WATER QUALITY BEFORE AND AFTER RECLAMATION AT THE ABANDONED VALZINCO Zn-Pb MINE SITE, SPOTSYLVANIA COUNTY, VIRGINIA[1]

Robert R. Seal, II[2], Jane M. Hammarstrom, Allen Bishop, Nadine M. Piatak, Denise M. Levitan, Edward Epp, and Robert G. Sobeck, Jr.

Abstract: The Valzinco deposit was a massive sulfide ore body, dominated by pyrite, sphalerite, galena, and chalcopyrite. It was mined intermittently in the first half of the 20th century by underground methods. The host rocks were metamorphosed felsic volcanic rocks. Mine wastes were dominated by flotation tailings deposited in the stream channel, which were subsequently partially transported downstream by fluvial processes. Acid-base accounting results indicate that the tailings are net acid (net neutralizing potential = -268 to -138 kg $CaCO_3$/tonne) and leach significant quantities of Fe, Al, Zn, Pb, Cu, Cd, and SO_4^{2-}.

Pre-reclamation quarterly sampling of the stream below the site documented low-pH waters having elevated concentrations of Fe, Al, Zn, Pb, Cu, Cd, and SO_4^{2-}. Reclamation began in 2001 and major construction was completed in 2002. Reclamation included the removal and encapsulation on site of tailings, application of bactericide, installation of limestone drains, construction of wetlands, and revegetation. Results of recent sampling of the site (June 2007) indicate an increase in pH from 3.4 to 5.1, an increase in hardness of 37 %, and decreases in total dissolved solids (68 %), Fe (94 %), Al (98 %), Zn (77 %), Pb (99.5 %), Cu (97 %), Cd (94 %), and SO_4^{2-} (81 %) relative to mean pre-reclamation values. Even though significant reductions in dissolved metals have been achieved and positive biologic indicators of ecosystem health are present, the concentrations of Cu and Zn remain above hardness-based acute ecosystem toxicity criteria. The elevated concentrations, in part, appear to be a natural, pre-mining characteristic of the watershed. The elevated concentrations also highlight the sensitivity of calculated hardness-based toxicity criteria for soft waters. The hardness-based criteria do not account for the mitigating effect of dissolved organic carbon on metal toxicity in wetland areas such as at Valzinco.

Additional Key Words: zinc, lead, copper, aquatic ecosystem, volcanic-associated massive sulfide

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[1] Paper was presented at the 2008 National Meeting of the American Society of Mining and Reclamation, Richmond, VA, ***New Opportunities to Apply Our Science*** June 14-19, 2008. R.I. Barnhisel (Ed.) Published by ASMR, 3134 Montavesta Rd., Lexington, KY 40502

[2] Robert R. Seal, II, Research Geologist, U.S. Geological Survey, 954 National Center, Reston, VA 20192 (rseal@usgs.gov); Jane M. Hammarstrom, Nadine M. Piatak, and Denise M. Levitan U.S. Geological Survey, Reston, VA 20192; Allen Bishop, Edward Epp, and Robert G. Sobeck, Jr., Virginia Dept. of Mines, Minerals, and Energy, Charlottesville, VA 22903.

Proceedings America Society of Mining and Reclamation, 2008 pp 969-997
DOI: 10.21000/JASMR08010969
http://dx.doi.org/10.21000/JASMR08010969

Introduction

The legacy from 19th and 20th century mining in the 175 km (110 mile) long Virginia gold-pyrite belt extending from central to northern Virginia includes a number of abandoned base-metal bearing pyrite mines, and abandoned gold mines. The disposal of mine wastes from these historical mines was done with little regard to potential environmental impacts. Sulfide-rich mine wastes in temperate climates commonly impact surrounding ecosystems through contamination of surface and ground waters with acidic, metal laden drainage. The sites typically consist of waste rock, flotation tailings, or both, deposited on stream banks or in the stream channels themselves. Drainage discharge from mine workings is also common at some sites. Oxidation of pyrite or pyrrhotite in mine waste generates acid. This acid then attacks other sulfide and aluminosilicate minerals in the waste material releasing base metals, aluminum, and manganese. The resultant acid and leached metals can then impact surface and ground waters.

This paper focuses on post-reclamation water quality at the abandoned Valzinco mine in the central part of the Virginia gold-pyrite belt, northeast of the Mineral district. The study includes three separate sample collections. The first post-reclamation sampling was done a few months after the completion of remediation construction, the second approximately ten months later, and the last five years after the first post-reclamation sampling. Pre-reclamation characterization of the water quality and mine waste has been presented by Seal et al. (2002) and Hammarstrom et al. (2006), respectively. Seal et al. (2008) described processes controlling the generation of acid drainage and the associated mobility of metals. Sobeck et al. (this volume) presented design and construction details of the reclamation project, and biologic indicators of its effectiveness.

Site Description

Hydrologic and climatic setting

The study site (38°10.68'N; 77°47.90'W) is in the headwaters of Knight's Branch in the Chesapeake Bay watershed. The catchment of the study area upstream of site VLZN-3 is small (2.45 km^2 [0.94 miles^2], Fig. 1). The study period spanned from May 1998 to June 2007. Measured discharges at site VLZN-3 ranged widely from 4.8 to 113 L/s (Seal et al., 2002). On an annual basis, discharges tend to be highest in the late winter or early spring, and lowest in the late summer or early fall. The area receives an average of 109 cm (42.9 in) of precipitation per year. Mean monthly temperatures range from a low of 1 °C (34 °F) in January to a high of 26 °C (79 °F) in July.

