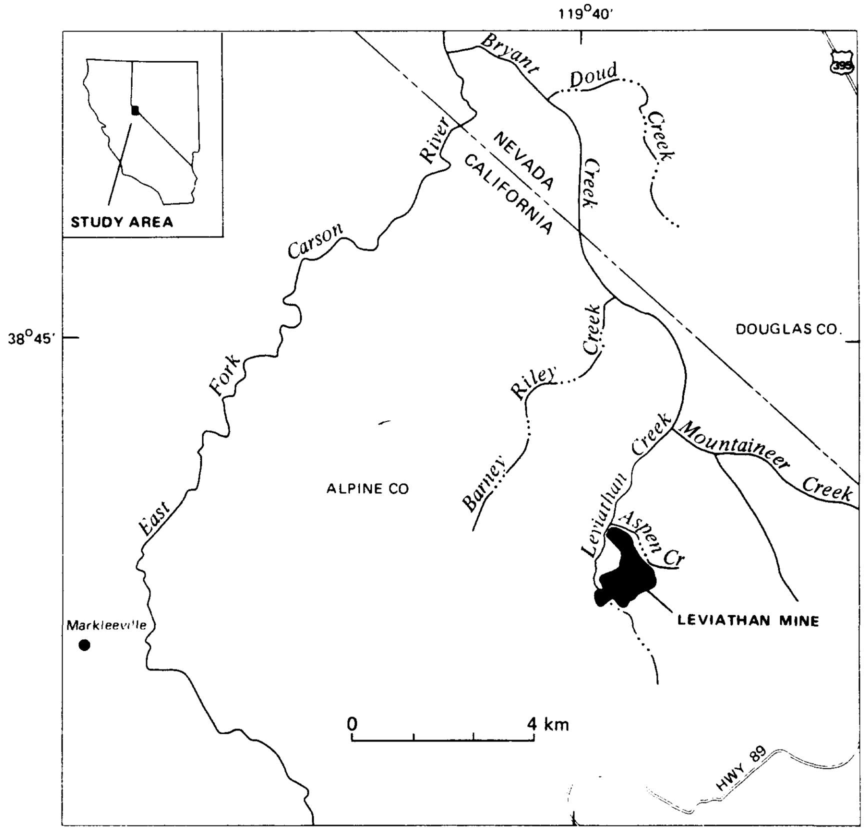

FIGURE 1.--Location of Leviathan Mine.
(from Hammermeister and Walmsley, 1985)

APPROACH

The previous set of analytical data reported by Ball and Nordstrom (1985) provided immediate information that was needed to implement water quality improvement of the Leviathan/Bryant Creek drainage system, in cooperation with the California Regional Water Quality Control Board. The scientific motivation for this investigation was to model the attenuation of major and trace elements during downstream transport with the best available techniques of surface water flow measurement, analytical chemistry and physical chemistry. Surface water flow was determined by a tracer injection experiment (Flint and others, 1985). These data provide quantitative estimates of convection and dispersion for solutes in most of the stream reach sampled in the drainage basin. Statistically, the accuracy and precision of the chemical analyses should be greatly improved by additional determinations for metals using more than one analytical technique. Many determinations were below detection by either DCP or ICP techniques and these low concentration values were needed for chemical modeling purposes. Hence, GFAAS determinations were done in these instances. These additional determinations were considered essential for reliable calculations of chemical equilibrium with such programs as WATEQ4F (Ball and others, 1987) and for evaluating the discharge measurements. In addition, it was clear that much new knowledge could be gained about the relative merits of DCP as compared with ICP by analyzing these samples by both techniques and comparing the results. Because these acid mine waters contain a very large range of concentration (orders of magnitude) they are ideally suited to this type of analytical comparison and evaluation.

ANALYTICAL METHODS

Three techniques were employed in the additional analysis of the samples. They are: (1) ICP multi-element atomic emission spectrometry, for the determination of Al, As, B, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, Pb, Se, SiO_2, Sr, V and Zn; (2) Zeeman GFAAS, for the determination of low levels of Al, As, Cd, Co, Cr, Cu, Mn, Ni, Pb, V and Zn, and (3) Flame atomic absorption spectrometry (flame AAS) for the determination of Na and K in a selected subset of samples. These techniques are discussed in more detail in the following sections.

Inductively-Coupled-Plasma Spectrometry

Samples were analyzed using a Leeman Labs Plasma-Spec III[1] simultaneous direct-reading inductively-coupled-plasma spectrometer (Leeman Labs, Lowell, Mass.). A set of working standards was prepared by making 1 N HNO_3 dilutions of the primary multi-element standard containing the 22 elements in 1 N HNO_3. A solution of 0.1 N HNO_3 was used as a blank and was prepared by diluting ultrapure HNO_3 with double distilled, deionized water. The multi-element solution was composed of alkali and alkaline earth salts of purity 99.99 percent or better and other metal salts, acids, and commercially prepared solutions of purity 99.999 percent or better. The individual photomultiplier tube voltages were optimized by the manufacturer to achieve the best combination of sensitivity and stability. The position of the torch image on the

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[1] The use of trade, brand, or product names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

spectrometer input slit was optimized for maximum sensitivity for the detection of Mn. Manganese was chosen because it has a midrange excitation potential and because high Mn concentrations are quickly flushed out of the ICP torch. Several other metals, including Cu and Ni, are equally suitable.

Analytical settings and wavelengths for the ICP spectrometer are shown in table 1. Four standard solutions and the 0.1 N HNO_3 blank, analyzed as unknowns, were interspersed among samples during analysis, and a calibration curve for each element was constructed using the resulting emission data. The 22 elements determined using the simultaneous multi-element mode of operation were: Al, As, Ba, Be, B, Cd, Ca, Cr, Co, Cu, Fe, Pb, Mg, Mn, Mo, Ni, K, Si, Na, Sr, V and Zn. Elements available in the simultaneous mode of operation but found by prior experiment to be below detection using ICP are: Li, P, Rb, Se, Ti, Tl, W and U.

Samples were diluted as required for compatibility with the 0.1 percent w/v dissolved solids concentration limit of the sample introduction tube of the torch. Otherwise, no dilution was required, as the linear dynamic range of the instrument was not exceeded, even by several decades of concentration difference between samples. Memory effects can be severe for some elements, depending on differences in concentration among samples. Therefore, samples of similar concentration were grouped together, and nebulized in increasing concentration order. The emission data generated by the instrument were collected on the flexible diskette storage device of an IBM or IBM-compatible personal computer.

The factory-installed dynamic background correction feature was used for each channel, wherein the emission at a wavelength near each primary emission line is measured immediately after measurement of the emission at the primary wavelength and subtracted from the primary emission. When data for all elements were available, sample concentrations were corrected for inter-element spectral effects which result from the presence of concomitant major elements and are observed when measuring concentrations of minor elements. This correction required collection of background-corrected apparent concentration data for a representative concentration range of the suspected interferent in the absence of analyte at the appropriate wavelengths. The resulting apparent analyte concentration values were fitted to various types of linear and exponential simple regression equations, and the selected fit parameters were determined. The concentration of the concomitant element in an unknown sample was combined with the fit parameters to yield a numerical value for its interference which was then subtracted from the apparent concentration of the analyte. The resulting data were stored in a master data set, to which additional data from other sources could be added later.

The above inter-element interference correction technique was used to correct for the effects of Ca, Mg, Si, Fe and Al on the apparent concentrations of Al, As, Cd, Ca, Cr, Cu, Fe, Pb, Mg, Mn, Ni, Na, Sr, V and Zn. No effects of Ca, Mg, Si, Fe or Al at their upper concentration limits (490, 110, 110, 2,510 and 620 mg/L, respectively) were observed on the apparent concentrations of Ba, Be, B, Co, Mo, K or Si. The effect of Ca (Johnson and others, 1979) is the most serious, followed by the effect of Fe (Ball and Nordstrom, 1985), for the analysis of acid mine effluent by ICP spectrometry.

Table 1.--Instrument settings and individual element data for the ICP spectrometer

[RF, radio frequency; mg/L, milligrams per liter]

Torch settings:

RF current - 0.55 amperes
Nebulizer pressure - 38 pounds per square inch
Coolant flow - 12.5 (arbitrary units)
Auxiliary flow - 0

Wavelengths and analytical ranges for the individual elements:

Element	Wavelength, nanometers	Maximum standard concentration, mg/L	[1]Detection limit, mg/L
Al	308.22	2.0	0.5
As	197.20	20.0	0.3
Ba	455.40	0.5	0.005
Be	313.04	0.1	0.001
B	249.68	5.0	0.2
Cd	214.44	0.1	0.005
Ca	315.89	5.0	0.05
Cr	205.55	0.5	0.01
Co	228.62	0.5	0.002
Cu	327.40	1.0	0.05
Fe	238.20	2.0	0.1
Pb	220.35	1.0	0.2
Mg	279.08	20.0	0.5
Mn	257.61	2.0	0.02
Mo	202.03	1.0	none[2]
Ni	231.60	0.5	0.003
K	766.49	20.0	0.3
Si	288.16	10.0	0.5
Na	589.59	20.0	0.2
Sr	407.77	0.5	0.002
V	310.23	1.0	0.075
Zn	206.20	1.0	0.01

[1] Determined in this study, for these waters.

[2] Analysis was so poor in the simultaneous mode that no standard curve could be calculated.

Zeeman Graphite Furnace Atomic Absorption Spectrometry

Samples were analyzed using a Perkin-Elmer Zeeman/5000 atomic absorption spectrometer equipped with a HGA-500 controller, AS-40 autosampler and Perkin-Elmer Model 7300 computer, driven by the Perkin-Elmer HGA Graphics II software. Instrument settings for the determinations using Zeeman GFAAS are in table 2. The graphite tube used was of the platform configuration, except for the analysis of Al and V, for which wall atomization was used.

Table 2.--Instrument settings and individual element data for the Zeeman graphite furnace atomic absorption analyses

[°C, degree Celsius; µL, microliter; mg/L, milligrams per liter]

General GFAAS settings:

Typical furnace settings:	
Dry	- 140 °C, 60 seconds
Pretreat	- 45 seconds
Atomize	- 6 seconds, interrupted gas flow
Clean	- 2,700 °C, 8 seconds
Autosampler settings:	
Sample volume	- 20 µL
Alt volume	- 5 µL
Spectrometer settings:	
Integration time	- 7 seconds
Number of replicates	- 3

Specific element data:

Element	Wavelength, nanometers	Atomization temperature, °C	Matrix modifier	Detection limit, mg/L
Al	309.3	2,500	none	0.005
As	193.7	2,500	$Ni(NO_3)_2$	0.001
Cd	228.8	1,600	$Mg(NO_3)_2 + NH_4H_2PO_4$	0.00005
Co	240.7	2,500	$Mg(NO_3)_2$	0.001
Cr	357.8	2,500	$Mg(NO_3)_2$	0.0001
Cu	324.7	2,500	$Mg(NO_3)_2$	0.0005
Pb	283.3	1,800	$Mg(NO_3)_2 + NH_4H_2PO_4$	0.0005
Mn	279.5	2,200	$Mg(NO_3)_2$	0.0001
Ni	232.0	2,500	$Mg(NO_3)_2$	0.00015
V	318.4	2,650	$Mg(NO_3)_2$	0.001
Zn	213.9	1,800	$Mg(NO_3)_2$	0.0001

Flame Atomic Absorption Determinations for Na and K

The compromise torch power and entrance slit alignment settings used for the ICP and DCP determinations were significantly suboptimal for the alkali metals. Hence, we have concluded that the flame AAS Na and K data were the most accurate of the data collected for these two elements. Accordingly, all available flame AAS Na and K data have been substituted into the master data table of this report. The estimated maximum error in the Na and K values presented here is about 5 percent of the reported concentration for the flame AAS determinations and 20 percent of the reported concentration for the DCP determinations.

ANALYTICAL RESULTS

Accuracy of Plasma Analyses

Accuracy of analysis is variable between elements, and is generally dependent on analyte concentration compared with instrument sensitivity, presence of background or inter-element spectral interferences, and precision with which the spectrometer can measure the emitted energy from the ICP source at the wavelength of interest. Instrument sensitivity depends on which wavelength is selected for inclusion in the multi-element array. This is sometimes a function of space constraints within the detector module. Sensitivity also depends on torch and nebulizer operating conditions and positioning of the torch image on the spectrometer entrance slit. The severity of background and inter-element effects depends on the proximity of analyte wavelengths to interferent wavelengths, and on the interferent-to-analyte concentration ratio. The closer the wavelengths are to each other, and the larger the magnitude of the interferent-to-analyte ratio, the more severe the interference will be, and the less precise will be its correction.

Instrument precision depends on the excitation energy and concentration of the element of interest. If either the excitation energy or analyte concentration or both are exceedingly low or high, the measurement will be less precise. Thus, Ni at 0.25 mg/L, an element with a midrange excitation energy present at a midrange concentration, can be measured with far greater precision than can Na at 1,000 mg/L, an element with a very low excitation energy present at very high concentration. Similarly, B at 0.05 mg/L, an element with a very high excitation energy present at very low concentration, also may be determined with only limited precision.

Accuracy of Zeeman GFAAS Analyses

The accuracy with which elements can be determined using Zeeman GFAAS is, like that of the plasma determinations, variable among elements. It depends on analyte concentration compared to instrument sensitivity, and on the presence of interferences due to a specific solution species (chemical interferences) or those due to bulk, or ionic strength and viscosity effects (matrix or background interferences). These types of interference effects are largely mitigated by using the Zeeman feature of the instrument and the matrix modifiers referred to in table 2. Also, the highest concentrations of the analyte of interest usually occur in the most concentrated solutions. Thus, it was nearly always possible to dilute them as necessary to eliminate such interferences. The largest source of inaccuracy is probably degradation of the graphite tube over the course of an analytical run, such that accurate, precise standardization over several hours is a serious problem. This effect is particularly noticeable for the more refractory elements such as Al and V, which require higher atomization temperatures.

Physical Measurements and Chemical Analyses

Physical measurements and concentration values for chemical constituents are shown in table 3, which is formatted identically to the table 3 of Ball and Nordstrom (1985). The data are arranged in order of site number,with earlier samples preceding later ones at a given site. Figures 2a and 2b show locations of all sites from which water samples were collected. Values identical to those of Ball and Nordstrom (1985) are: discharge, temperature, specific conductance (field and lab), pH (field and lab), Eh, alkalinity, Sb, Be, Bi, B, Cl, F, Fe^{2+}, Fe^{total}, Li, Mo, Se, and Tl. All other major and trace constituents have been revised based on new information obtained by ICP spectrometry or Zeeman GFAAS, and are discussed in the following sections.

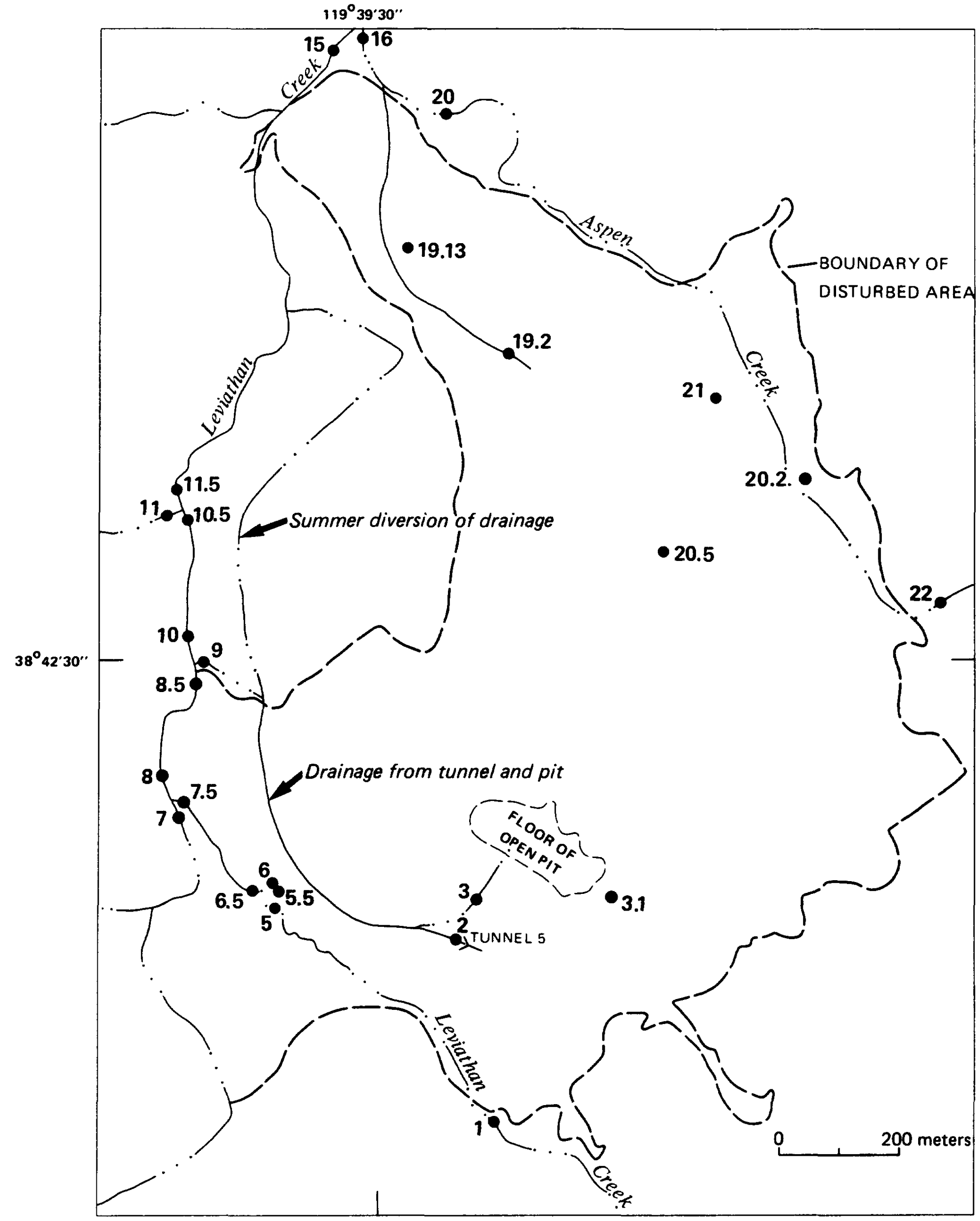

FIGURE 2A.--Surface-water sampling sites in the mine area. Site numbers correspond with those in table 3. (from Hammermeister and Walmsley, 1985)

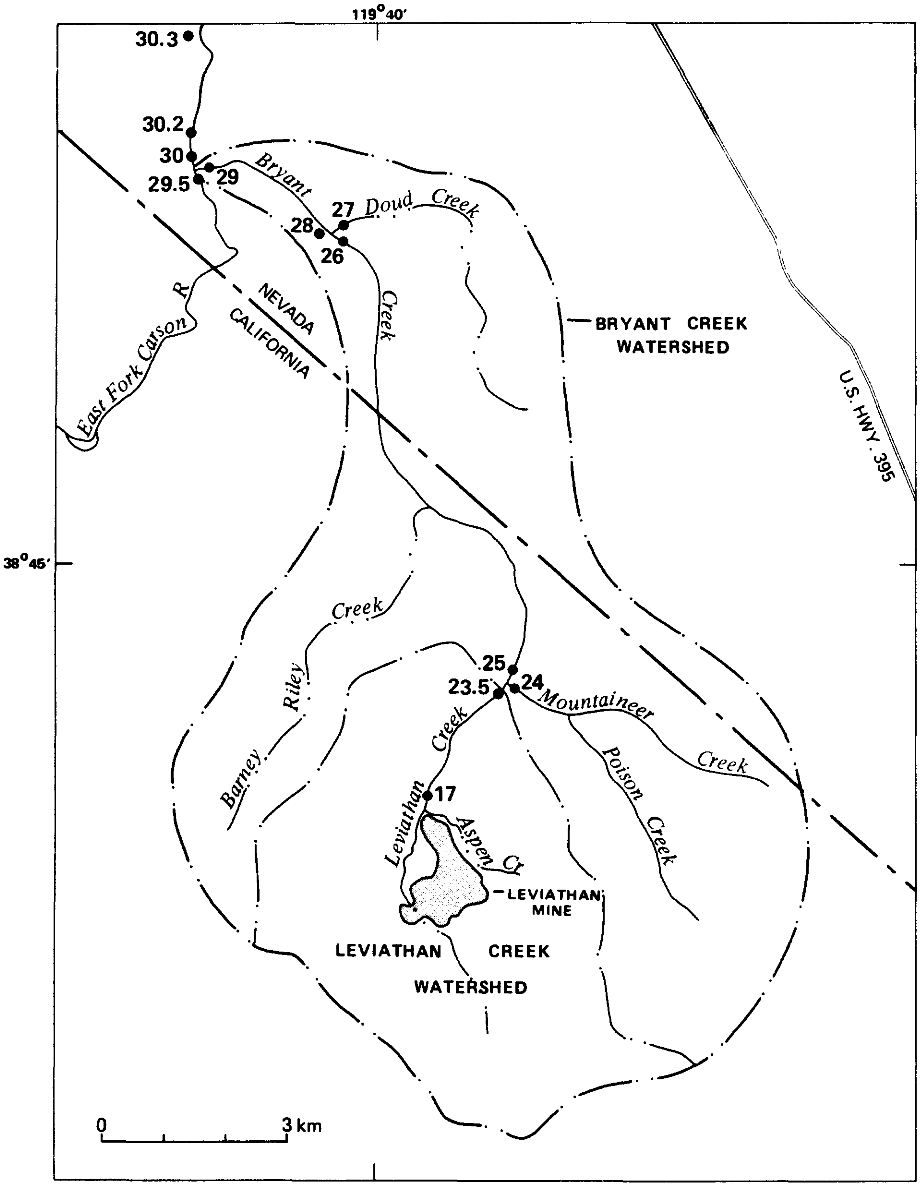

FIGURE 2B.--Surface-water sampling sites downstream from the mine area. Site numbers correspond with those in table 3. (from Hammermeister and Walmsley, 1985)

Table 3.--Physical measurements and revised chemical analyses of water collected from the Leviathan/Bryant Creek drainage basin

[m^3/s, cubic meter per second; °C, degree Celsius; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; %, percent]

	Site#1		Site#2	
	Sample Code Number			
	82WA117	82WA170	81WA132C	82WA118
	Date Collected			
Determination	6/16/82	10/6/82	10/9/81	6/16/82
Discharge, m^3/s	0.025	0.0031	0.001	0.001
Temperature, °C	12.5	6.0	12.5	12.0
Specific Conductance,				
field, µS/cm	105	150	6,250	9,300
lab, µS/cm	113	138	4,150	8,040
pH, field	8.10	7.50	2.45	1.80
lab	8.27	8.34	2.60	2.00
Eh, volts	0.380	0.279	0.463	0.465
Alkalinity,				
mg/L as HCO_3	60.4	82.4	------	------
Aluminum	0.018	0.029	440	438
Antimony	<0.0005	------	0.002	0.002
Arsenic	0.004	0.0007	27.1	35
Barium	0.065	0.060	0.007	0.0075
Beryllium	<0.002	<0.002	0.01	0.013
Bismuth	<0.0005	------	0.003	0.067
Boron	<0.02	<0.02	<0.02	0.1
Cadmium	0.00010	0.00045	0.15	0.282
Calcium	10.4	13.0	110	131
Chloride	1	1.1	------	8.4
Chromium	0.0003	0.0002	1.8	2.58
Cobalt	<0.001	<0.001	3.3	5.11
Copper	0.0015	<0.0005	1.2	5.32
Fluoride	0.054	0.063	------	3.4
Iron(Fe^{2+})	0.0076	0.0005	1,100	1,440
Iron(total)	0.0088	0.0041	1,160	1,570
Lead	0.0010	0.0005	<0.02	0.0745
Lithium	0.0021	0.0018	0.0815	0.0935
Magnesium	3.21	4.61	42	53.8
Manganese	0.0187	0.0085	7.6	10.5
Molybdenum	0.0111	0.0151	<0.003	0.0244
Nickel	0.00075	<0.00015	8.0	11.9
Potassium	2.08	3.37	13	13.8
Selenium	<0.002	------	0.01	<0.002
Silica	42.6	40.8	100	109
Sodium	6.39	8.36	26	19.4
Strontium	0.209	0.237	2.4	2.84
Sulfate	5.30	7.21	5,400	7,540
Thallium	0.001	0.002	0.81	2.0
Vanadium	0.003	<0.001	0.76	1.23
Zinc	0.0001	0.0046	1.4	1.39
Charge Balance, %	-0.481	-1.66	-2.19	-0.515

Table 3.--Physical measurements and revised chemical analyses of water collected from the Leviathan/Bryant Creek drainage basin--Continued

	Site #2	Site #3	Site #3.1	Site #5
	Sample Code Number			
	82WA169	82WA119	82WA120	82WA166
	Date Collected			
	10/6/82	6/16/82	6/16/82	10/6/82
Determination				
Discharge, m^3/s	0.001	0.0009	<0.0003	0.003
Temperature, °C	12.0	14.0	10.5	8.2
Specific Conductance,				
field, μS/cm	5,900	12,900	2,200	315
lab, μS/cm	5,690	7,530	2,070	376
pH, field	2.28	1.85	2.50	5.08
lab	2.14	2.10	2.38	3.64
Eh, volts	0.494	0.543	0.756	0.437
Alkalinity,				
mg/L as HCO_3	------	------	------	------
Aluminum	399	623	24.4	2.13
Antimony	------	0.002	<0.0005	------
Arsenic	33	41	0.002	0.001
Barium	0.009	0.013	<0.005	0.063
Beryllium	0.013	0.012	0.004	<0.002
Bismuth	------	0.041	<0.0005	------
Boron	0.09	0.35	0.1	<0.02
Cadmium	0.194	0.338	0.00285	0.00170
Calcium	114	266	64.9	24.3
Chloride	6.9	9.2	0.9	1.3
Chromium	2.31	3.69	0.0760	0.0039
Cobalt	4.08	5.07	0.099	0.069
Copper	1.48	9.64	0.424	0.0260
Fluoride	3.6	5.1	1.5	0.27
Iron(Fe^{2+})	1,240	2,150	4.46	11.1
Iron(total)	1,270	2,510	60.6	11.4
Lead	0.0320	0.0375	<0.0005	<0.0005
Lithium	0.101	0.163	0.0368	0.0055
Magnesium	42.2	97.0	14.8	7.41
Manganese	7.98	9.32	2.74	0.775
Molybdenum	0.0729	0.0657	0.0350	0.0171
Nickel	9.73	13.0	0.153	0.139
Potassium	14.1	23.2	1.62	3.91
Selenium	------	<0.002	<0.002	------
Silica	98.6	109	9.8	43.4
Sodium	20.7	24.3	3.26	9.27
Strontium	2.47	3.61	0.112	0.282
Sulfate	5,690	11,200	680	143
Thallium	1.1	0.82	0.007	0.002
Vanadium	1.10	1.91	0.002	<0.001
Zinc	1.05	2.62	0.289	0.0346
Charge Balance, %	-4.70	-2.50	2.53	-1.03

Table 3.--Physical measurements and revised chemical analyses of water collected from the Leviathan/Bryant Creek drainage basin--Continued

	Site#5.5	Site#6	Site#6.5	Site#7
	Sample Code Number			
	82WA167	82WA168	82WA165	82WA121
	Date Collected			
	10/6/82	10/6/82	10/6/82	6/17/82
Determination				
Discharge, m^3/s	0.003	0.002	0.0031	0.0037
Temperature, °C	7.9	7.9	7.8	18.0
Specific Conductance,				
field, µS/cm	4,050	3,500	1,800	750
lab, µS/cm	5,270	5,060	2,460	690
pH, field	2.97	3.28	3.78	6.85
lab	2.10	2.05	2.75	8.18
Eh, volts	0.563	0.528	0.547	0.238
Alkalinity,				
mg/L as HCO_3	------	------	------	146
Aluminum	108	103	51.0	0.038
Antimony	------	------	------	<0.0005
Arsenic	0.52	0.43	0.023	0.002
Barium	0.016	0.008	0.044	0.069
Beryllium	0.012	0.012	0.007	<0.002
Bismuth	------	------	------	<0.0005
Boron	0.2	0.2	0.08	0.03
Cadmium	0.0154	0.0182	0.00970	0.00030
Calcium	307	310	158	99.9
Chloride	4.6	4.4	1.6	0.9
Chromium	0.197	0.179	0.0826	0.0002
Cobalt	2.14	2.04	0.963	0.035
Copper	0.0630	0.398	0.192	0.0005
Fluoride	5.1	4.9	2.4	0.22
Iron(Fe^{2+})	626	606	278	6.03
Iron(total)	631	621	280	6.38
Lead	0.0040	<0.0005	<0.0005	<0.0005
Lithium	0.0735	0.0741	0.0365	0.0060
Magnesium	88.0	89.4	43.2	25.1
Manganese	22.6	22.6	11.1	2.13
Molybdenum	0.108	0.107	0.0881	0.0481
Nickel	4.08	4.09	1.93	0.0778
Potassium	20.1	20.4	10.2	2.74
Selenium	------	------	------	<0.002
Silica	54.3	50.8	46.2	31.7
Sodium	25.0	24.3	14.4	14.0
Strontium	1.61	1.52	0.890	1.02
Sulfate	2,880	2,810	1,450	276
Thallium	0.037	0.099	0.067	0.002
Vanadium	0.234	0.230	0.025	0.002
Zinc	0.675	0.712	0.332	0.0182
Charge Balance, %	1.88	5.35	-3.86	-0.865

Table 3.--Physical measurements and revised chemical analyses of water collected from the Leviathan/Bryant Creek drainage basin--Continued