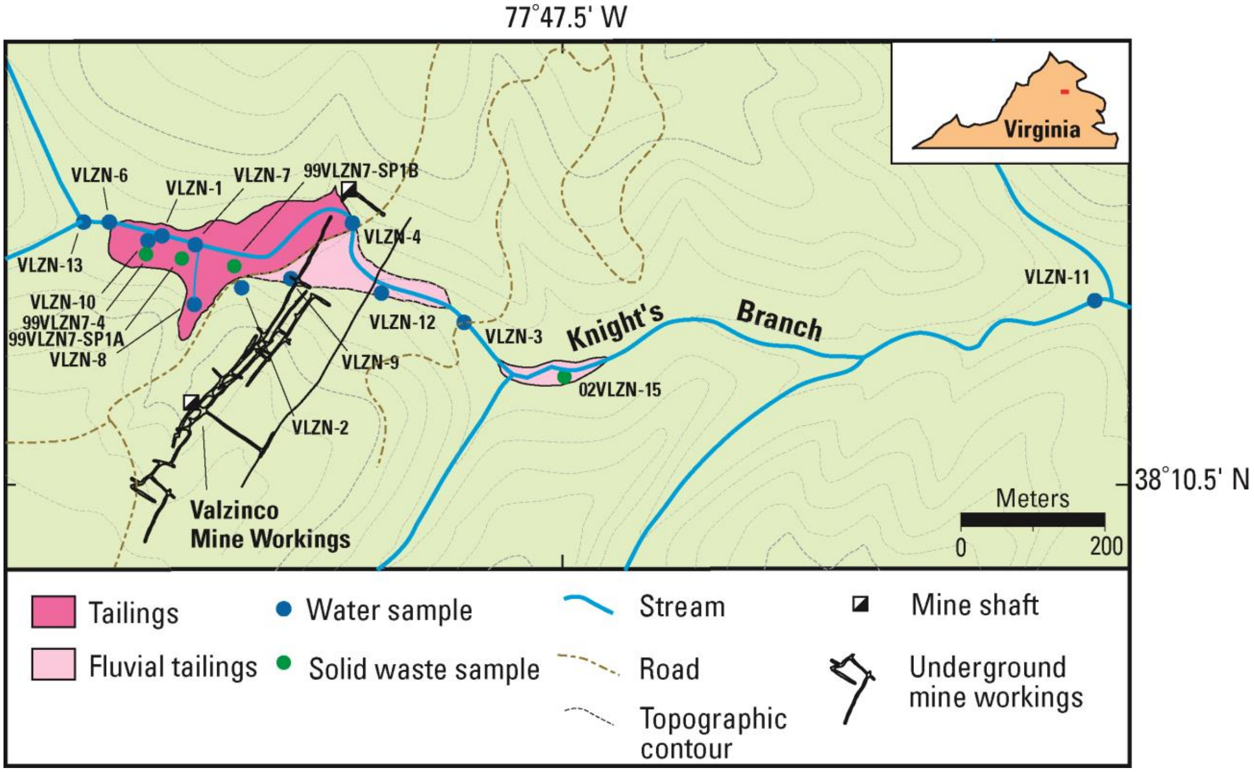

Figure 1. Pre-reclamation features of the Valzinco abandoned mine site showing location of sample sites. Contour interval is 20 ft (6.1 m). Modified from Seal et al. (2008).

Geologic setting

The abandoned Valzinco mine is in the center of the Virginia gold-pyrite belt, northeast of the Mineral district. The deposit is near a contact between underlying metamorphosed felsic volcanic rocks of the Chopawamsic Formation (460 Ma), which are regionally overlain by slates and phyllites of the Quantico Formation (Pavlides et al., 1982). The deposit is a Kuroko-type volcanic-associated massive sulfide deposit and comprises two subparallel massive sulfide lenses separated by 90 m (295 ft) of rock, striking N40E and dipping 60 to 70 °SE (Grosh, 1949). The host rocks are dominated by quartz, muscovite, chlorite, and feldspar. The ore consisted of pyrite, sphalerite, and galena, with lesser amounts of chalcopyrite and pyrrhotite.

The total tonnage of the deposit was less than 0.25 Mt with Zn grades ranging between 7.8 and 12.5 % and Pb grades between 3.7 and 5.0 % with trace amounts of Cu, Au, and Ag (Grosh, 1949; Pavlides et al., 1982). The deposit was mined intermittently from 1909 to 1927, and again from 1942 to 1945 by underground methods (Grosh, 1949; Luttrell, 1966). The mine workings reached a depth of 110 m (361 ft) and had a length of 575 m (1886 ft) (Fig. 1). The ore zone had a maximum thickness of 3 m (9.8 ft).

Mine-waste characteristics

Mine wastes include flotation tailings and waste rock although waste rock is minor due to the access to the deposit through vertical shafts. During mining, tailings were deposited in the stream channel. A significant amount of tailings has been transported fluvially downstream and redeposited (Fig. 1). The total area covered by in-situ and fluvial tailings prior to reclamation was around 40,000 m^2 (430,500 ft^2) with a maximum thickness less than 3 m (9.8 ft). Fluvial tailings were generally < 1 m (3.3 ft) thick. In general, unoxidized tailings were encountered at depths between 20 and 30 cm (7.9 to 11.8 in) (Hammarstrom et al., 2006). The tailings were dominated by quartz, muscovite, chlorite, and pyrite, and lesser amounts of sphalerite, galena, chalcopyrite, magnetite, and albite. Jarosite, gypsum, and secondary efflorescent salts were common in the oxidized upper zones of the tailings material (Hammarstrom et al., 2006; Seal et al., 2008).

The bulk geochemistry of the tailings reflects their mineralogy (Hammarstrom et al., 2006; Seal et al., 2008). All samples of tailings have concentrations of Fe (8.0 to 12.0 wt. %) and Pb (1,910 to 6,200 mg/kg) in excess of preliminary remediation goals (PRG) for residential soils (Fe PRG: 2.3 wt. %; Pb PRG: 400 mg/kg) and the majority of samples had As concentrations (11 to 46 mg/kg) in excess of the PRG (22 mg/kg) (USEPA, 2004). All other elements were below the corresponding PRG. Paste pH values for the tailings range from 2.2 to 4.5. Net neutralization potentials range from -251 to -138 kg $CaCO_3$/tonne. Thus, the tailings have high short- and long-term acid-generating potential.

Leach tests designed to mimic the synthetic precipitation leaching procedure (SPLP – EPA Method 1312; USEPA, 1994) of tailing samples produced leachates with pH values in the range of 2.7 to 4.5. The leachates also had dissolved concentrations of Al, Cd, Cu, Pb, and Zn in excess of aquatic chronic toxicity criteria (Seal et al., 2008). All other elements were below the aquatic chronic criteria.

Reclamation

The mine site was reclaimed beginning in spring 2001 and ending in 2002, with additional maintenance in the late summer and fall of 2007. Details of design and construction are presented by Sobeck et al. (this volume). The project included: (1) the removal of tailings from the stream channel, amendment with a bactericide, and isolation in a covered pit, (2) the installation of several limestone channels, and (3) the construction of a series of ponds and wetlands (Fig. 2). The initial reclamation plan did not include removal of the fluvial tailings between sample sites VLZN-3 and VLZN-11 (Fig. 1). Thus, they remained a source of contamination for the lower reach of Knight's Branch during the period of the post reclamation water-quality sampling.

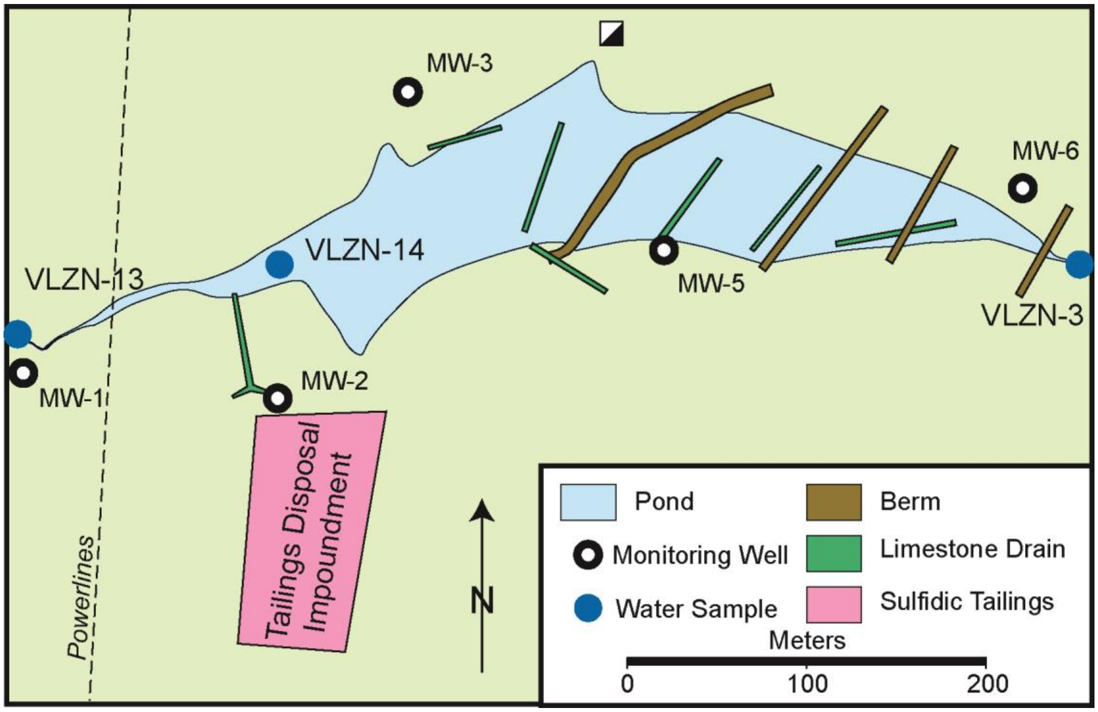

Figure 2. Post reclamation features of the Valzinco abandoned mine site showing location of sample sites. Sample sites VLZN-3 and VLZN-13 can be used to orient this map relative to Fig. 1. Modified from Sobeck et al. (this volume).