	Site#7	Site#7.5		Site#8
	Sample Code Number			
	82WA162	82WA129	82WA164	82WA122
	Date Collected			
Determination	10/5/82	6/17/82	10/5/82	6/17/82
Discharge, m^3/s	0.0003	0.021	0.0057	0.032
Temperature, °C	14.3	18.0	11.5	18.0
Specific Conductance,				
field, µS/cm	1,870	875	2,240	920
lab, µS/cm	1,870	1,610	3,550	1,520
pH, field	6.00	4.18	3.43	4.50
lab	7.29	2.68	2.23	2.68
Eh, volts	0.263	0.488	0.574	0.471
Alkalinity,				
mg/L as HCO_3	37.6	------	------	------
Aluminum	0.45	21.7	55.6	16.0
Antimony	<0.0005	<0.0005	<0.0005	<0.0005
Arsenic	0.006	0.008	0.032	0.005
Barium	0.035	0.049	0.039	0.057
Beryllium	<0.002	<0.002	0.007	<0.002
Bismuth	<0.0005	<0.0005	<0.0005	<0.0005
Boron	0.05	0.04	0.09	0.03
Cadmium	0.00070	0.00515	0.0100	0.00455
Calcium	334	64.0	176	75.0
Chloride	1.4	1.3	2.3	1.0
Chromium	0.0003	0.0290	0.118	0.0130
Cobalt	0.180	0.363	1.02	0.326
Copper	<0.0005	0.180	0.209	0.165
Fluoride	0.72	0.69	2.8	0.55
Iron(Fe^{2+})	37.6	90.0	299	77.8
Iron(total)	38.1	91.1	308	80.0
Lead	<0.0005	0.0005	0.0035	0.0015
Lithium	0.0162	0.0154	0.0426	0.0142
Magnesium	71.1	18.8	48.5	21.1
Manganese	11.4	3.87	12.0	3.85
Molybdenum	0.104	0.0475	0.07748	0.0318
Nickel	0.415	0.734	2.03	0.672
Potassium	3.89	4.68	11.6	4.92
Selenium	<0.002	<0.002	<0.002	<0.002
Silica	25.0	44.7	47.7	43.7
Sodium	19.6	8.70	16.4	11.0
Strontium	2.34	0.425	0.912	0.570
Sulfate	1,200	517	1,570	504
Thallium	0.004	0.029	0.070	0.024
Vanadium	<0.001	0.001	0.100	0.001
Zinc	0.0510	0.137	0.383	0.155
Charge Balance, %	-0.890	1.87	-1.56	1.98

Table 3.--Physical measurements and revised chemical analyses of water collected from the Leviathan/Bryant Creek drainage basin--Continued

Determination	Site #8	Site #8.5	Site #9	Site #10
Sample Code Number	82WA163	82WA130	82WA132	82WA131
Date Collected	10/5/82	6/17/82	6/17/82	6/17/82
Discharge, m^3/s	0.0082	0.032	0.003	0.031
Temperature, °C	12.0	18.0	18.0	18.0
Specific Conductance, field, µS/cm	2,160	900	7,280	1,340
lab, µS/cm	3,450	1,550	5,180	2,390
pH, field	3.78	4.58	2.10	3.40
lab	2.24	2.72	2.27	2.41
Eh, volts	0.555	0.461	0.601	0.591
Alkalinity, mg/L as HCO_3	------	------	------	------
Aluminum	46.9	15.0	355	39.9
Antimony	<0.0005	<0.0005	0.002	<0.0005
Arsenic	0.019	0.007	27	1.5
Barium	0.034	0.051	0.012	0.047
Beryllium	0.007	<0.002	0.012	0.002
Bismuth	<0.0005	<0.0005	0.015	<0.0005
Boron	0.09	0.04	0.2	0.05
Cadmium	0.00815	0.00485	0.188	0.0144
Calcium	205	82.0	234	95.5
Chloride	2.3	1.4	7.7	1.2
Chromium	0.0941	0.0135	2.09	0.168
Cobalt	0.894	0.323	3.97	0.566
Copper	0.196	0.153	5.43	0.447
Fluoride	2.9	0.60	3.9	1.3
Iron(Fe^{2+})	264	79.4	1,070	142
Iron(total)	266	81.3	1,210	150
Lead	<0.0005	<0.0005	0.0350	0.0025
Lithium	0.0386	0.0148	0.0924	0.0193
Magnesium	51.8	23.2	86.1	27.0
Manganese	12.6	4.31	15.4	5.05
Molybdenum	0.0919	0.0436	0.0887	0.0546
Nickel	1.83	0.665	9.24	1.27
Potassium	9.99	5.10	12.9	5.18
Selenium	<0.002	<0.002	<0.002	<0.002
Silica	45.6	44.7	92.0	48.7
Sodium	15.9	11.1	21.9	11.3
Strontium	1.17	0.625	2.87	0.749
Sulfate	1,520	530	5,730	833
Thallium	0.057	0.023	1.1	0.093
Vanadium	0.033	0.002	0.967	0.068
Zinc	0.320	0.146	1.29	0.205
Charge Balance, %	-1.94	-5.10	3.53	3.29

Table 3.--Physical measurements and revised chemical analyses of water collected from the Leviathan/Bryant Creek drainage basin--Continued

	Site#10.5		Site#11	
	Sample Code Number			
	82WA116	82WA161	82WA114	82WA159
	Date Collected			
Determination	6/16/82	10/5/82	6/16/82	10/5/82
Discharge, m^3/s	0.041	0.0079	0.0045	0.002
Temperature, °C	18.5	9.1	13.5	4.0
Specific Conductance,				
field, μS/cm	1,300	2,620	240	415
lab, μS/cm	2,390	3,840	231	394
pH, field	3.32	3.10	8.00	7.15
lab	2.36	2.24	8.20	8.03
Eh, volts	0.622	0.612	0.384	0.463
Alkalinity,				
mg/L as HCO$_3$	------	------	73.4	75.7
Aluminum	37.5	58.1	0.195	0.016
Antimony	<0.0005	<0.0005	<0.0005	<0.0005
Arsenic	1.2	0.032	0.005	0.001
Barium	0.045	0.029	0.079	0.089
Beryllium	0.002	0.008	<0.002	<0.002
Bismuth	<0.0005	<0.0005	<0.0005	<0.0005
Boron	0.05	0.07	<0.02	<0.02
Cadmium	0.0168	0.0103	0.00005	<0.00005
Calcium	96.0	254	25.0	42.5
Chloride	1.8	2.4	1.1	1.0
Chromium	0.154	0.162	0.0014	0.0006
Cobalt	0.541	0.970	<0.001	<0.001
Copper	0.348	0.224	0.0020	0.0005
Fluoride	1.3	2.8	0.15	0.23
Iron(Fe^{2+})	123	254	0.0081	0.0053
Iron(total)	141	277	0.0091	0.0127
Lead	0.0025	0.0010	0.0110	<0.0005
Lithium	0.0207	0.0483	0.0041	0.0072
Magnesium	28.5	70.9	7.24	11.9
Manganese	5.25	15.2	0.0247	0.0109
Molybdenum	0.0524	0.0890	0.0153	0.0337
Nickel	1.21	2.06	0.00240	0.00125
Potassium	4.72	8.59	2.67	3.43
Selenium	<0.002	<0.002	<0.002	<0.002
Silica	48.7	50.6	43.2	39.0
Sodium	11.5	17.0	9.60	14.1
Strontium	0.780	1.44	0.401	0.634
Sulfate	790	1,870	57.2	130
Thallium	0.093	0.047	0.001	<0.001
Vanadium	0.030	0.051	0.002	<0.001
Zinc	0.192	0.385	0.0013	0.0003
Charge Balance, %	5.95	-1.89	-2.05	-2.35

Table 3.--Physical measurements and revised chemical analyses of water collected from the Leviathan/Bryant Creek drainage basin--Continued

	Site#11.5		Site#15	
	Sample Code Number			
	82WA115	82WA160	82WA113	82WA152
	Date Collected			
Determination	6/16/82	10/5/82	6/16/82	10/4/82
Discharge, m^3/s	0.031	0.011	0.040	0.010
Temperature, °C	18.0	6.0	14.5	7.0
Specific Conductance,				
field, $\mu S/cm$	1,200	2,260	1,050	2,230
lab, $\mu S/cm$	2,090	3,450	1,880	3,200
pH, field	3.58	3.52	3.31	3.11
lab	2.55	2.29	2.63	2.35
Eh, volts	0.612	0.607	0.644	0.658
Alkalinity,				
mg/L as HCO_3	------	------	------	------
Aluminum	32.2	47.8	28.8	45.0
Antimony	<0.0005	<0.0005	<0.0005	<0.0005
Arsenic	1.0	0.032	0.45	0.019
Barium	0.054	0.035	0.055	0.036
Beryllium	<0.002	0.007	<0.002	0.006
Bismuth	<0.0005	<0.0005	<0.0005	<0.0005
Boron	0.03	0.07	0.03	0.06
Cadmium	0.0134	0.00880	0.0119	0.00795
Calcium	87.9	221	81.6	219
Chloride	1.6	1.8	1.4	1.7
Chromium	0.124	0.132	0.105	0.114
Cobalt	0.466	0.802	0.400	0.753
Copper	0.261	0.213	0.260	0.202
Fluoride	0.89	2.5	0.81	2.2
Iron(Fe^{2+})	103	215	66.6	112
Iron(total)	117	233	83.3	174
Lead	0.0020	<0.0005	<0.0005	<0.0005
Lithium	0.0179	0.0432	0.0165	0.0408
Magnesium	25.2	61.3	24.2	61.5
Manganese	4.31	12.7	3.84	11.8
Molybdenum	0.0452	0.0863	0.0441	0.0868
Nickel	1.05	1.67	0.875	1.57
Potassium	5.60	8.71	5.15	8.38
Selenium	<0.002	<0.002	<0.002	<0.002
Silica	49.5	48.4	50.0	47.2
Sodium	12.8	20.3	12.7	18.9
Strontium	0.734	1.34	0.771	1.36
Sulfate	686	1,550	631	1,480
Thallium	0.092	0.044	0.070	0.043
Vanadium	0.013	0.060	0.002	0.012
Zinc	0.147	0.332	0.136	0.307
Charge Balance, %	4.96	-1.12	3.34	-0.441

Table 3.--Physical measurements and revised chemical analyses of water collected from the Leviathan/Bryant Creek drainage basin--Continued

	Site#16		Site#17	
	Sample Code Number			
	82WA111	82WA150	81WA131C	82WA112
	Date Collected			
Determination	6/16/82	10/4/82	10/9/81	6/16/82
Discharge, m^3/s	0.018	0.014	------	0.070
Temperature, °C	13.0	11.9	12.5	14.0
Specific Conductance,				
field, $\mu S/cm$	610	610	1,170	880
lab, $\mu S/cm$	640	597	1,440	1,450
pH, field	7.98	7.62	3.62	3.68
lab	7.98	8.04	3.04	2.74
Eh, volts	0.304	0.235	0.641	0.628
Alkalinity,				
mg/L as HCO_3	50.8	59.6	------	------
Aluminum	0.109	0.088	13	20.5
Antimony	<0.0005	<0.0005	<0.0005	<0.0005
Arsenic	0.003	0.005	0.008	0.35
Barium	0.027	0.029	0.04	0.044
Beryllium	<0.002	<0.002	<0.002	0.003
Bismuth	<0.0005	<0.0005	<0.0005	<0.0005
Boron	0.03	<0.02	0.04	0.03
Cadmium	0.00040	0.00015	<0.01	0.00820
Calcium	78.7	77.4	150	83.8
Chloride	1.2	1.3	2.8	1.4
Chromium	0.0001	0.0048	0.009	0.0632
Cobalt	0.016	0.010	0.29	0.283
Copper	0.0120	0.0015	0.10	0.231
Fluoride	0.38	0.35	------	0.58
Iron(Fe^{2+})	0.0177	0.0045	30.0	47.9
Iron(total)	0.0207	0.0123	39.0	55.7
Lead	<0.0005	<0.0005	<0.02	0.0010
Lithium	0.0114	0.0075	0.118	0.0145
Magnesium	21.45	20.4	42	23.8
Manganese	1.26	0.950	6.2	3.06
Molybdenum	<0.003	0.0572	<0.003	0.0363
Nickel	0.0418	0.0204	0.61	0.634
Potassium	3.89	4.24	4.9	4.31
Selenium	<0.002	<0.002	<0.002	<0.002
Silica	25.6	23.2	31	36.4
Sodium	10.7	13.2	15	10.9
Strontium	0.608	0.611	1.1	0.696
Sulfate	283	245	760	564
Thallium	0.002	<0.001	0.012	0.053
Vanadium	<0.001	<0.001	<0.005	0.001
Zinc	<0.0001	0.0015	0.11	0.109
Charge Balance, %	-4.09	1.31	-3.37	-2.37

Table 3.--Physical measurements and revised chemical analyses of water collected from the Leviathan/Bryant Creek drainage basin--Continued

	Site#17	Site#19.13		Site#19.2
	Sample Code Number			
	82WA151	82WA128	82WA158	82WA127
	Date Collected			
Determination	10/4/82	6/17/82	10/5/82	6/17/82
Discharge, m^3/s	0.024	<0.0003	0.0003	<0.0003
Temperature, °C	7.8	17.0	14.0	15.0
Specific Conductance, field, $\mu S/cm$	1,290	2,200	2,780	2,100
lab, $\mu S/cm$	1,560	2,490	2,440	2,420
pH, field	3.55	7.44	7.75	3.65
lab	2.84	7.81	6.80	3.75
Eh, volts	------	0.521	0.463	0.667
Alkalinity, mg/L as HCO_3	------	34.9	106	------
Aluminum	18.8	0.222	0.100	52.7
Antimony	<0.0005	<0.0005	<0.0005	<0.0005
Arsenic	0.012	0.004	0.001	0.008
Barium	0.033	0.019	0.018	0.008
Beryllium	0.003	<0.002	<0.002	0.007
Bismuth	<0.0005	<0.0005	<0.0005	<0.0005
Boron	0.04	0.1	0.1	0.1
Cadmium	0.00305	0.00125	0.00035	0.00730
Calcium	145	465	465	352
Chloride	1.6	1.7	1.6	1.9
Chromium	0.0413	0.0007	0.0003	0.0065
Cobalt	0.320	0.069	0.012	0.375
Copper	0.101	0.0095	0.0070	0.761
Fluoride	1.1	1.1	1.5	4.4
Iron(Fe^{2+})	45.6	0.0055	0.0058	1.08
Iron(total)	56.2	0.0056	0.0124	1.90
Lead	<0.0005	0.0005	<0.0005	0.0010
Lithium	0.0223	0.0297	0.0262	0.0580
Magnesium	37.9	108	104	95.7
Manganese	5.53	5.18	1.97	17.3
Molybdenum	0.0646	0.114	0.106	0.114
Nickel	0.682	0.151	0.0420	0.527
Potassium	5.18	7.52	8.34	8.37
Selenium	<0.002	<0.002	<0.002	<0.002
Silica	34.8	24.4	17.4	54.7
Sodium	13.9	26.1	25.3	24.1
Strontium	0.962	1.82	2.14	0.986
Sulfate	764	1,650	1,580	1,600
Thallium	0.016	0.004	0.003	0.018
Vanadium	0.002	<0.001	<0.001	<0.001
Zinc	0.125	0.0385	0.0094	0.521
Charge Balance, %	-0.775	-2.94	-3.31	0.249

Table 3.--Physical measurements and revised chemical analyses of water collected from the Leviathan/Bryant Creek drainage basin--Continued