Sampling and Analytical Methods

Sampling

Surface waters from Knight's Branch were sampled on a quarterly basis at one site upstream of the mine site (VLZN-13) and two sites downstream of the mine site (VLZN-3 and VLZN-11) prior to and after remediation to evaluate the effectiveness of the reclamation project (Figs. 1 and 2). In addition, the pond constructed during reclamation was sampled once (VLZN-14). The pre-reclamation sampling was conducted between May 1998 and April 2001. Post reclamation sampling was done less than a year after the completion of construction (June 2002), in April 2003, and finally in June 2007. Analyses of source waters around the site and pre-reclamation quarterly samples from Knight's Branch were presented and discussed by Seal et al. (2002; 2008).

Ground waters from shallow wells installed during reclamation were sampled once (June 2007). Four wells were sampled; a fifth well did not recharge during pumping. Well volumes were purged three times and water levels were allowed to return to starting elevations prior to sampling using a peristaltic pump and low-flow methods.

Analytical Methods

Geochemical analyses included the measurement of unstable parameters on site and laboratory analysis of major, minor, and trace constituents following the procedures described by Seal et al. (2002). Unstable parameters included water temperature, pH, specific conductance, and dissolved concentrations of O_2, Fe^{2+}, and total Fe. Sample splits include unfiltered splits for cations, and filtered splits (0.45 μm pore size) for cations, anions, and alkalinity. Cations were analyzed by ICP-AES and ICP-MS. Anions were analyzed by ion chromatography (IC). Analyses followed procedures described by Ficklin et al. (1999) and Crock et al. (1999).

Water Quality Results

Before Reclamation

Water-quality data in the vicinity of the Valzinco mine before reclamation has been presented and discussed by Seal et al. (2002) and Seal et al. (2008). Prior to reclamation, the pH of Knight's Branch upstream of the site ranged between 4.4 and 6.1 (Figs. 3 and 4). Total dissolved solids were low (< 35 mg/L). The water was soft; dissolved hardness was less than 11 mg/L $CaCO_3$ equivalent. Dissolved concentrations of Fe and Al locally exceeded USEPA chronic aquatic toxicity criteria (Fig. 3c, d). Similarly, dissolved concentrations of Cu, Pb, and Zn locally exceeded both USEPA acute and chronic aquatic toxicity criteria (Fig. 4). The values in excess of water-quality criteria probably reflect the elevated natural concentrations of these elements in the host rocks of the deposit prior to mining. In addition, they also reflect the low hardness values of the waters relative to hardness-based water-quality criteria.

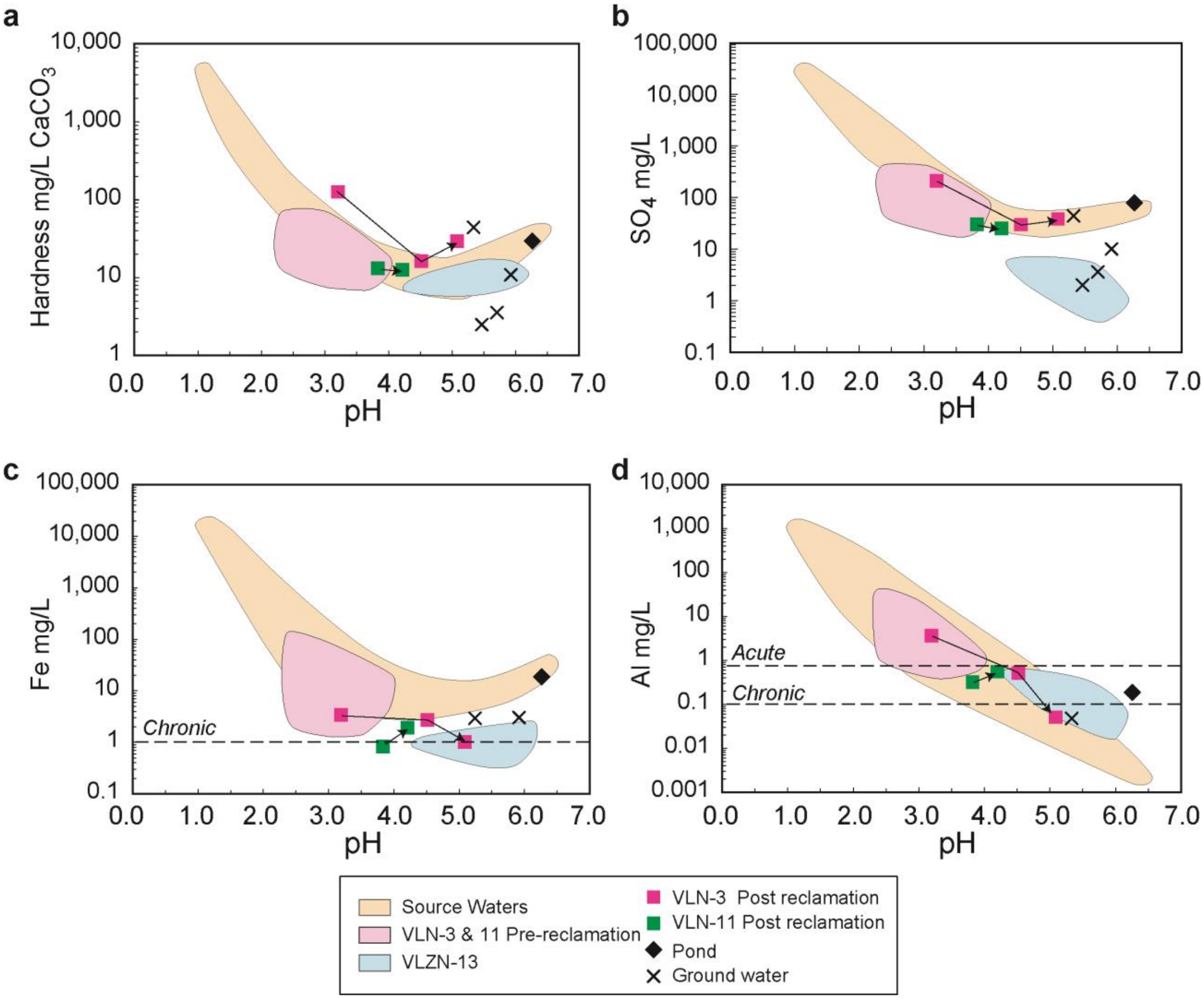

Figure 3. Variation of the concentrations of selected major element solutes with pH. Pre-reclamation fields are from Seal et al. (2008). The fields encompass the range of values for multiple sample sites for source waters and multiple sampling events for sites VLZN-3, VLZN-11, and VLZN-13. Arrows connect oldest to most recent sampling periods for VLZN-3 (June 2002, April 2003 and June 2007) and VLZN-11 (June 2002 and April 2003). Field for VLZN-13 includes both pre- and post reclamation data. Dashed lines represent USEPA water-quality standards.

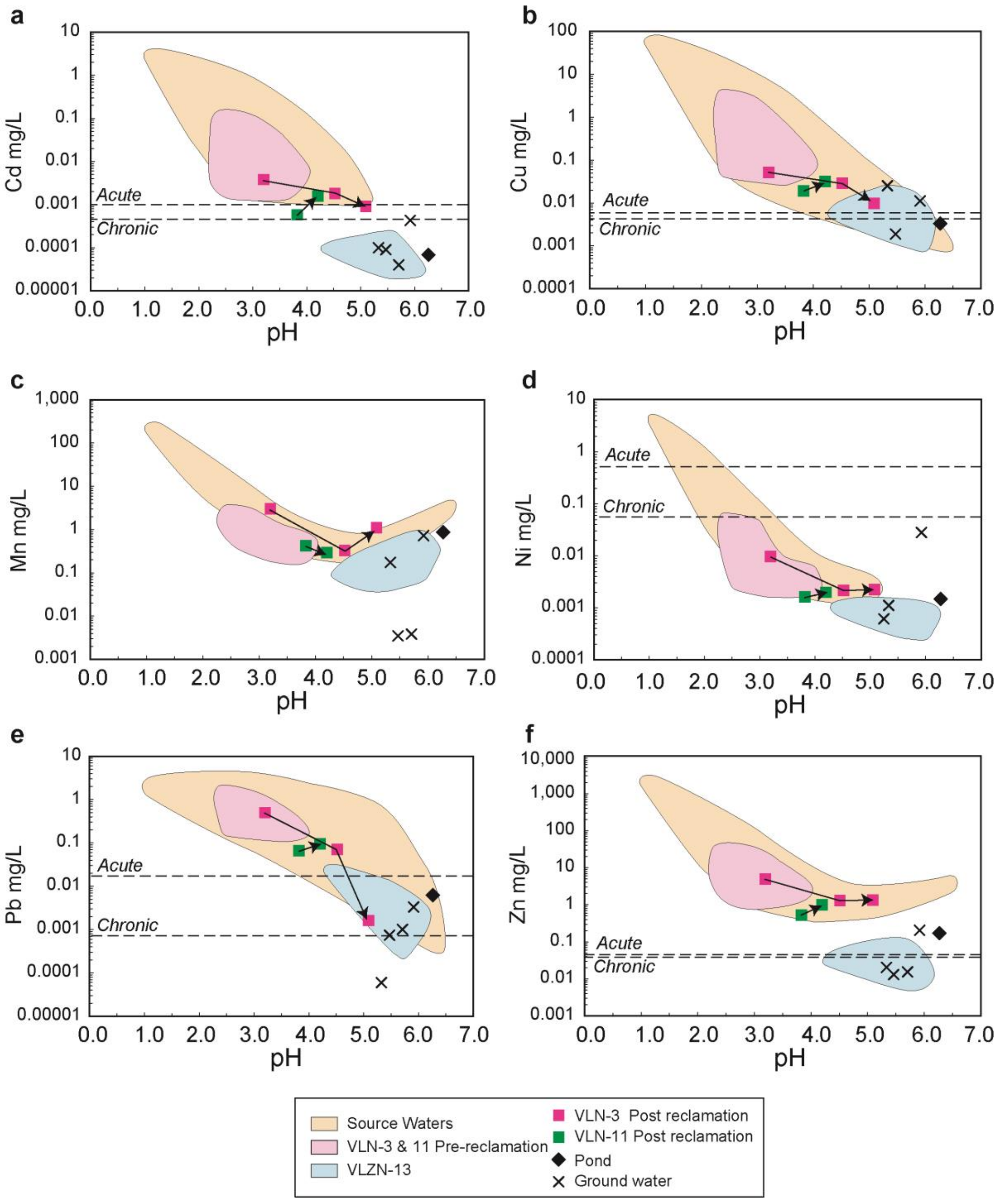

Figure 4. Variation of the concentrations of selected minor element solutes with pH. Pre-reclamation fields are from Seal et al. (2008). The fields encompass the range of values for multiple sample sites for source waters and multiple sampling events for sites VLZN-3, VLZN-11, and VLZN-13. Arrows connect oldest to most recent sampling periods for VLZN-3 (June 2002, April 2003 and June 2007) and VLZN-11 (June 2002 and April 2003). Field for VLZN-13 includes both pre- and post reclamation data. Dashed lines represent USEPA hardness-based water-quality standards assuming a hardness of 30 mg/L $CaCO_3$ equivalent.

Seeps and other source waters had pH values between 1.0 and 6.5 with most between 2.5 to 5.0. Knight's Branch downstream of the site at VLZN-3 (2.6 to 4.0) had a more restricted range. Total dissolved solid values in sources waters ranged between 47.5 and 16,800 mg/L; those at VLZN-3 ranged from 57.5 to 796 mg/L. Source waters and Knight's Branch at VLZN-3 had elevated concentrations of sulfate, Fe, Al, Mn, Cd, Cu, Ni, Pb, and Zn (Figs 3 and 4; Table 1). Knight's Branch at VLZN-3 had dissolved concentrations of Fe, Al, Cd, Cu, Pb, and Zn in excess of USEPA chronic and acute aquatic toxicity criteria (Table 1). Dissolved Ni was below chronic toxicity criteria.

Table 1. Pre- and post reclamation water quality for filtered (0.45 μm) samples at site VLZN-3 compared to aquatic ecosystem toxicity criteria for dissolved constituents.

Parameter	Units	Pre-Reclamation n = 8				Post Reclamation		Acute Toxicity	Chronic Toxicity
		Low	High	Mean	Standard Deviation	June 2007	Percent of Pre-Reclamation Mean		
pH	S.U.	2.6	4.0	3.4	0.5	5.1	151		
Hardness	mg/L $CaCO_3$	10.0	62.0	21.2	14.5	29.0	137		
Sulfate	mg/L	27.0	1,400	204	421	38.0	19		
Fe	mg/L	5.0	69.7	17.7	18.9	1.01	6		1.0
Al	mg/L	0.6	19.5	3.1	5.8	0.051	2	0.75	0.087
Mn	μg/L	410	2100	779	529	1,120	144		
Cd*	μg/L	3.2	88	15.2	25.6	0.91	6	1.0	0.4
Cu*	μg/L	49.0	2,200	311.6	664.6	9.7	3	5.7	4.2
Ni*	μg/L	2.0	37.0	8.5	10.2	2.3	27	512	57
Pb*	μg/L	170	1,300	349	340	1.6	0.5	17.6	0.7
Zn*	μg/L	1,900	27,000	5,750	7,548	1,320	23	42.2	3.2

* USEPA acute and chronic toxicity limits are based on a hardness of 30 mg/L $CaCO_3$ equivalent.