Determination	Site #19.2	Site #20	Site #20.2	Site #20.5
	Sample Code Number			
	82WA157	82WA126	82WA155	82WA124
	Date Collected			
	10/5/82	6/17/82	10/5/82	6/17/82
Discharge, m^3/s	<0.0003	0.012	0.0009	0.003
Temperature, °C	12.8	13.5	8.6	15.5
Specific Conductance,				
field, μS/cm	2,670	418	758	1,680
lab, μS/cm	2,490	447	736	1,550
pH, field	3.78	7.73	4.19	3.65
lab	3.66	7.66	3.99	3.83
Eh, volts	0.669	0.385	0.497	0.602
Alkalinity,				
mg/L as HCO_3	------	39.2	------	------
Aluminum	54.7	0.134	7.18	29.8
Antimony	<0.0005	<0.0005	<0.0005	<0.0005
Arsenic	0.017	0.005	0.030	0.002
Barium	0.009	0.038	<0.005	0.011
Beryllium	0.009	<0.002	<0.002	0.007
Bismuth	<0.0005	<0.0005	<0.0005	<0.0005
Boron	0.10	0.02	0.04	0.10
Cadmium	0.00675	0.00080	0.00195	0.00465
Calcium	399	52.0	91.9	209
Chloride	2.0	1	1.4	2.1
Chromium	0.0076	0.0002	0.0007	0.0053
Cobalt	0.409	0.015	0.027	0.182
Copper	0.891	0.0065	0.307	0.470
Fluoride	4.4	0.39	0.61	1.7
Iron(Fe^{2+})	0.500	0.0147	0.0089	1.86
Iron(total)	1.29	0.0154	0.0336	2.27
Lead	0.0005	<0.0005	0.0005	<0.0005
Lithium	0.0650	0.0102	0.0161	0.0413
Magnesium	102	13.9	22.5	53.1
Manganese	19.5	1.18	3.24	8.75
Molybdenum	0.104	0.0174	0.0565	0.0713
Nickel	0.588	0.0378	0.110	0.323
Potassium	8.50	3.58	6.83	12.1
Selenium	<0.002	<0.002	<0.002	<0.002
Silica	49.3	28.46	37.48	45.9
Sodium	19.8	9.69	10.1	13.5
Strontium	0.951	0.361	0.401	0.840
Sulfate	1,670	190	364	912
Thallium	0.016	0.002	0.003	0.008
Vanadium	<0.001	0.001	<0.001	0.001
Zinc	0.686	0.0064	0.102	0.418
Charge Balance, %	3.19	-4.31	3.27	2.36

Table 3.--Physical measurements and revised chemical analyses of water collected from the Leviathan/Bryant Creek drainage basin--Continued

	Site#20.5	Site#21		Site#22
	Sample Code Number			
	82WA154	82WA125	82WA156	82WA123
	Date Collected			
Determination	10/5/82	6/17/82	10/5/82	6/17/82
Discharge, m^3/s	0.0005	0.003	0.003	0.003
Temperature, °C	11.2	15.5	14.0	19.0
Specific Conductance,				
field, μS/cm	183	2,900	3,000	200
lab, μS/cm	122	4,160	3,360	198
pH, field	7.60	3.19	3.35	8.10
lab	7.66	2.38	2.27	8.29
Eh, volts	0.396	0.622	0.618	0.328
Alkalinity,				
mg/L as HCO_3	107	------	------	131
Aluminum	0.002	74.6	58.8	0.007
Antimony	<0.0005	<0.0005	<0.0005	<0.0005
Arsenic	0.001	0.001	0.001	0.003
Barium	<0.005	0.006	<0.005	0.028
Beryllium	<0.002	0.013	0.012	<0.002
Bismuth	<0.0005	<0.0005	<0.0005	<0.0005
Boron	<0.02	0.30	0.27	<0.02
Cadmium	<0.00005	0.00840	0.00510	0.00240
Calcium	20.6	392	373	23.1
Chloride	0.8	2.0	2.0	0.8
Chromium	0.0007	0.0130	0.0116	0.0008
Cobalt	<0.001	0.485	0.446	0.001
Copper	0.0010	1.91	1.56	0.0010
Fluoride	0.02	5.9	5.2	0.03
Iron(Fe^{2+})	0.0010	173	167	0.0461
Iron(total)	0.0040	196	190	0.0569
Lead	<0.0005	<0.0005	<0.0005	<0.0005
Lithium	0.0018	0.0704	0.0714	<0.0010
Magnesium	4.88	106	96.9	6.18
Manganese	0.0001	23.0	21.2	0.0055
Molybdenum	0.0209	0.115	0.112	0.0074
Nickel	<0.00015	0.693	0.636	<0.00015
Potassium	0.665	22.6	23.8	2.32
Selenium	<0.002	<0.002	<0.002	<0.002
Silica	23.4	45.7	35.7	30.8
Sodium	9.29	18.7	18.6	10.5
Strontium	0.292	0.570	0.560	0.351
Sulfate	1.27	2,340	2,030	1.14
Thallium	<0.001	0.013	0.012	0.002
Vanadium	0.002	0.027	0.026	0.003
Zinc	0.0003	0.786	0.816	0.0001
Charge Balance, %	1.52	-2.66	1.12	-0.189

Table 3.--Physical measurements and revised chemical analyses of water collected from the Leviathan/Bryant Creek drainage basin--Continued

	Site#22	Site#23.5		Site#24
	Sample Code Number			
	82WA153	82WA110	82WA149	82WA108
	Date Collected			
	10/5/82	6/15/82	10/4/82	6/15/82
Determination				
Discharge, m^3/s	0.0037	0.071	0.040	0.091
Temperature, °C	7.3	19.5	8.3	12.5
Specific Conductance, field, μS/cm	209	1,100	1,350	150
lab, μS/cm	179	1,260	1,600	143
pH, field	8.25	3.25	------	8.85
lab	8.20	2.90	2.84	8.24
Eh, volts	0.399	0.689	0.662	0.379
Alkalinity, mg/L as HCO_3	125	------	------	94.3
Aluminum	<0.005	19.8	19.9	(0.045)
Antimony	<0.0005	<0.0005	<0.0005	<0.0005
Arsenic	0.002	0.018	0.011	0.002
Barium	0.009	0.048	0.034	0.039
Beryllium	<0.002	<0.002	0.003	<0.002
Bismuth	<0.0005	<0.0005	<0.0005	<0.0005
Boron	<0.02	0.02	0.03	<0.02
Cadmium	<0.00005	0.00790	0.00390	0.00020
Calcium	22.8	82.2	143	13.7
Chloride	0.9	1.1	1.4	1
Chromium	0.0002	0.0447	0.0296	(0.0090)
Cobalt	<0.001	0.276	0.322	(0.023)
Copper	0.0020	0.231	0.108	0.0010
Fluoride	0.02	0.52	1.2	0.04
Iron(Fe^{2+})	0.0035	9.01	23.6	0.0086
Iron(total)	0.0058	18.4	35.5	0.0099
Lead	<0.0005	<0.0005	0.0010	<0.0005
Lithium	0.0016	0.0145	0.0208	0.0024
Magnesium	5.86	23.6	38.3	5.78
Manganese	0.0018	3.04	5.48	(0.0221)
Molybdenum	0.0265	0.0442	0.0710	0.0102
Nickel	<0.00015	0.608	0.684	(0.0146)
Potassium	0.83	4.57	5.00	2.29
Selenium	<0.002	<0.002	<0.002	<0.002
Silica	26.0	46.4	36.9	42.6
Sodium	9.89	11.8	13.7	6.83
Strontium	0.334	0.708	1.00	0.237
Sulfate	1.25	483	723	1.89
Thallium	<0.001	0.033	0.017	<0.001
Vanadium	0.003	<0.001	<0.001	0.004
Zinc	0.0008	0.147	0.129	(0.510)
Charge Balance, %	-0.505	2.46	3.14	-2.72

Table 3.--Physical measurements and revised chemical analyses of water collected from the Leviathan/Bryant Creek drainage basin--Continued

	Site#24		Site#25	
	Sample Code Number			
	82WA147	81WA130C	82WA109	82WA148
	Date Collected			
Determination	10/4/82	10/9/81	6/15/82	10/4/82
Discharge, m^3/s	0.057	------	0.16	0.091
Temperature, °C	7.0	5.0	16.0	7.0
Specific Conductance,				
field, μS/cm	162	455	435	500
lab, μS/cm	151	407	477	467
pH, field	8.20	6.70	4.90	5.53
lab	8.14	6.84	3.87	4.34
Eh, volts	0.344	0.303	0.692	0.370
Alkalinity,				
mg/L as HCO$_3$	95.5	------	------	------
Aluminum	0.010	0.11	5.06	0.62
Antimony	<0.0005	<0.0005	<0.0005	<0.0005
Arsenic	0.003	<0.0005	0.010	0.004
Barium	0.030	0.03	0.042	0.034
Beryllium	<0.002	<0.002	<0.002	<0.002
Bismuth	<0.0005	<0.0005	<0.0005	<0.0005
Boron	<0.02	<0.02	<0.02	<0.02
Cadmium	0.00010	<0.01	0.00400	0.00165
Calcium	15.4	52	44.7	51.2
Chloride	1.1	------	1	1.1
Chromium	0.0003	<0.003	0.0027	0.0008
Cobalt	<0.001	0.067	0.112	0.098
Copper	0.0020	0.005	0.0930	0.0175
Fluoride	0.04	------	0.30	0.21
Iron(Fe^{2+})	0.0059	3.60	4.44	6.94
Iron(total)	0.0110	3.70	4.72	7.00
Lead	<0.0005	<0.02	<0.0005	<0.0005
Lithium	0.0021	<0.0010	0.0073	0.0084
Magnesium	6.19	15	13.5	15.8
Manganese	0.0052	1.5	1.26	1.57
Molybdenum	0.0230	<0.003	0.0073	0.0297
Nickel	0.00030	0.14	0.247	0.184
Potassium	2.21	3.1	3.21	3.848
Selenium	<0.002	<0.002	<0.002	<0.002
Silica	34.4	29	42.6	36.4
Sodium	6.81	9.6	8.60	9.93
Strontium	0.242	0.44	0.438	0.478
Sulfate	1.26	195	206	219
Thallium	<0.001	0.002	0.017	0.005
Vanadium	0.003	<0.005	<0.001	<0.001
Zinc	0.0001	<0.006	0.0429	0.0388
Charge Balance, %	0.368	0.250	2.75	1.97

Table 3.--Physical measurements and revised chemical analyses of water collected from the Leviathan/Bryant Creek drainage basin--Continued

	Site#26		Site#27	
	Sample Code Number			
	82WA107	82WA146	82WA105	82WA144
	Date Collected			
Determination	6/15/82	10/4/82	6/15/82	10/4/82
Discharge, m^3/s	0.22	0.11	0.0085	0.0057
Temperature, °C	21.0	12.7	17.5	12.2
Specific Conductance,				
field, μS/cm	390	412	350	369
lab, μS/cm	445	396	345	355
pH, field	5.30	7.69	8.41	8.20
lab	3.76	7.53	8.36	8.40
Eh, volts	0.398	0.404	0.340	0.439
Alkalinity,				
mg/L as HCO_3	------	33.8	168	173
Aluminum	0.73	0.036	0.007	0.009
Antimony	<0.0005	<0.0005	<0.0005	<0.0005
Arsenic	0.003	0.002	0.003	0.003
Barium	0.042	0.030	0.044	0.037
Beryllium	<0.002	<0.002	<0.002	<0.002
Bismuth	<0.0005	<0.0005	<0.0005	<0.0005
Boron	<0.02	<0.02	<0.02	<0.02
Cadmium	0.00225	0.00020	0.00015	0.00005
Calcium	41.0	42.0	29.7	32.2
Chloride	1.2	1.2	4.0	4.1
Chromium	0.0003	0.0006	0.0002	0.0004
Cobalt	0.088	0.058	<0.001	<0.001
Copper	0.0555	0.0020	0.0020	0.0015
Fluoride	<0.002	0.22	0.069	0.008
Iron(Fe^{2+})	5.12	0.0018	0.0236	0.0155
Iron(total)	5.52	0.0091	0.0242	0.0389
Lead	<0.0005	<0.0005	<0.0005	<0.0005
Lithium	0.0067	0.0078	0.0044	0.0047
Magnesium	13.4	14.8	15.45	16.2
Manganese	1.04	1.04	0.0115	0.0075
Molybdenum	0.0095	0.0349	0.0124	0.0270
Nickel	0.190	0.131	0.00045	0.00015
Potassium	3.99	3.81	5.17	5.03
Selenium	<0.002	<0.002	<0.002	<0.002
Silica	45.6	35.7	55.6	53.6
Sodium	9.54	9.81	16.3	16.7
Strontium	0.410	0.410	0.3245	0.341
Sulfate	188	152	38.9	44.7
Thallium	0.013	0.003	0.001	<0.001
Vanadium	<0.001	<0.001	0.007	0.007
Zinc	0.0327	0.0019	0.0002	0.0006
Charge Balance, %	0.330	1.85	-1.08	-1.05

Table 3.--Physical measurements and revised chemical analyses of water collected from the Leviathan/Bryant Creek drainage basin--Continued

Determination	Site#28		Site#29	
	Sample Code Number			
	82WA106	82WA145	82WA104	82WA143
	Date Collected			
	6/15/82	10/4/82	6/14/82	10/4/82
Discharge, m^3/s	0.24	0.11	0.071	0.11
Temperature, °C	20.0	13.5	23.0	14.0
Specific Conductance,				
field, μS/cm	350	406	430	442
lab, μS/cm	431	396	452	416
pH, field	5.88	7.78	5.50	7.80
lab	3.86	7.45	3.83	7.80
Eh, volts	0.338	0.394	0.392	0.423
Alkalinity,				
mg/L as HCO_3	2.65	39.7	------	39.2
Aluminum	0.202	0.107	0.048	0.14
Antimony	<0.0005	<0.0005	<0.0005	<0.0005
Arsenic	0.003	0.003	0.002	0.003
Barium	0.042	0.026	0.040	0.029
Beryllium	<0.002	<0.002	<0.002	<0.002
Bismuth	<0.0005	<0.0005	<0.0005	<0.0005
Boron	<0.02	<0.02	0.02	<0.02
Cadmium	0.00215	0.00025	0.00200	0.00030
Calcium	38.6	41.9	40.6	41.5
Chloride	1.3	0.9	1.3	1.6
Chromium	0.0002	0.0001	0.0001	0.0006
Cobalt	0.078	0.044	0.074	0.041
Copper	0.0385	0.0340	0.0445	0.0015
Fluoride	0.11	<0.002	0.20	0.22
Iron(Fe^{2+})	4.84	0.0013	4.29	0.0019
Iron(total)	5.17	0.0033	4.59	0.0066
Lead	<0.0005	<0.0005	<0.0005	0.0025
Lithium	0.0079	0.0075	0.0070	0.0081
Magnesium	12.6	15.1	13.4	15.45
Manganese	0.961	0.928	0.957	0.923
Molybdenum	0.0127	0.0321	0.0095	0.0370
Nickel	0.187	0.118	0.164	0.0964
Potassium	4.07	4.55	3.81	4.20
Selenium	<0.002	<0.002	<0.002	<0.002
Silica	45.4	37.9	46.6	36.2
Sodium	9.92	10.3	10.7	11.7
Strontium	0.438	0.441	0.466	0.408
Sulfate	180	158	189	156
Thallium	0.013	0.003	0.014	0.003
Vanadium	<0.001	<0.001	<0.001	0.002
Zinc	0.0335	0.0017	0.0331	0.0032
Charge Balance, %	-1.30	-0.263	-0.965	0.835

Table 3.--Physical measurements and revised chemical analyses of water collected from the Leviathan/Bryant Creek drainage basin--Continued