After Reclamation

Over the course of a six year period since the completion of major remediation construction at Valzinco, water quality at VLZN-3 has shown steady improvement (Figs. 3 and 4). The pH has increased to a value of 5.1 in June 2007, dissolved hardness has increased to 29 mg/L $CaCO_3$ equivalent relative to a pre-reclamation average of 21.2 mg/L, and dissolved concentrations of Fe, Al, Cd, Cu, Ni, Pb, and Zn have all decreased substantially to anywhere from 23 % (Zn) to 0.5 % (Pb) of the pre-reclamation average concentrations (Figs. 3 and 4; Table 1). Manganese is the only significant element that increased appreciably from 0.78 to 1.12 mg/L after reclamation.

In contrast, downstream at site VLZN-11 dissolved concentrations of many constituents, such as Fe, Al, Cd, Cu, Ni, Pb, and Zn, showed increases during the period since reclamation. Likewise, the pH values in Knight's Branch at VLZN-11 only reach a maximum of 4.2 compared to 5.1 at VLZN-3. The decreased water quality at VLZN-11 suggests that the fluvial tailings between VLZN-3 and VLZN-11 that were left in place continue to be a source of contamination for the stream (Fig. 1).

Ground-water data prior to reclamation are lacking. Nevertheless, four shallow monitoring wells were sampled after reclamation (Fig. 2). Total (unfiltered) concentrations were below USEPA drinking waters guidelines, except locally for Al, Fe, Mn, and Pb (Table 2). These guidelines include maximum contaminant limits for the protection of human health, secondary maximum contaminant limits to address aesthetic properties of drinking water (color, odor, turbidity), and treatment-technique action levels for elements such as Cu and Pb, which are found in domestic plumbing systems. Concentrations in ground waters increase with distance downstream from the headwaters of Knight's Branch, which suggests that infiltration of surface water may be the dominant source of these constituents in shallow ground water in the vicinity of the mine.

Table 2. Post reclamation ground-water quality (unfiltered) at Valzinco compared to USEPA drinking water standards.

Parameter	Units	MW-1	MW-2	MW-3	MW-6	Drinking Water Standard
Sulfate	mg/L	3.6	2.0	44	10	250*
Al	µg/L	76	20	119	252	50 – 200*
As	µg/L	<1	<1	<1	<1	10†
Cd	µg/L	0.05	0.08	0.1	0.45	5†
Cu	µg/L	0.73	2.1	26.7	24.4	1,300**
Fe	µg/L	105	<20	149	4150	300*
Mn	µg/L	4.7	3.8	175	756	50*
Ni	µg/L	<0.4	<0.4	1.3	30.2	100†
Pb	µg/L	2.8	0.84	0.2	36.4	15**
Zn	µg/L	18.5	13.8	22.3	222	5,000*

† Maximum contaminant level.

*Secondary maximum contaminant level.

**Treatment technique action level.

Discussion and Conclusions

The water data presented in this study demonstrate that the reclamation project at Valzinco has substantially improved water quality at the site. This conclusion is supported by successful revegetation of the site, both planted and volunteered, and by the return of terrestrial and aquatic animals to the site (Sobeck et al., this volume). The removal of tailings from the stream channel, their amendment with bactericide, and their isolation and encapsulation appear to have eliminated the impact of tailings on surface waters in Knight's Branch. The constructed pond and wetlands also limit the availability of atmospheric oxygen to oxidize any residual sulfidic material left in the vicinity of the stream channel after reclamation. The installation of limestone drains at the site has increased the hardness of Knight's Branch by approximately 40 % relative to average pre-reclamation concentrations, and further serves to protect aquatic organisms.

Many dissolved constituents, including Fe, Cd, Cu, Pb, and Zn remain above chronic or acute aquatic toxicity criteria despite substantial reductions in most contaminants due to reclamation. The fact that upstream, unimpacted waters have elevated concentrations of Fe, Al, Cu, Pb, and Zn suggests that the concentrations may, in part, be a natural background geochemical feature of this watershed prior to mining. Of these elements, Cd and Zn are the only ones with post reclamation concentrations above upstream concentrations. The concentration of these elements above chronic and acute aquatic toxicity criteria despite documented biologic recovery at the site (Sobeck et al., this volume) underscores the complexity in natural settings in which metal concentrations, major element water chemistry, including hardness, dissolved organic carbon concentrations, and pH all contribute to the toxicity of metals (Paquin et al., 2002). Thus, criteria solely based on water hardness may not accurately describe metal toxicity in watersheds such as the one at Valzinco where hardness is low, and dissolved organic matter contributed from upstream and constructed wetlands is significant.

Acknowledgements

This work received funding from the Mineral Resources Program of the U.S. Geological Survey and from the Environmental Protection Agency's Section 319 Nonpoint Source Implementation Grant Program at the Virginia Department of Conservation and Recreation

(DCR) through grant number 319-1999-2-PT, from the Virginia Water Quality Improvement Fund provided by the DCR through grant number 91934-WQIA-2001-14 and from Virginia's Orphaned Land Program. The manuscript benefited from reviews by Richard Barnhisel, P. Behum, I-Ming Chou, Larry Gough, and Rob Liddle.

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Appendix 1. Field and laboratory data for post reclamation surface water samples at Valzinco.

Field No.	**Units**	**Method**	**VLZN 3-10**	**VLZN 3-11**	**VLZN 3-12**	**VLZN 11-10**	**VLZN 11-11**
Latitude			38.1773	38.1773	38.1773	38°10.587	38°10.587
Longitude			-77.7928	-77.7928	-77.7928	77°46.969	77°46.969
Date			6/5/2002	4/14/2003	6/6/2007	6/5/2002	4/14/2003
T water	C		24.1	18.7	26.1	25.0	18.9
Flow	L/s		5.7	70.0	20.7	8.7	130.375
pH			3.2	4.5	5.1	3.8	4.2
Spec. Con.	µS/cm		612	98.8	100.7	120.6	84.1
D.O.	mg/L		5	8	8	6	8
ORP	mV		492.2	146.1	456.4	480.1	185.5
Fe^{2+}/Fe_{tot}			0.484	0.904		0.835	0.923
Alkalinity	mg/L			0.0	2.4		0.0
Hardness	mg/L		124.5	16.1	29.0	13.2	12.5
Filtered (0.45 µm)							
Cl	mg/L	IC	4	4	2.6	1.6	3
SO_4	mg/L	IC	210	30	38	30	25
F	mg/L	IC			0.2		
NO_3	mg/L	IC			<.08		
Ag	µg/L	ICP-MS	<0.01	<0.01	<1	<0.01	<0.01
Al	µg/L	ICP-MS	2900	380	78.6	280	400
As	µg/L	ICP-MS	<0.2	<1	<1	0.2	<1
Ba	µg/L	ICP-MS	61	39	20.7	36	40
Be	µg/L	ICP-MS	0.42	0.1	0.05	0.11	0.17
Bi	ug/L	ICP-MS	< 0.01	< 0.04	< 0.2	< 0.01	< 0.04
Ca	mg/L	ICP-MS	28	3.2	12.4	3	2.2
Cd	µg/L	ICP-MS	3.8	1.8	0.91	0.57	1.6
Ce	µg/L	ICP-MS	59	10	2.6	4.7	8.3
Co	µg/L	ICP-MS	44	7.1	11.9	6.7	6.9
Cr	µg/L	ICP-MS	<1	<1	<1	<1	<1
Cs	µg/L	ICP-MS	0.1	< 0.01	< 0.02	0.015	< 0.01
Cu	µg/L	ICP-MS	51	29	9.7	19	31
Dy	µg/L	ICP-MS	1.7	0.28	0.063	0.18	0.26
Er	µg/L	ICP-MS	0.7	0.13	0.04	0.081	0.13
Eu	µg/L	ICP-MS	0.56	0.092	0.03	0.052	0.089
Fe	µg/L	ICP-MS	2400	2200	1550	740	1500
Ga	µg/L	ICP-MS	< 0.02	< 0.02	0.07	< 0.02	< 0.02
Gd	µg/L	ICP-MS	2.5	0.51	0.14	0.29	0.44
Ge	µg/L	ICP-MS	< 0.02	< 0.02	< 0.05	< 0.02	< 0.02
Ho	µg/L	ICP-MS	0.29	0.045	0.01	0.032	0.049
K	mg/L	ICP-MS	6200	1500	3.03	2300	1500
La	µg/L	ICP-MS	22	3.2	0.95	2.1	3
Li	µg/L	ICP-MS	2.1	0.3	3	0.4	0.3
Lu	µg/L	ICP-MS			< 0.1		

Appendix 1 (cont.). Field and laboratory data for post reclamation surface water samples at Valzinco.