	Site#29.5		Site#30	
	Sample Code Number			
	82WA101	82WA142	81WA129N	82WA103
	Date Collected			
Determination	6/14/82	10/4/82	10/8/81	6/14/82
Discharge, m^3/s	40	5.6	------	40
Temperature, °C	10.0	11.5	13.0	12.8
Specific Conductance,				
field, μS/cm	65.0	126	233	80.0
lab, μS/cm	53.0	113	195	60.0
pH, field	7.65	8.18	8.72	7.60
lab	7.79	6.92	8.05	7.72
Eh, volts	0.347	0.379	0.302	0.239
Alkalinity,				
mg/L as HCO_3	27.6	52.6	------	29.2
Aluminum	0.042	0.059	<0.01	0.068
Antimony	<0.0005	<0.0005	<0.0005	<0.0005
Arsenic	0.002	0.006	0.008	0.003
Barium	0.017	0.019	0.03	0.019
Beryllium	<0.002	<0.002	<0.002	<0.002
Bismuth	<0.0005	<0.0005	<0.0005	<0.0005
Boron	0.02	0.09	0.22	0.02
Cadmium	0.00120	0.00010	<0.01	0.00060
Calcium	5.23	10.3	18	6.22
Chloride	0.6	2.8	8.3	0.7
Chromium	0.0003	0.0002	<0.003	0.0001
Cobalt	<0.001	<0.001	<0.005	0.002
Copper	<0.0005	0.0010	0.003	0.0020
Fluoride	0.05	0.074	------	0.05
Iron(Fe^{2+})	0.0162	0.0152	0.0130	0.0076
Iron(total)	0.0239	0.0426	0.0260	0.0087
Lead	<0.0005	0.0005	<0.02	<0.0005
Lithium	0.0047	0.0158	<0.0010	0.0041
Magnesium	1.46	3.02	4.9	1.87
Manganese	0.0044	0.0060	0.01	0.0305
Molybdenum	0.0136	0.0199	<0.003	0.0177
Nickel	<0.00015	0.00030	<0.004	0.00375
Potassium	0.80	1.73	2	0.893
Selenium	<0.002	<0.002	<0.002	<0.002
Silica	13.1	21.0	21	14.4
Sodium	2.65	8.96	16	3.32
Strontium	0.0833	0.165	0.26	0.0956
Sulfate	2.86	10.2	27.0	8.17
Thallium	<0.001	<0.001	<0.001	<0.001
Vanadium	0.001	<0.001	<0.005	<0.001
Zinc	0.0007	0.0014	<0.006	0.0008
Charge Balance, %	-1.05	1.91	-1.37	-2.57

Table 3.--Physical measurements and revised chemical analyses of water collected from the Leviathan/Bryant Creek drainage basin--Continued

	Site #30	Site #30.2	Site #30.3
		Sample Code Number	
	82WA141	82WA102	82WA100
		Date Collected	
Determination	10/4/82	6/14/82	6/14/82
Discharge, m^3/s	5.6	40	40
Temperature, °C	9.2	10.4	8.0
Specific Conductance,			
field, $\mu S/cm$	144	69.1	56.0
lab, $\mu S/cm$	137	55.0	51.0
pH, field	8.05	7.60	8.20
lab	8.11	7.73	7.59
Eh, volts	0.421	0.300	0.352
Alkalinity,			
mg/L as HCO_3	49.1	28.6	32.3
Aluminum	0.043	0.047	0.039
Antimony	<0.0005	<0.0005	<0.0005
Arsenic	0.008	0.002	0.003
Barium	0.019	0.017	0.014
Beryllium	<0.002	<0.002	<0.002
Bismuth	<0.0005	<0.0005	<0.0005
Boron	0.08	0.03	0.03
Cadmium	0.00010	0.00030	0.00005
Calcium	12.5	5.70	5.35
Chloride	3.0	0.6	0.6
Chromium	0.0003	0.0003	0.0003
Cobalt	0.002	0.001	<0.001
Copper	0.0010	0.0020	0.0015
Fluoride	0.090	0.051	0.04
Iron(Fe^{2+})	0.0040	0.0309	0.0167
Iron(total)	0.0089	0.0394	0.0207
Lead	<0.0005	<0.0005	<0.0005
Lithium	0.0158	0.0038	0.0047
Magnesium	3.845	1.70	1.545
Manganese	0.0673	0.0156	0.0061
Molybdenum	0.0191	0.0192	0.0150
Nickel	0.00600	0.00225	0.00090
Potassium	1.49	0.705	0.689
Selenium	<0.002	<0.002	<0.002
Silica	22.1	13.2	12.9
Sodium	7.88	2.92	2.87
Strontium	0.186	0.0885	0.0839
Sulfate	19.7	5.41	2.36
Thallium	<0.001	<0.001	<0.001
Vanadium	0.001	0.001	0.001
Zinc	0.0010	0.0010	0.0005
Charge Balance, %	1.02	-2.35	-5.15

COMPARISON OF RESULTS

In the following sections, the determinations of individual elements are discussed, and the various analytical techniques are compared. This report is primarily a presentation of the data. The details of the comparisons are presented in a separate report (Ball and Nordstrom, written commun., April, 1989), which focuses on the methods used. The discussions in this report are limited to identifying the values selected for inclusion in table 3 and briefly explaining why they were selected. On many occasions we refer to the term percent difference ($\Delta\%$) between values determined using alternative methods. This $\Delta\%$ function is calculated by:

$$\Delta\% = \frac{(\text{Method A Concentration} - \text{Method B Concentration})*100}{(\text{Method A Concentration} + \text{Method B Concentration})/2} \qquad (1)$$

Thus, the maximum value of the result of this calculation is ±200. This means that a value for $\Delta\%$ of zero denotes perfect matching of analytical values, and a value approaching ±200 means there is no similarity between values.

Aluminum

For Al concentrations greater than 0.5 mg/L, the ICP and DCP results appear to be equivalent. Since there is a significant interference from Ca at the wavelength used for DCP analysis (Ball and Nordstrom, 1985), all DCP Al values except one have been replaced. For concentrations above 2 mg/L, ICP Al values have replaced the DCP values in table 3, and with one exception, GFAAS determinations for samples with concentrations below 2 mg/L have replaced the remaining DCP values. The exception is sample 82WA143, for which the GFAAS Al concentration estimate of 0.52 mg/L is about 10 times the GFAAS Al concentration of nearby samples of similar chemistry, and hence is believed to be contaminated. Thus, for this sample we have retained the DCP Al estimate of 0.14 mg/L.

Arsenic

In the following discussion, data for As obtained by the various techniques are compared with concentrations of As obtained by the hydride generation technique as the reference method. The hydride data are the most complete, precise and internally consistent, and are therefore the most convenient to use as a reference. However, as the reader will see from the ensuing discussion, no one method for the determination of As is always reliable.

Comparing the ICP with the DCP

Of the 63 samples in the set, seven measurable As concentrations were obtained by ICP, and eighteen by DCP. The three ICP As values less than 25 mg/L yielded $\Delta\%$ values of -64, 190 and 199 with respect to hydride values. The four ICP As values greater than 25 mg/L gave $\Delta\%$ values of -9.3, -2.7, 1.0 and 36.7. The fourteen samples with DCP As less than 25 mg/L yielded $\Delta\%$ values between 7.6 and 199, whereas the four samples with DCP As greater than 25 mg/L gave $\Delta\%$ values of -4.2, -2.6, -1.0 and 22.5. These results suggest that the ICP and DCP have equivalent capabilities to measure As, which evidently do not extend into the sub-mg/L range.

Comparing the GFAAS Technique with the Hydride Technique

Maest and Wing (1987) present evidence that for accurate total As determination by hydride generation, the sample must be pre-reduced before the sodium borohydride addition. The hydride determination procedure of Ball and Nordstrom (1985) did not include a pre-reduction step. This initially suggested that the hydride values of Ball and Nordstrom (1985) may have been erroneously low. Figure 3 is a plot of Δ% between hydride and GFAAS As as a function of hydride As concentration for all data, and illustrates the distinct positive bias in the GFAAS data at low As concentrations. This suggests that the GFAAS method of Maest and Wing (1987) may contain a systematic positive bias in the concentrations determined. Re-analysis of several samples in this set by both the hydride and the GFAAS techniques (table 4) strongly reinforces this hypothesis. For example, sample 82WA125, which gave an initial GFAAS As concentration of 0.022 mg/L, yielded a hydride-with-pre-reduction As value of 0.0016 mg/L. Similarly, sample 82WA126, which gave an initial GFAAS As concentration of 0.062 mg/L, yielded a GFAAS value of 0.006 mg/L upon re-analysis. Several similar examples listed in table 4 demonstrate that for the determination of As, the GFAAS technique is subject to a wide range of variability which is not yet under control.

Table 4.--Results of repeated As determinations for eight samples
[mg/L, milligrams per liter]

Sample	Hydride	GFAAS	GFAAS Reruns	Hydride Reruns
	- - - - - - -	- - - - - - - mg/L	- - - - - - -	- - - - - - -
82WA103	0.002	0.100		0.004, 0.126[1]
82WA125	0.001	0.022		0.0016
82WA126	0.003	0.062	0.006	
82WA141	0.004	0.013, 0.007	0.009	
82WA146	0.001	0.0085, 0.0015	0.002	
82WA156	0.001	0.022		0.0018
82WA163	0.017	0.019, 0.040	0.020	
82WA164	0.032	0.025, 0.069	0.067	

[1] Analysis was done on a separate subsample

GFAAS, ICP, and additional hydride data have been used to revise the initial hydride and DCP As data for the generation of the values in table 3. If initial hydride, GFAAS and additional hydride values approximate each other within ±15 percent above 2 mg/L or within ±150 percent below 2 mg/L they are averaged. If not, individual values for specific samples are examined with respect to what might be expected as a result of mixing and other downstream attenuation processes. Concentrations found by these techniques to be unreasonable are discarded. If no determination can be made, the original hydride values are retained.

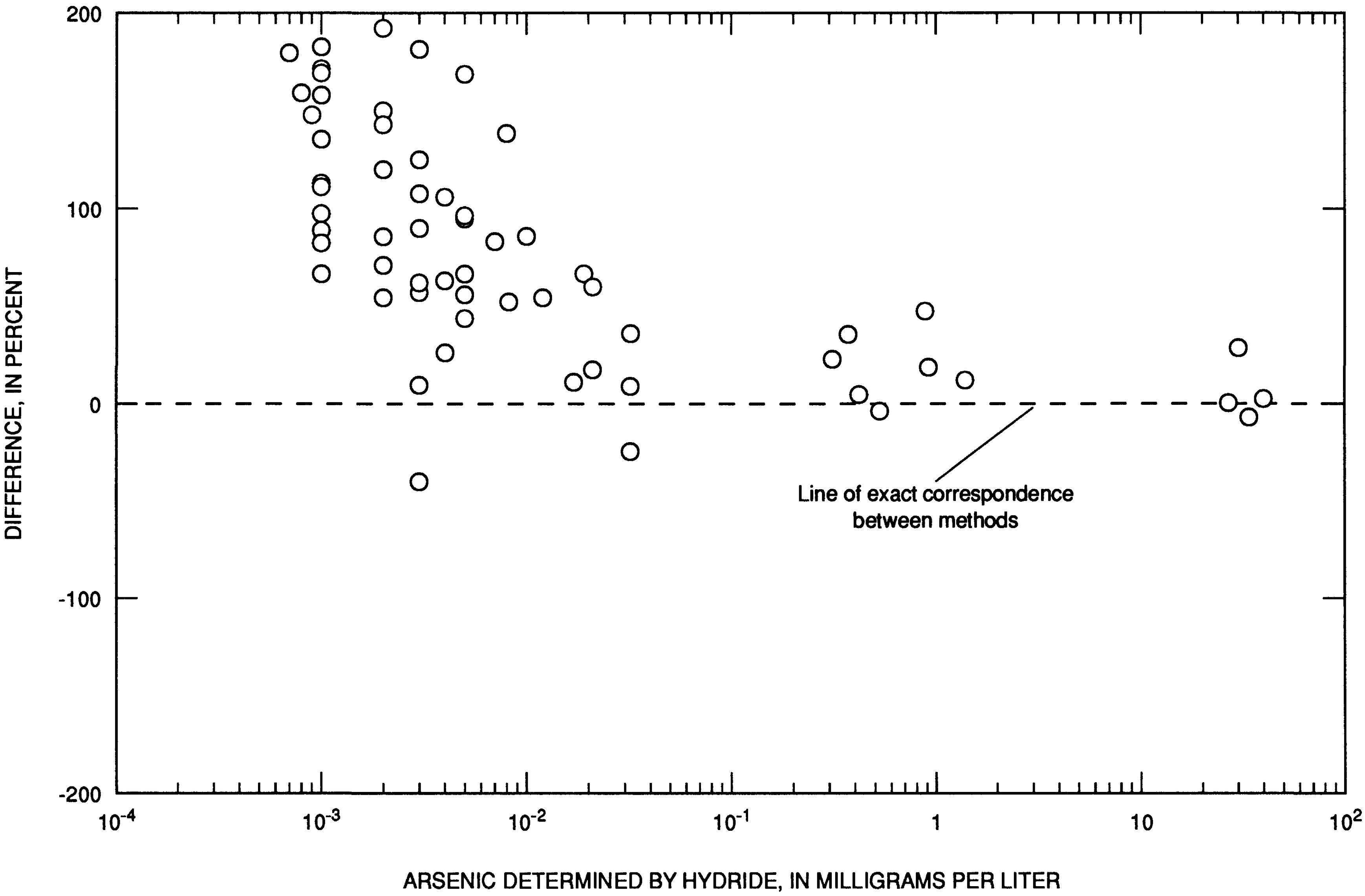

Figure 3. Plot of hydride-graphite furnace atomic absorption spectrometry percent difference as compared with hydride arsenic concentration for all data.

Barium

The Ba concentrations in table 3 are the average of the ICP and DCP values, except for samples 82WA118, 119, 132, 165, 167, 168 and 169. These samples were analyzed by ICP only at a dilution of 1/10; hence their concentration values were below the ICP detection limit. DCP data were retained for these 7 samples. The maximum Δ% between averaged values was 150, which occurred at the detection limit. More typical Δ% values were 10 to 40.

Cadmium, Lead and Vanadium

Since all Cd, Pb and V concentrations were near or below both the ICP and DCP detection limits, GFAAS values for Cd, Pb and V were substituted into table 3 for all samples.

Calcium

For the revisions shown in table 3, ICP and DCP data for Ca were averaged in all but one case. For sample 82WA129, the DCP value was determined by plotting main stem Ca/SO_4 concentration ratios against SO_4 concentration (fig. 4) to be almost certainly in error. The DCP value of 49 mg/L therefore was ignored, and the ICP value of 64 mg/L was substituted.

Chromium

The results of the GFAAS Cr determinations suggest that the inter-element corrections for Fe on Cr determined by ICP and Ca on Cr determined by DCP may be in error. Therefore, GFAAS values for Cr were substituted where available; otherwise, the ICP and DCP concentration values which were computed before inter-element interference correction were retrieved from the intermediate data files and averaged. This was done only for the four most concentrated samples, 82WA118, 119, 132 and 169. The maximum Δ% obtained for the values was 9.1.

Cobalt

No significant interferences are apparent in the ICP determination of Co in acid mine water matrix containing high concentrations of Ca, Fe, SiO_2, Al and Mg. The GFAAS and ICP Co determinations strongly suggest that many DCP Co values are inaccurate. Therefore, GFAAS values for Co were substituted where no ICP data were available; ICP values for Co were substituted where no GFAAS data were available; and, where both GFAAS and ICP data were available, the average of ICP and GFAAS was adopted. The maximum Δ% calculated was -35.6; a more typical value was 10 to 20.