Field No.	Units	Method	VLZN 3-10	VLZN 3-11	VLZN 3-12	VLZN 11-10	VLZN 11-11
Mg	mg/L	ICP-MS	7.4	1.3	4.58	1.3	1.1
Mn	µg/L	ICP-MS	3000	330	1120	420	290
Mo	µg/L	ICP-MS	< 0.02	< 0.02	< 2	< 0.02	< 0.02
Na	mg/L	ICP-MS	2.7	2.4	4.55	1.7	1.8
Nb	µg/L	ICP-MS			< 0.2		
Nd	µg/L	ICP-MS	18	3.2	0.82	1.6	2.8
Ni	µg/L	ICP-MS	10	2.2	2.3	1.6	2
P	mg/L	ICP-MS	< 20	< 1	< 0.01	< 4	< 1
Pb	µg/L	ICP-MS	500	70	1.6	66	93
Pr	µg/L	ICP-MS	5	0.85	0.21	0.44	0.76
Rb	µg/L	ICP-MS	26	4.3	9.22	6.5	3.8
Sb	µg/L	ICP-MS	<0.02	0.1	<0.3	0.051	0.06
Sc	µg/L	ICP-MS			2.4		
Se	µg/L	ICP-MS	< 0.2	< 0.4	< 1	< 0.2	< 0.4
SiO_2	mg/L	ICP-MS	14	5.8	18.4	11	7.1
Sm	µg/L	ICP-MS	3.2	0.61	0.15	0.31	0.55
SO_4	mg/L	ICP-MS	190	24	54	35	19
Sr	µg/L	ICP-MS	160	19	42.2	14	14
Ta	µg/L	ICP-MS	0.33	0.052	< 0.02	0.031	0.053
Tb	µg/L	ICP-MS			0.02		
Th	µg/L	ICP-MS	0.12	0.03	< 0.2	< 0.03	0.02
Tl	µg/L	ICP-MS	0.18	<0.05	<0.1	<0.05	<0.05
Tm	µg/L	ICP-MS	0.098	0.016	< 0.005	0.0098	0.016
U	µg/L	ICP-MS	0.45	0.06	< 0.1	0.038	0.05
V	µg/L	ICP-MS	<0.1	<0.1	<0.5	<0.1	<0.1
W	µg/L	ICP-MS	< 0.02	0.03	< 0.5	< 0.02	0.02
Y	µg/L	ICP-MS	7.9	1.4	0.44	0.9	1.4
Yb	µg/L	ICP-MS	0.52	0.11	0.03	0.058	0.1
Zn	µg/L	ICP-MS	5000	1300	1320	540	990
Ag	µg/L	ICP-AES	<1	<1	<5	<1	<1
Al	mg/L	ICP-AES	3.6	0.51	0.051	0.31	0.55
As	µg/L	ICP-AES	<100	<100	<200	<100	<100
B	µg/L	ICP-AES	8.8	<5	<5	<5	<5
Ba	µg/L	ICP-AES	59	36	25	37	41
Be	µg/L	ICP-AES	<10	<10	<10	<10	<10
Ca	mg/L	ICP-AES	35.2	3.8	7.41	3	2.7
Cd	µg/L	ICP-AES	<5	<5	<5	<5	<5
Co	µg/L	ICP-AES	56	12	<10	10	<10
Cr	µg/L	ICP-AES	<10	<10	<10	<10	<10
Cu	µg/L	ICP-AES	64	33	<10	20	37
Fe	mg/L	ICP-AES	3.3	2.7	1.01	0.81	1.9
K	mg/L	ICP-AES	7.6	1.8	1.83	2.4	1.8
Li	µg/L	ICP-AES	2.6	<1	<5	<1	<1

Appendix 1 (cont.). Field and laboratory data for post reclamation surface water samples at Valzinco.

Field No.	**Units**	**Method**	**VLZN 3-10**	**VLZN 3-11**	**VLZN 3-12**	**VLZN 11-10**	**VLZN 11-11**
Mg	mg/L	ICP-AES	8.7	1.6	2.6	1.4	1.4
Mn	µg/L	ICP-AES	3540	375	833	406	334
Mo	µg/L	ICP-AES	<20	<20	<20	<20	<20
Na	mg/L	ICP-AES	3.2	2.8	2.8	1.8	2.3
Ni	µg/L	ICP-AES	14	<10	<10	<10	<10
P	mg/L	ICP-AES	<0.1	<0.1	<0.5	<0.1	<0.1
Pb	µg/L	ICP-AES	486	62	<50	65	85
Sb	µg/L	ICP-AES	<50	<50	<50	<50	<50
SiO_2	mg/L	ICP-AES	16.9	7.1	10.2	12.4	8.8
SO_4	mg/L	ICP-AES			35.3		
Sr	µg/L	ICP-AES	152	19	34	15	14
Ti	µg/L	ICP-AES	<50	<50	<50	<50	<50
V	µg/L	ICP-AES	<10	<10	<10	<10	<10
Zn	µg/L	ICP-AES	5670	1480	999	498	1180

Appendix 1 (cont.). Field and laboratory data for post reclamation surface water samples at Valzinco.

Field No.	Units	Method	VLZN 3-10	VLZN 3-11	VLZN 3-12	VLZN 11-10	VLZN 11-11
Unfiltered							
Ag	µg/L	ICP-MS	<0.01	<0.01	<1	<0.01	<0.01
Al	µg/L	ICP-MS	3000	450	369	280	430
As	µg/L	ICP-MS	0.2	<1	<1	<0.2	<1
Ba	µg/L	ICP-MS	62	38	19.8	36	41
Be	µg/L	ICP-MS	0.54	0.14	<0.05	0.14	0.15
Bi	µg/L	ICP-MS	< 0.01	< 0.04	< 0.2	< 0.01	< 0.04
Ca	mg/L	ICP-MS	28	3.2	12	3	2.2
Cd	µg/L	ICP-MS	3.9	1.8	0.88	0.56	1.6
Ce	µg/L	ICP-MS	60	12	6.48	5	8.8
Co	µg/L	ICP-MS	45	7.1	11.9	6.8	6.9
Cr	µg/L	ICP-MS	<1	<1	<1	<1	<1
Cs	µg/L	ICP-MS	0.11	< 0.01	< 0.02	0.014	< 0.01
Cu	µg/L	ICP-MS	52	30	17.6	19	31
Dy	µg/L	ICP-MS	1.6	0.32	0.15	0.18	0.3
Er	µg/L	ICP-MS	0.68	0.15	0.062	0.094	0.13
Eu	µg/L	ICP-MS	0.55	0.12	0.063	0.056	0.1
Fe	µg/L	ICP-MS	2500	2800	6360	920	1600
Ga	µg/L	ICP-MS	< 0.02	< 0.02	0.1	< 0.02	< 0.02
Gd	µg/L	ICP-MS	2.5	0.52	0.32	0.27	0.46
Ge	µg/L	ICP-MS	< 0.02	< 0.02	< 0.05	< 0.02	< 0.02
Ho	µg/L	ICP-MS	0.3	0.058	0.02	0.033	0.047
K	mg/L	ICP-MS	6400	1600	3.04	2300	1500
La	µg/L	ICP-MS	22	3.6	2.14	2.2	3.1
Li	µg/L	ICP-MS	2.1	< 0.3	3.1	0.4	0.4
Lu	µg/L	ICP-MS			< 0.1		
Mg	mg/L	ICP-MS	7.5	1.4	4.45	1.3	1.1
Mn	µg/L	ICP-MS	3100	340	1090	430	290
Mo	µg/L	ICP-MS	< 0.02	< 0.02	< 2	0.025	0.033
Na	mg/L	ICP-MS	2.8	2.3	4.57	1.6	1.8
Nb	µg/L	ICP-MS			< 0.2		
Nd	µg/L	ICP-MS	18	3.8	1.87	1.6	3
Ni	µg/L	ICP-MS	10	2.2	2.3	1.6	2
P	mg/L	ICP-MS	< 20	2	< 0.01	< 4	< 1
Pb	µg/L	ICP-MS	500	77	34	67	96
Pr	µg/L	ICP-MS	5	0.99	0.5	0.46	0.78
Rb	µg/L	ICP-MS	26	4.4	8.88	6.8	4
Sb	µg/L	ICP-MS	<0.02	<0.06	<0.3	<0.02	<0.06
Sc	µg/L	ICP-MS			2.6		
Se	µg/L	ICP-MS	< 0.2	< 0.4	< 1	< 0.2	< 0.4
SiO_2	mg/L	ICP-MS	14	5.9	18.5	11	7.2
Sm	µg/L	ICP-MS	3.3	0.75	0.36	0.31	0.57
SO_4	mg/L	ICP-MS	190	24	53	35	19
Sr	µg/L	ICP-MS	160	19	40.9	14	13

Appendix 1 (cont.). Field and laboratory data for post reclamation surface water samples at Valzinco.

Field No.	**Units**	**Method**	**VLZN 3-10**	**VLZN 3-11**	**VLZN 3-12**	**VLZN 11-10**	**VLZN 11-11**
Ta	µg/L	ICP-MS	0.32	0.062	< 0.02	0.035	0.055
Tb	µg/L	ICP-MS			0.04		
Th	µg/L	ICP-MS	0.13	0.077	< 0.2	< 0.03	0.03
Tl	µg/L	ICP-MS	0.2	<0.05	<0.1	<0.05	<0.05
Tm	µg/L	ICP-MS	0.09	0.021	0.008	0.011	0.016
U	µg/L	ICP-MS	0.46	0.074	< 0.1	0.043	0.061
V	µg/L	ICP-MS	<0.1	<0.1	0.6	<0.1	<0.1
W	µg/L	ICP-MS	< 0.02	< 0.02	< 0.5	< 0.02	< 0.02
Y	µg/L	ICP-MS	7.9	1.5	0.91	0.89	1.4
Yb	µg/L	ICP-MS	0.54	0.13	0.06	0.062	0.12
Zn	µg/L	ICP-MS	5100	1300	1330	540	970
Ag	µg/L	ICP-AES	<1	<1	<5	<1	<1
Al	mg/L	ICP-AES	3.5	0.62	0.179	0.32	0.6
As	µg/L	ICP-AES	<100	<100	<200	<100	<100
B	µg/L	ICP-AES	8.7	<5	<5	<5	<5
Ba	µg/L	ICP-AES	57	36	26	36	42
Be	µg/L	ICP-AES	<10	<10	<10	<10	<10
Ca	mg/L	ICP-AES	34.5	3.8	7.58	3	2.8
Cd	µg/L	ICP-AES	<5	<5	<5	<5	<5
Co	µg/L	ICP-AES	55	10	<10	<10	<10
Cr	µg/L	ICP-AES	<10	<10	<10	<10	<10
Cu	µg/L	ICP-AES	62	36	13	20	39
Fe	mg/L	ICP-AES	3.4	3.5	4.49	0.99	2.1
K	mg/L	ICP-AES	7.4	1.8	1.91	2.3	1.8
Li	µg/L	ICP-AES	2.4	<1	<5	1.2	<1
Mg	mg/L	ICP-AES	8.7	1.6	2.6	1.4	1.4
Mn	µg/L	ICP-AES	3540	375	833	406	334
Mo	µg/L	ICP-AES	<20	<20	<20	<20	<20
Na	mg/L	ICP-AES	3.2	2.8	2.8	1.8	2.3
Ni	µg/L	ICP-AES	14	<10	<10	<10	<10
P	mg/L	ICP-AES	<0.1	<0.1	<0.5	<0.1	<0.1
Pb	µg/L	ICP-AES	486	62	<50	65	85
Sb	µg/L	ICP-AES	<50	<50	<50	<50	<50
SiO_2	mg/L	ICP-AES	16.9	7.1	10.2	12.4	8.8
SO_4	mg/L	ICP-AES			35.3		
Sr	µg/L	ICP-AES	152	19	34	15	14
Ti	µg/L	ICP-AES	<50	<50	<50	<50	<50
V	µg/L	ICP-AES	<10	<10	<10	<10	<10
Zn	µg/L	ICP-AES	5670	1480	999	498	1180

Appendix 1 (cont.). Field and laboratory data for post reclamation surface water samples at Valzinco.

Field No.	Units	Method	VLZN 13-10	VLZN 13-11	VLZN 13-12	VLZN 14-12
Latitude			38.1792	38.1792	38.1792	38.1779
Longitude			-77.7828	-77.7828	-77.7828	-77.7977
Date			6/5/2002	4/14/2003	6/6/2007	6/6/2007
T water	C		22.5	13.9	22.5	27.6
Flow	L/s					
pH			5.8	5.5	5.2	6.3
Spec. Con.	µS/cm		57.8	36.5	38.1	56.8
D.O.	mg/L		5	8	8	10
ORP	mV		217.0	87.4	430.4	389.9
Fe^{2+}/Fe_{tot}			0.714	0.274		
Alkalinity	mg/L		14.3	0.0	17.9	7.7
Hardness	mg/L		13.6	7.4	10.4	29.8
Filtered (0.45 µm)						
Cl	mg/L	IC	2.1	4.4	2.8	3
SO_4	mg/L	IC	0.5	4.5	2.3	77
F	mg/L	IC			<.08	0.1
NO_3	mg/L	IC			<.08	<.08
Ag	µg/L	ICP-MS	<0.01	<0.01	<1	<1
Al	µg/L	ICP-MS	8.7	200	31.1	286
As	µg/L	ICP-MS	0.43	<1	<1	1
Ba	µg/L	ICP-MS	33	33	32.2	28.2
Be	µg/L	ICP-MS	<0.05	0.14	<0.05	0.08
Bi	µg/L	ICP-MS	< 0.01	< 0.04	< 0.2	< 0.2
Ca	mg/L	ICP-MS	2.8	1.1	1.07	10.3
Cd	µg/L	ICP-MS	0.024	0.12	0.02	0.07
Ce	µg/L	ICP-MS	0.35	2.7	1.8	16.1
Co	µg/L	ICP-MS	3.2	1.3	2.3	6.17
Cr	µg/L	ICP-MS	<1	<1	<1	<1
Cs	µg/L	ICP-MS	< 0.01	< 0.01	< 0.02	< 0.02
Cu	µg/L	ICP-MS	1.2	6.6	1.8	3.4
Dy	µg/L	ICP-MS	0.019	0.13	0.081	0.2
Er	µg/L	ICP-MS	0.013	0.073	0.05	0.086
Eu	µg/L	ICP-MS	< 0.005	0.037	0.03	0.096
Fe	µg/L	ICP-MS	360	550	2170	26900
Ga	µg/L	ICP-MS	< 0.02	< 0.02	< 0.05	0.2
Gd	µg/L	ICP-MS	0.023	0.2	0.12	0.42
Ge	µg/L	ICP-MS	< 0.02	< 0.02	< 0.05	0.05
Ho	µg/L	ICP-MS	< 0.005	0.027	0.02	0.03
K	mg/L	ICP-MS	1300	1100	0.48	4.43
La	µg/L	ICP-MS	0.092	0.89	0.59	2.19
Li	µg/L	ICP-MS	< 0.3	< 0.3	< 0.1	2.5
Lu	µg/L	ICP-MS			< 0.1	< 0.1