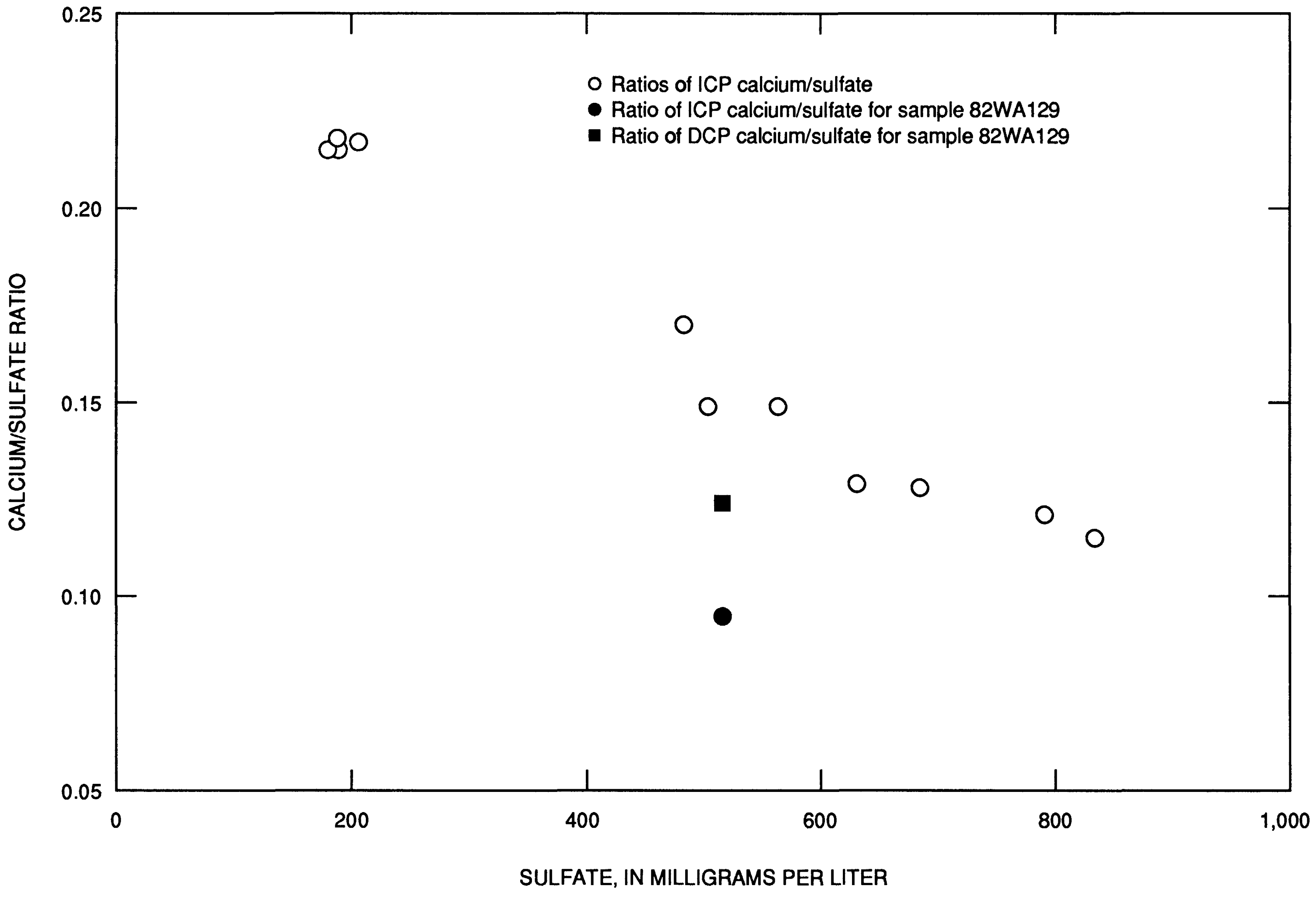

Figure 4. Plot of calcium/sulfate ratio as compared with sulfate concentration-June main stem.

Copper

GFAAS Cu concentrations are consistently less than DCP and ICP values above 0.5 mg/L. This difference could not be explained; therefore only GFAAS data for Cu less than 0.5 mg/L were adopted. Because the ICP Cu wavelength selected for the simultaneous element array was a secondary one because of geometric constraints in the construction of the slit plate, ICP Cu values are known with reduced precision and accuracy. Therefore, DCP Cu data have been retained at concentrations above 0.5 mg/L.

Iron

The Fe values of Ball and Nordstrom (1985) are unchanged. Geochemical modeling results from Fe redox species input data are shown in figures 5a and 5b, which are plots of Pt electrode Eh minus the Eh calculated by WATEQ4F from the activities of the Fe^{2+} and Fe^{3+} aqueous species (ΔEh) as a function of the concentration of total Fe and of pH. The outlying data point at a log total Fe concentration of 0.67 and a ΔEh of +0.23 is for an emf measurement and a water sample taken from a turbulent mixing zone where differential precipitation of Fe and Al oxides was occurring, and stable pH and emf readings could not be obtained. The second outlying point on the ΔEh as compared with pH plot, at a ΔEh of -0.14 and a pH of 4.2 is for a sample containing only 0.034 mg/L total Fe. This sample also contained detectable H_2S, the presence of which may significantly lower the emf measured using a Pt electrode. The outlying points at the high Fe, low pH end of the respective plots are more difficult to explain. They may represent measurements obscured by a mixed potential with significant contributions from other dissolved electroactive species. These two plots provide strong supporting evidence that, over the Fe concentration range in which the Fe(II/III) couple is known to determine the Pt electrode Eh (greater than 0.5 mg/L), excellent agreement may be expected between Eh values calculated from the activities of Fe^{2+} and Fe^{3+} and Eh values measured with a Pt electrode at the time of sample collection. These geochemical modeling results provide additional validation of the analytical values obtained for the Fe redox species.

Magnesium

On the basis of careful examination of all available Mg data and upon WATEQ4F charge balance calculations, the mean of the ICP and previously selected DCP value was adopted in all but 7 cases. For samples 82WA118, 119, 132, 165, 167, 168 and 169, the mean of the ICP value and the 1/100 dilution DCP value was adopted. The maximum $\Delta\%$ value calculated for Mg was -23.3, with more typical values ≤ 15.

Manganese

GFAAS data have been placed in table 3 for all samples having Mn concentrations below 0.5 mg/L. For the remaining samples, all differences between ICP and DCP concentrations determined using the two techniques are less than 13 percent, and most are less than 5 percent. Hence, the average of the values appears in table 3.

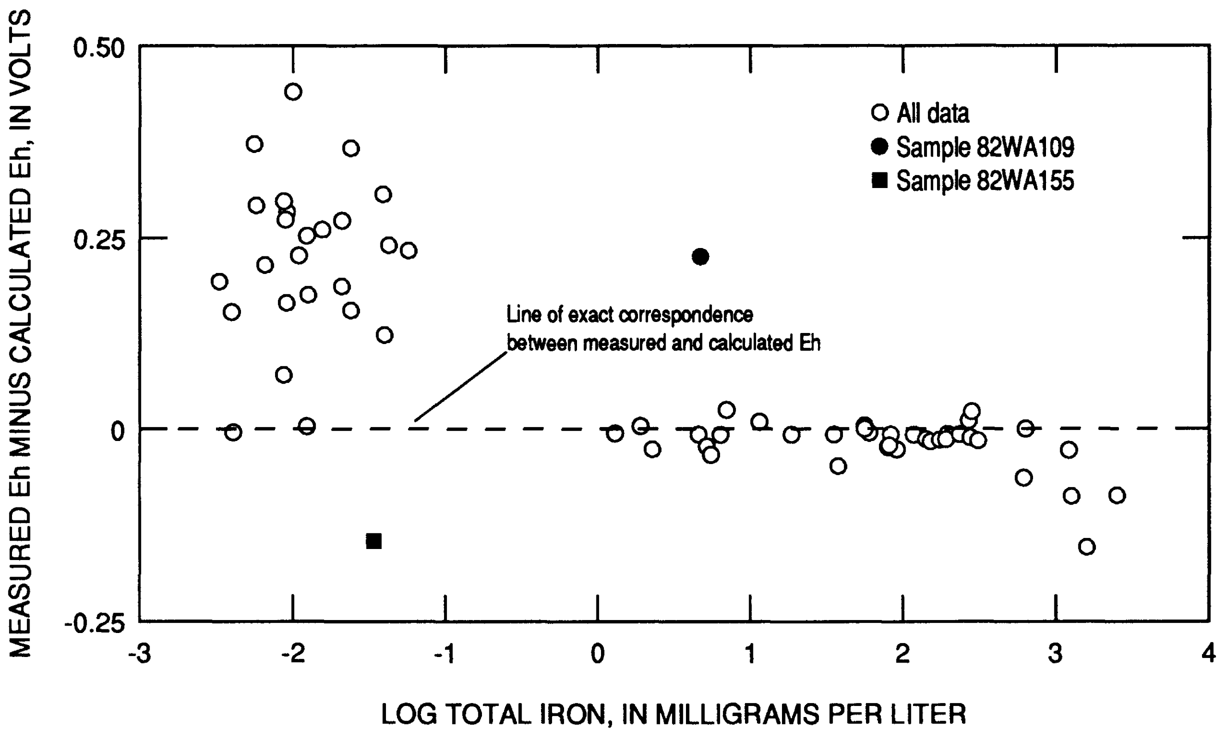

Figure 5a. Plot of Eh difference as compared with total iron - all Leviathan data.

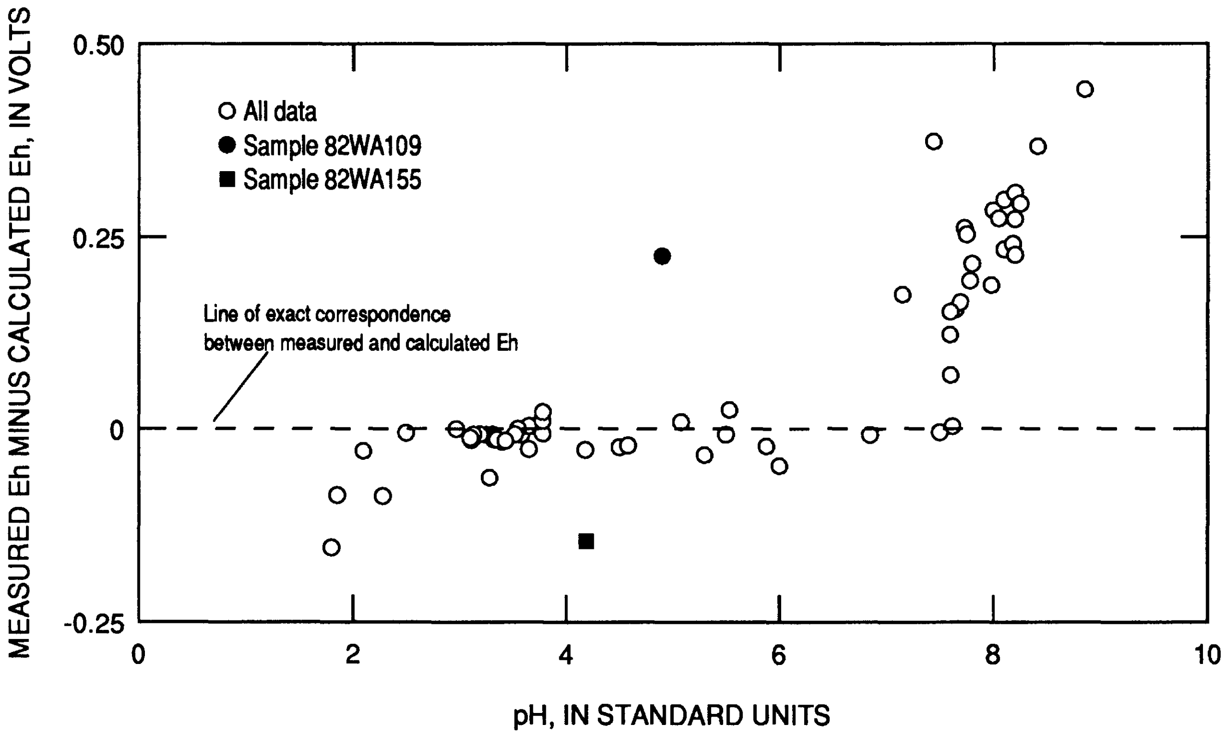

Figure 5b. Plot of Eh difference as compared with pH - all Leviathan data.

Nickel

All DCP values of Ball and Nordstrom (1985) have been replaced. GFAAS data for Ni were determined to be the most accurate because of the more favorable precision and sensitivity of the GFAAS technique, and were adopted when available. When GFAAS, DCP and ICP data were available, the ICP values were found by intercomparison to match the more accurate GFAAS estimates significantly better than the DCP values. Therefore, when Ni concentrations were above the 0.35 mg/L practical upper limit of GFAAS determination, the ICP values were placed in table 3.

Potassium and Sodium

The following selected samples were analyzed by flame AAS for K and Na: 82WA101, 104, 105, 109, 114, 116, 117, 118, 119, 120, 123, 125, 128, 132, 141, 143, 144, 146, 147, 153, 155, 156, 157, 159, 161, 162, 165 and 169. With the compromise torch power and entrance slit alignment settings used for the ICP analyses, the ICP spectrometer is only marginally useful for the analysis of K and Na in this range of matrix and K and Na concentrations. Therefore, all available flame AAS values have been adopted for these samples. For the remaining samples, the DCP K and Na values were retained. The maximum error in the DCP Na and K estimates remaining in table 3 is 20 percent of the concentration reported.

Silicon

No reliable ICP Si data could be obtained. However, the DCP detection limit for Si was redetermined for this investigation, and found to be 1 mg/L rather than the previously used 2 mg/L value. The best values selection procedure was repeated for the DCP determinations using the 1 mg/L detection limit, resulting in the selection of new SiO_2 values for the following 24 samples: 82WA108, 109, 111, 112, 117, 121, 123, 126, 128, 143, 145, 146, 147, 148, 149, 150, 151, 153, 154, 155, 156, 159, 162, 170.

Strontium

The DCP detection limit for Sr was reduced to 1 mg/L, the selection of best values was repeated, and the resulting DCP values and the ICP values were averaged. For two samples, 82WA125 and 82WA156, the ICP concentrations are significantly lower than their DCP counterparts. Strontianite solubility indices calculated using WATEQ4F and comparison of element ratios suggest that the DCP values are more accurate. Therefore, the ICP values were not used for these two samples. The maximum $\Delta\%$ calculated for Sr was 11.

Sulfate

Evaluation techniques additional to the those used to select the best SO_4 values presented by Ball and Nordstrom (1985) were employed to test the validity of those SO_4 values based on the more accurate and precise data for the other elements presented here. The primary technique was comparison of element ratios between sampling sites on the main stem of Leviathan/Bryant Creek. This technique simplified the identification of conservative and nonconservative constituents and of questionable or erroneous data values. Bencala and others (1987) define conservative behavior as an absence of sources or sinks of dissolved solutes within the water column. Thus, a conservative constituent is one that does not change in concentration by chemical reaction. Using the above techniques, Ba, Ca, Li, Mg, Na, K, SiO_2, Sr and SO_4 tended to be conservative over the stream reach between sampling sites 7.5 and 17.

The October Site 8 (82WA163) SO_4 value of 1,520 mg/L appears to be a reasonably reliable analysis because the charge balance is -1.9 percent and the Site 8/Site 7.5 ratio is 0.97, compared with a mean for all conservative constituents of 0.93 (see table 5 and fig. 6a). The SO_4 value for Site 10.5 (82WA161) of 1,600 mg/L yields a speciated charge balance of +9.4 percent and an element ratio for Site 10.5/Site 8 of 1.05, compared with the average ratio for the other conservative constituents of 1.23 (see table 5 and fig. 6b). If we take 1.23 times the Site 8 SO_4 value of 1,520 = 1,870 mg/L, charge balance is vastly improved from the initial +9.4 percent to -1.89 percent. Furthermore if we use 1,870 mg/L SO_4 for Site 10.5, the SO_4 ratio for Site 11.5/10.5 is reduced from 0.94 to 0.78. The average ratio for all conservative constituents for those two sites is 0.85. However, the earlier value of 1,460 mg/L for SO_4 at site 11.5 appears to be in error because nearly every constituent decreases slightly from site 11.5 to site 15, with an average ratio of 0.96. Hence, if we choose 1,550 mg/L SO_4 for 82WA160 (Site 11.5), its charge balance is greatly improved from +3.10 percent to -1.12 percent, the SO_4 ratio is improved to 0.83 (fig. 6c), and the Site 15/11.5 ratio is improved from 1.01 to 0.95 (figs. 6d and 7). Figures 8a and 8b and figures 9a and 9b show that the charge balance frequency distribution and the correspondence of conductance to SO_4 concentration, respectively, are also improved.

Metal/SO_4 ratios are another set of independent checks of the accuracy of SO_4 determinations. Four metal/SO_4 ratios are plotted as compared with SO_4 in figure 10 and five are plotted as compared with sample site in figure 11. The metal/SO_4 ratios are also improved using these revised SO_4 values. The Cr, Co, Mn and Ni relations shown in figure 10 illustrate that the June Mountaineer Creek site (82WA108) was likely contaminated at the time of collection, probably by airborne particulate matter. This sample was found to contain these four trace metals plus Al and Zn (data not shown) at concentrations 4.25 to 5,100 times higher than those found in the October sample at the same site (82WA147). The ion ratios and metal/SO_4 ratios suggest that Zn, Cd and Li are our most reliable conservative tracers so far. With the above two changes, all charge balances for the October 1982 set of samples are less than ±3.5 percent except those for 82WA165, 168 and 169.

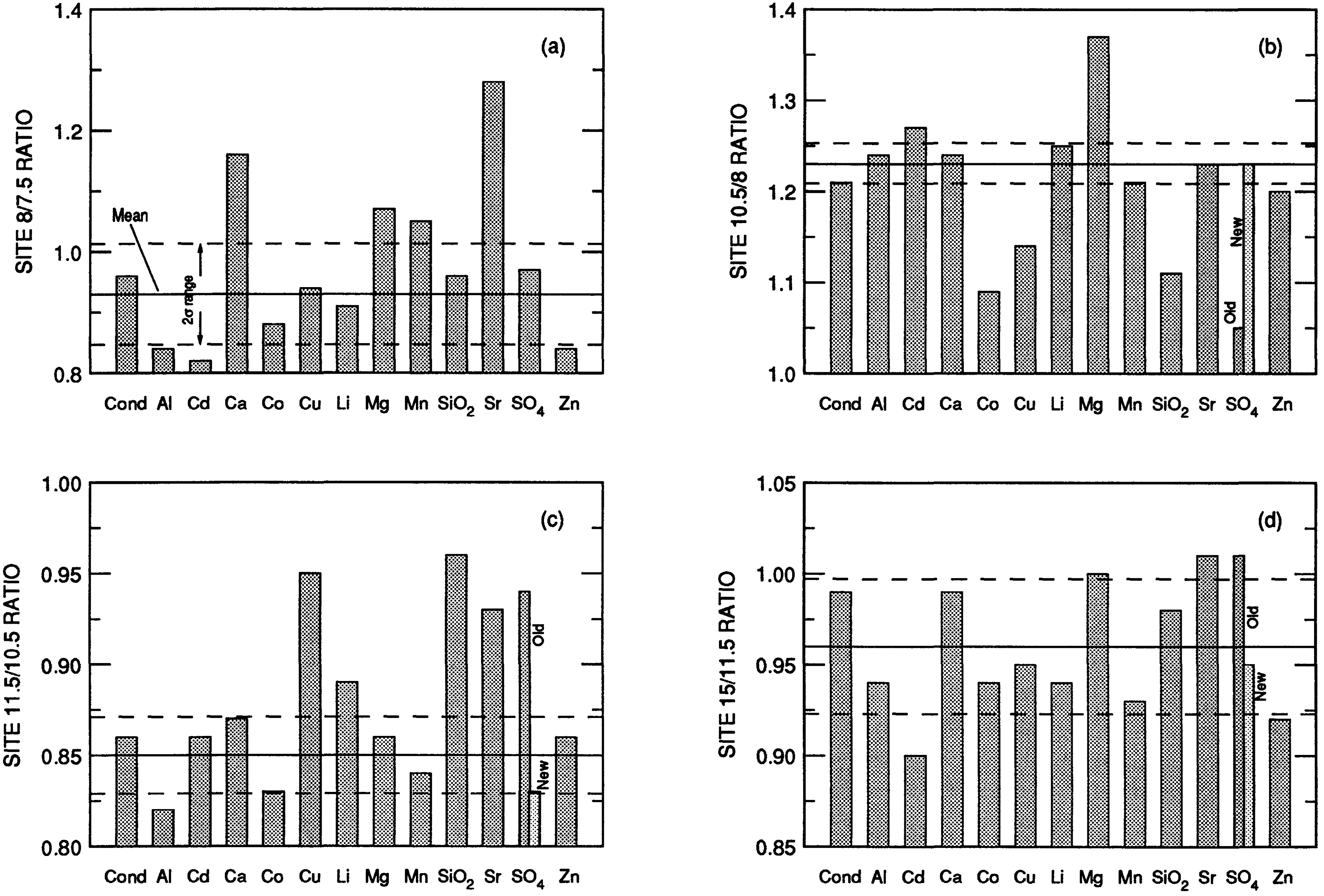

Figure 6. Plots of element ratios for sites 7.5 to 15 - October main stem.

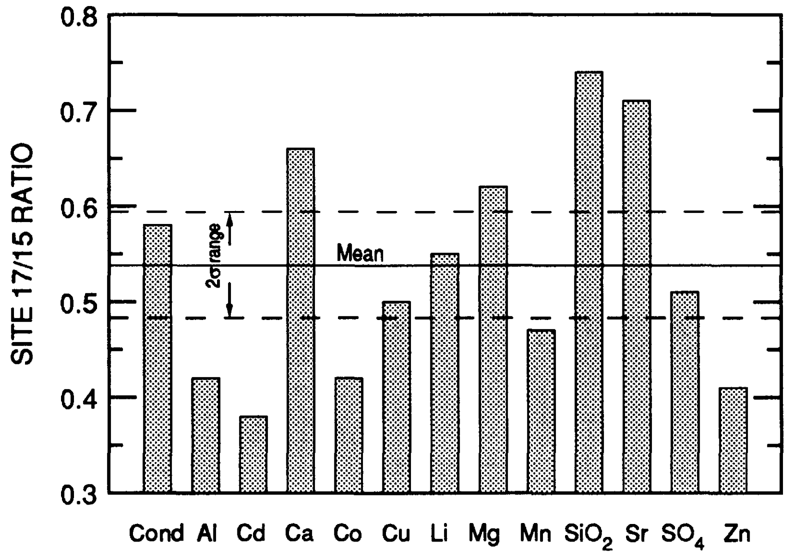

Figure 7. Plot of element ratios for sites 15 and 17 - October main stem.

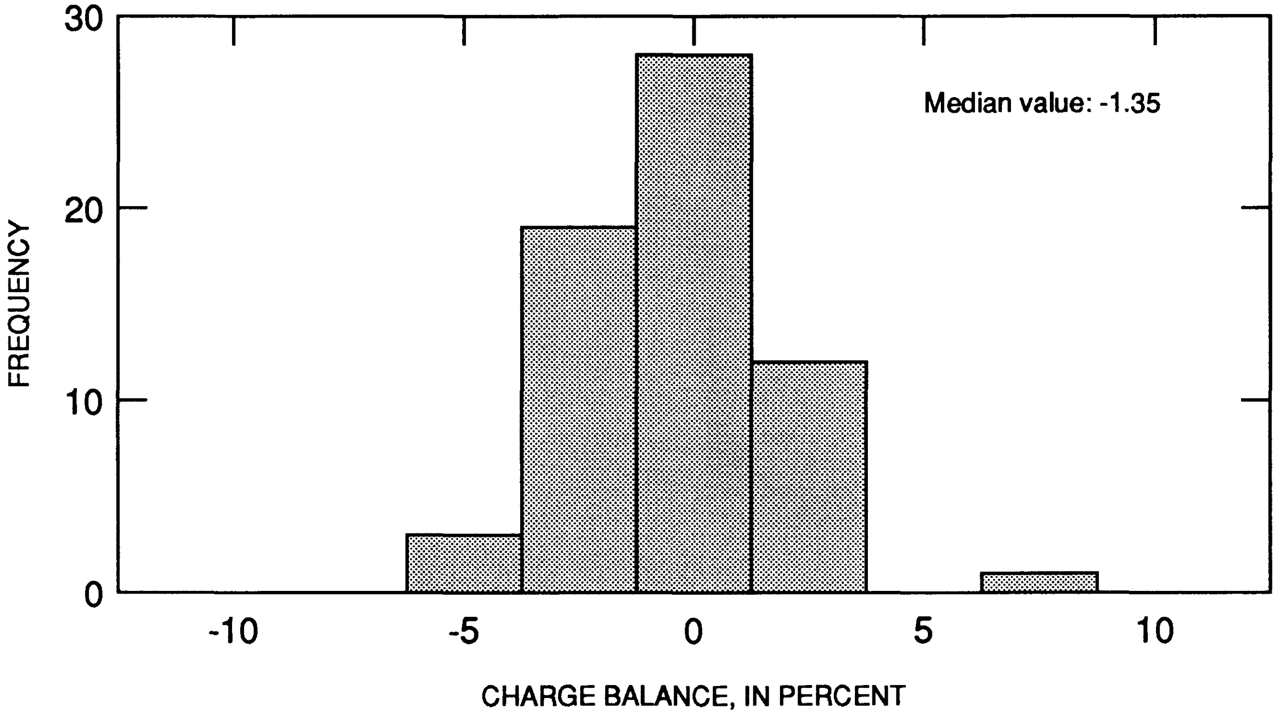

Figure 8a. Frequency plot of speciated charge balance (initial data).

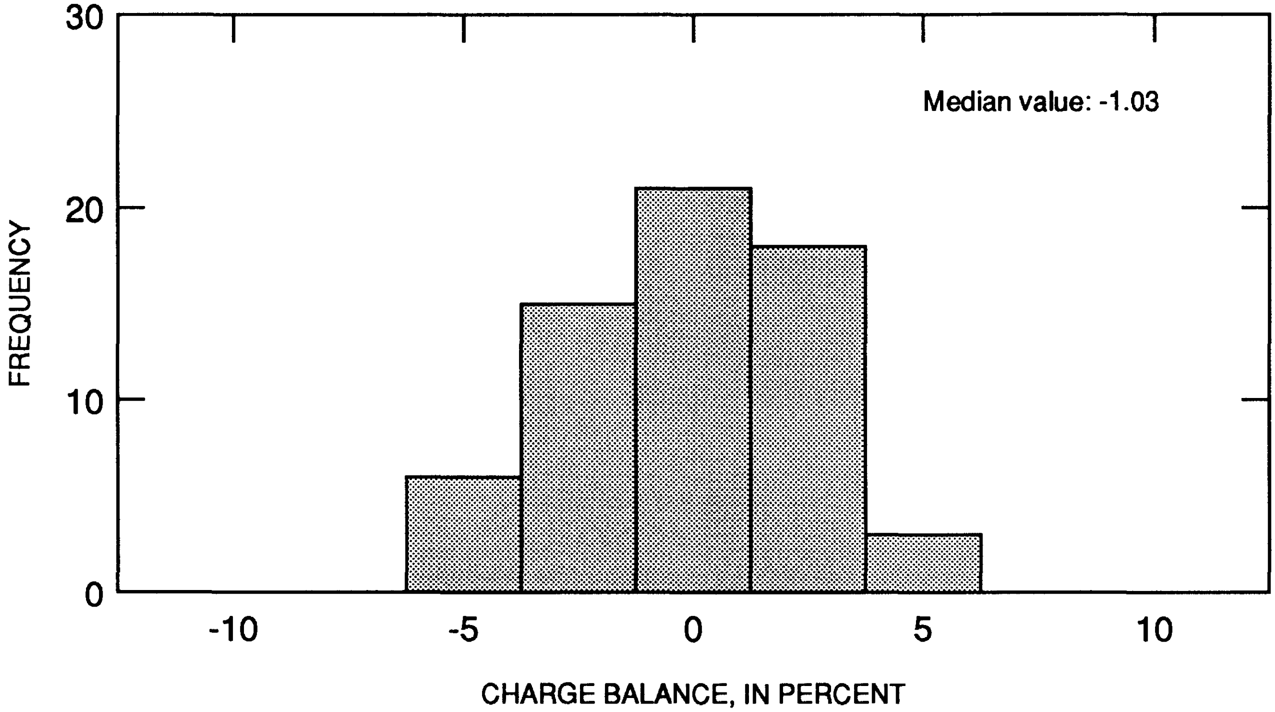

Figure 8b. Frequency plot of speciated charge balance (revised data).

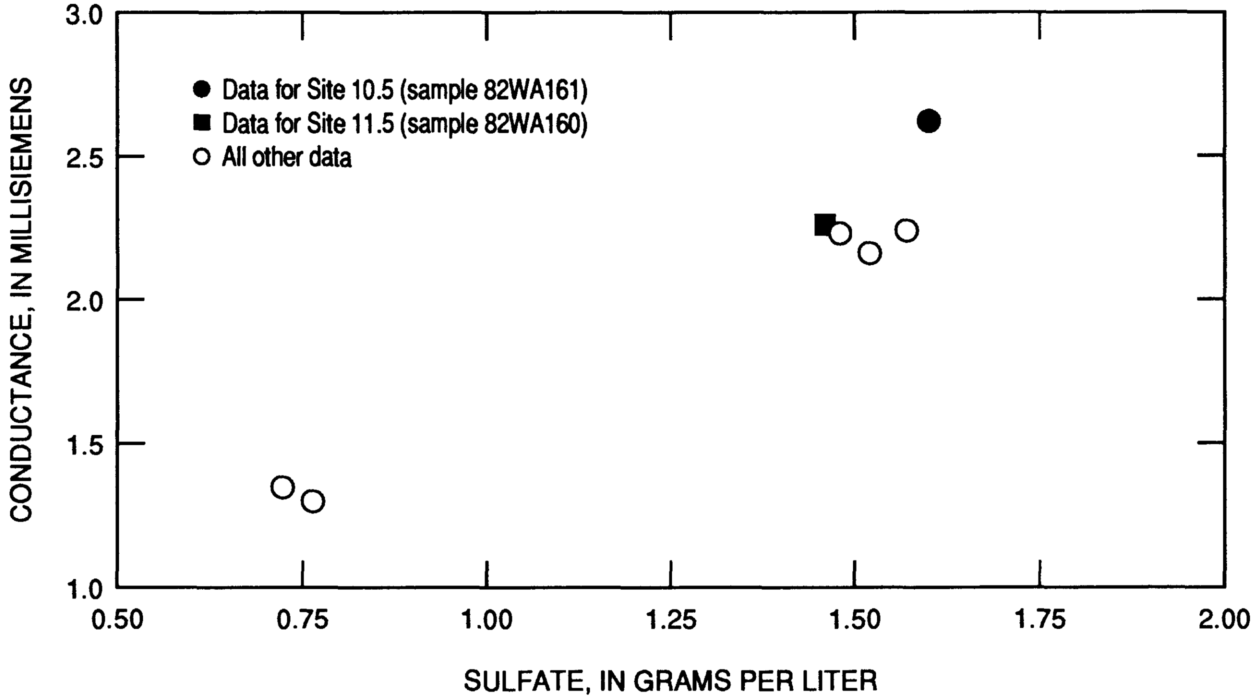

Figure 9a. Plot of conductance as compared with sulfate concentration-October main stem-before sulfate revision.

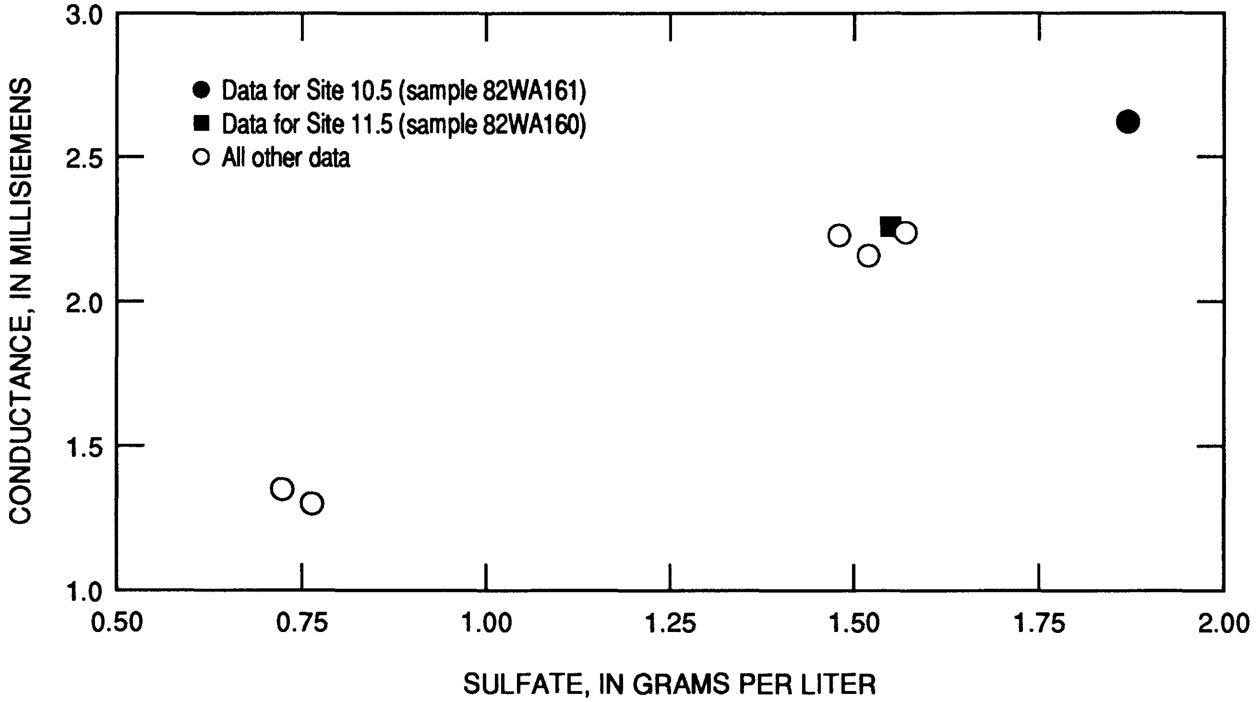

Figure 9b. Plot of conductance as compared with sulfate concentration-October main stem-after sulfate revision.

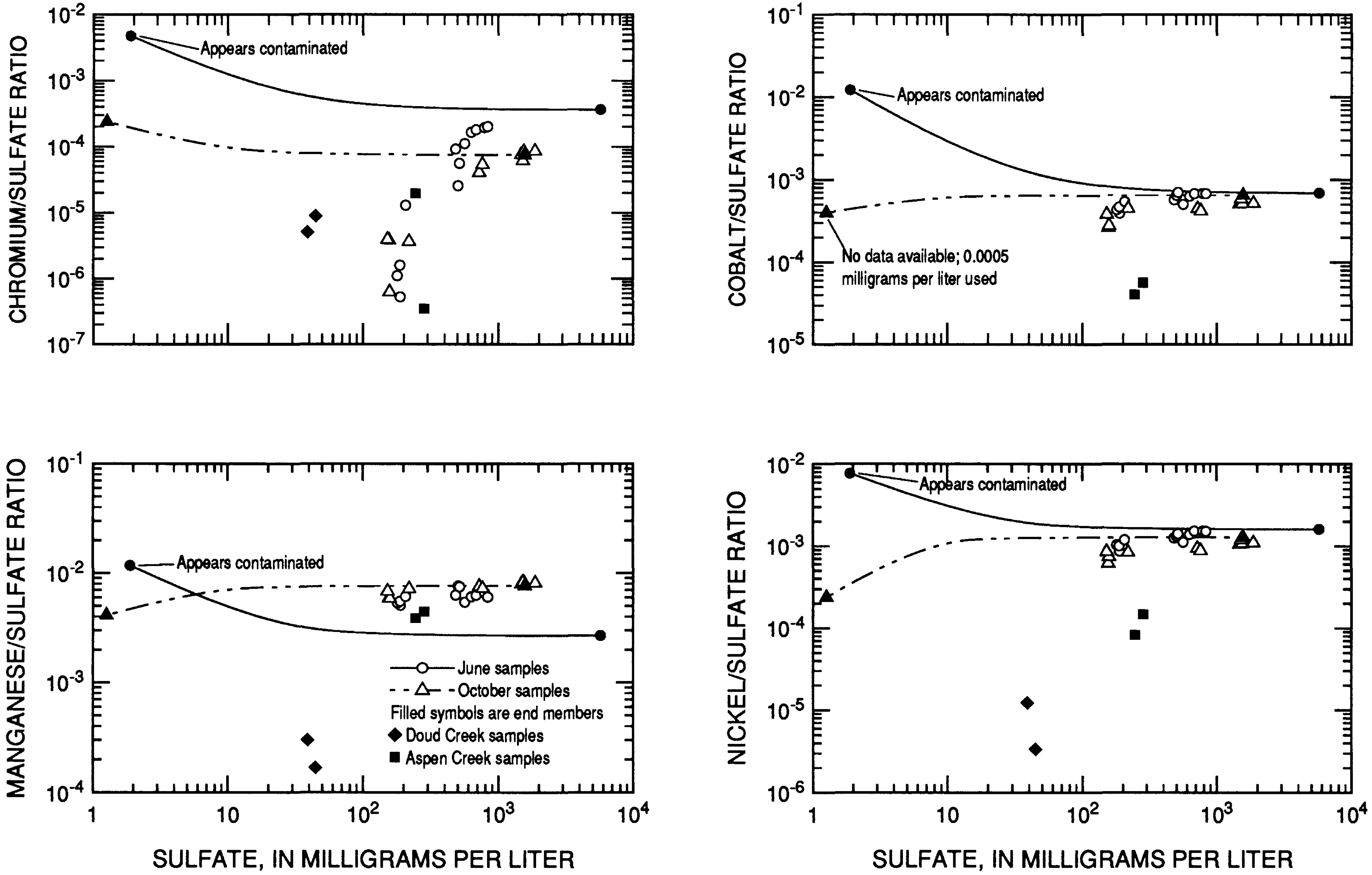

Figure 10. Plots of ideal mixing lines (solid for June, dashed for October samples) and element/sulfate ratios as compared with sulfate concentration for June and October main stem samples for chromium, cobalt, manganese and nickel.

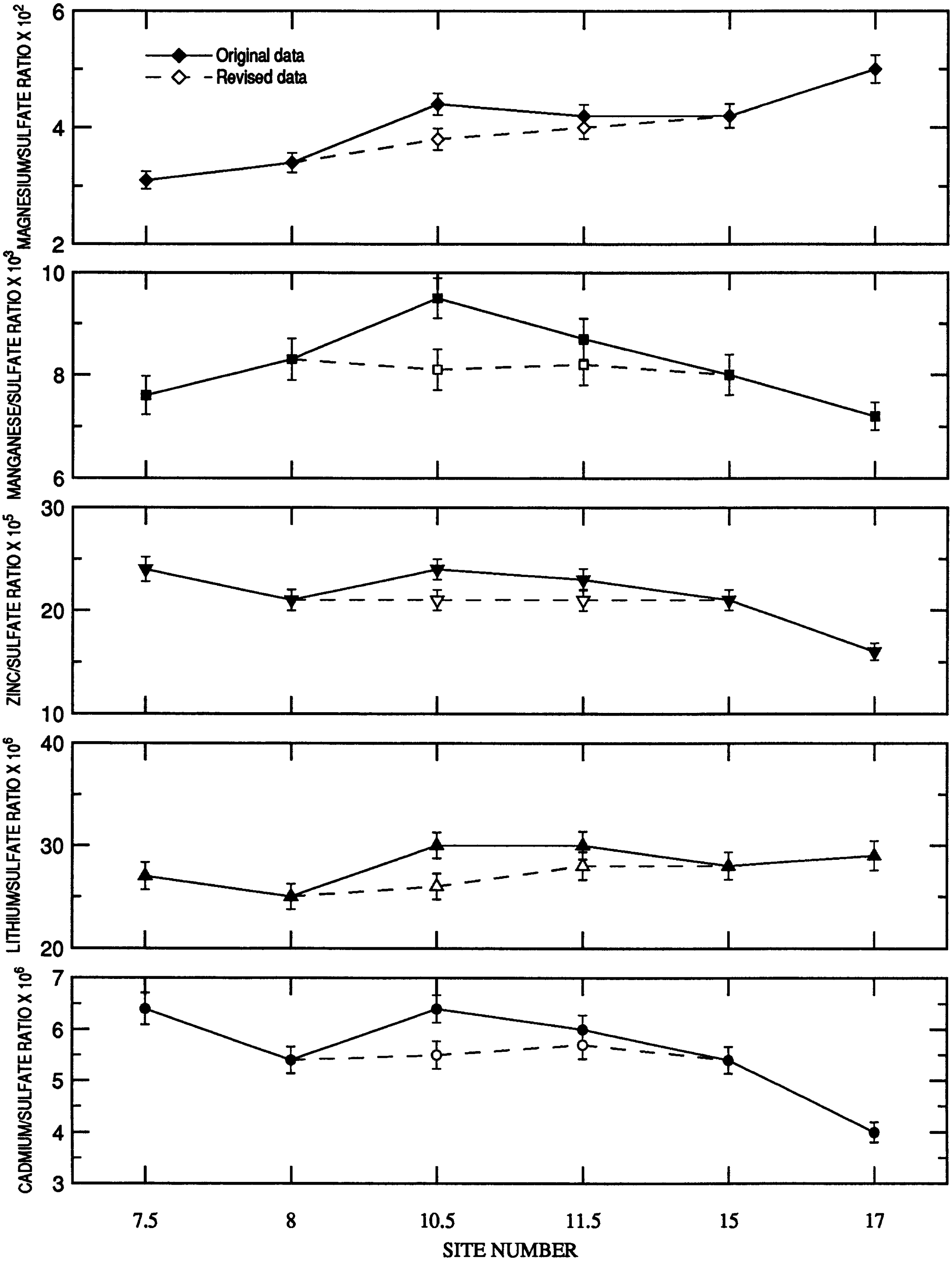

Figure 11. Metal/sulfate ratios for October sample sites 7.5 to 17 for magnesium, manganese, zinc, lithium and cadmium.

Table 5.--Element ratios for October, 1982 main stem sites 7.5 to 17

Measurement	Sites 8/7.5	 10.5/8	 11.5/10.5	 15/11.5	 17/15
Conductance	0.96	1.21	0.86	0.99	0.58
Al	0.84	1.24	0.82	0.94	0.42[1]
Cd	0.82	1.27	0.86	0.90	0.38[1]
Ca	1.16[1]	1.24	0.87	0.99	0.66[1]
Co	0.88	1.09[1]	0.83	0.94	0.42[1]
Cu	0.94	1.14[1]	0.95[1]	0.95	0.50
Li	0.91	1.25	0.89	0.94	0.55
Mg	1.07	1.37[1]	0.86	1.00	0.62
Mn	1.05	1.21	0.84	0.93	0.47
SiO_2	0.96	1.11[1]	0.96[1]	0.98	0.74[1]
Sr	1.28[1]	1.23	0.93[1]	1.01	0.71[1]
SO_4	0.97	1.05[1,2](1.23)[3]	0.94[1,2](0.83)[3]	1.01[2](0.95)[3]	0.51
Zn	0.84	1.20	0.86	0.92	0.41[1]
Average(s.d.)[4]	0.93(0.083)	1.23(0.022)	0.85(0.021)	0.96(0.037)	0.54(0.056)
2σ Range	0.85-1.01	1.21-1.25	0.83-0.88	0.92-1.00	0.48-0.59

[1] Outlier

[2] Ratio using initial SO_4 values

[3] Ratio using revised SO_4 values

[4] Calculated using conservative constituents only and excluding SO_4

Zinc

For samples containing Zn at a concentration of 50 μg/L or less, GFAAS values were adopted. For the remaining samples, the ICP, DCP cassette 1 and DCP cassette 2 values have been averaged. Several samples had values which were 15 percent or more higher than the other two estimates, and it was concluded that these samples were subject to random contamination at analysis time. The values were therefore ignored when computing the mean values. The maximum Δ% calculated using the above criteria was 15.

SUMMARY

Water samples collected from the Leviathan/Bryant Creek drainage basin during 1981-82 were analyzed shortly after collection for 37 major and trace constituents using direct-current-argon plasma emission spectrometry, flame, hydride generation and graphite furnace atomic absorption spectrometry, UV-visible colorimetry, and ion chromatography. Since the initial analyses, the same samples have been analyzed further by ICP and GFAAS for many metallic constituents. This additional analysis has resulted in many revisions of concentrations, the replacement of previously less-than-detection values for the trace metals, and multiple values for many major constituents, all of which provides a more complete and precise set of concentration estimates.

The constituents for which additional and revised concentration values have been substituted are Al, As, Ba, Cd, Ca, Cr, Co, Cu, K, Mg, Mn, Na, Ni, Pb, SiO_2, Sr, V and Zn. Concentrations remaining unchanged are those for B, Be, Bi, Cl, F, Fe^{2+}, Fe^{total}, Li, Mo, Sb, Se and Tl. Concentrations of Al, As, Ba, Be, B, Cd, Ca, Cr, Co, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, Pb, SiO_2, Sr, V, and Zn were determined by ICP spectrometry to obtain values that could be compared with their DCP counterparts. Elements determined by Zeeman GFAAS to extend the detection limit to levels below those obtainable by ICP or DCP spectrometry were: Al, As, Cd, Cr, Co, Cu, Mn, Ni, Pb, V and Zn. The alkali metals Na and K were determined by flame AAS on a selected subset of samples to obtain revised concentration estimates for those samples.

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