Appendix 1 (cont.). Field and laboratory data for post reclamation surface water samples at Valzinco.

Field No.	**Units**	**Method**	**VLZN 13-10**	**VLZN 13-11**	**VLZN 13-12**	**VLZN 14-12**
Mg	mg/L	ICP-MS	1.6	0.78	0.62	4.3
Mn	µg/L	ICP-MS	630	69	220	872
Mo	µg/L	ICP-MS	0.073	0.081	< 2	< 2
Na	mg/L	ICP-MS	3.6	2.8	1.51	4.88
Nb	µg/L	ICP-MS			< 0.2	< 0.2
Nd	µg/L	ICP-MS	0.12	1	0.66	3.07
Ni	µg/L	ICP-MS	0.54	1	0.6	1.5
P	mg/L	ICP-MS	17	5.4	< 0.01	< 0.01
Pb	µg/L	ICP-MS	0.3	6.6	3	6.4
Pr	µg/L	ICP-MS	0.024	0.26	0.16	0.73
Rb	µg/L	ICP-MS	2.6	2.3	2.16	15.5
Sb	µg/L	ICP-MS	0.36	0.2	<0.3	<0.3
Sc	µg/L	ICP-MS			0.9	3.4
Se	µg/L	ICP-MS	< 0.2	< 0.4	< 1	< 1
SiO_2	mg/L	ICP-MS	11	5.6	9.6	24
Sm	µg/L	ICP-MS	0.022	0.22	0.12	0.56
SO_4	mg/L	ICP-MS	0.34	3.3	< 2	69
Sr	µg/L	ICP-MS	16	7.4	9.2	30.2
Ta	µg/L	ICP-MS	< 0.005	0.023	< 0.02	< 0.02
Tb	µg/L	ICP-MS			0.02	0.051
Th	µg/L	ICP-MS	< 0.03	0.14	< 0.2	< 0.2
Tl	µg/L	ICP-MS	<0.05	<0.05	<0.1	<0.1
Tm	µg/L	ICP-MS	< 0.005	0.0092	0.006	0.01
U	µg/L	ICP-MS	0.012	0.043	< 0.1	< 0.1
V	µg/L	ICP-MS	0.19	0.2	<0.5	<0.5
W	µg/L	ICP-MS	0.02	0.02	< 0.5	< 0.5
Y	µg/L	ICP-MS	0.11	0.72	0.32	1.01
Yb	µg/L	ICP-MS	0.014	0.066	0.04	0.07
Zn	µg/L	ICP-MS	8	40	8	173
Ag	µg/L	ICP-AES	<1	<1	<5	<5
Al	mg/L	ICP-AES	<0.01	0.28	65	0.176
As	µg/L	ICP-AES	<100	<100	<200	<200
B	µg/L	ICP-AES	<5	<5	<5	<5
Ba	µg/L	ICP-AES	33	33	26	33
Be	µg/L	ICP-AES	<10	<10	<10	<10
Ca	mg/L	ICP-AES	2.8	1.4	1.88	7.24
Cd	µg/L	ICP-AES	<5	<5	<5	<5
Co	µg/L	ICP-AES	<10	<10	<10	<10
Cr	µg/L	ICP-AES	<10	<10	<10	<10
Cu	µg/L	ICP-AES	<10	<10	<10	<10
Fe	mg/L	ICP-AES	0.4	0.69	2.94	19
K	mg/L	ICP-AES	1.3	1.3	0.94	3.12
Li	µg/L	ICP-AES	<1	<1	<5	<5

Appendix 1 (cont.). Field and laboratory data for post reclamation surface water samples at Valzinco.

Field No.	**Units**	**Method**	**VLZN 13-10**	**VLZN 13-11**	**VLZN 13-12**	**VLZN 14-12**
Mg	mg/L	ICP-AES	1.7	0.92	1.45	3.36
Mn	µg/L	ICP-AES	682	81	384	783
Mo	µg/L	ICP-AES	<20	<20	<20	<20
Na	mg/L	ICP-AES	3.8	3.3	3.63	3.48
Ni	µg/L	ICP-AES	<10	<10	<10	<10
P	mg/L	ICP-AES	<0.1	<0.1	<0.5	<0.5
Pb	µg/L	ICP-AES	<50	<50	<50	<50
Sb	µg/L	ICP-AES	<50	<50	<50	<50
SiO_2	mg/L	ICP-AES	12.6	7.3	13.2	15.5
SO_4	mg/L	ICP-AES			2.1	64.3
Sr	µg/L	ICP-AES	18	7.8	12	28
Ti	µg/L	ICP-AES	<50	<50	<50	<50
V	µg/L	ICP-AES	<10	<10	<10	<10
Zn	µg/L	ICP-AES	12	52	<20	192

Appendix 1 (cont.). Field and laboratory data for post reclamation surface water samples at Valzinco.

Field No.	**Units**	**Method**	**VLZN 13-10**	**VLZN 13-11**	**VLZN 13-12**	**VLZN 14-12**
Unfiltered						
Ag	µg/L	ICP-MS	<0.01	<0.01	<1	<1
Al	µg/L	ICP-MS	120	240	251	1330
As	µg/L	ICP-MS	1.1	<1	2	2
Ba	µg/L	ICP-MS	40	33	29.5	29
Be	µg/L	ICP-MS	<0.05	0.15	0.1	0.1
Bi	µg/L	ICP-MS	< 0.01	< 0.04	< 0.2	< 0.2
Ca	mg/L	ICP-MS	3.1	1.1	2.39	13.1
Cd	µg/L	ICP-MS	0.14	0.15	0.03	0.12
Ce	µg/L	ICP-MS	2.9	3	3.54	36.3
Co	µg/L	ICP-MS	4.2	1.4	3.42	7.55
Cr	µg/L	ICP-MS	1	<1	<1	1.4
Cs	µg/L	ICP-MS	< 0.01	< 0.01	< 0.02	< 0.02
Cu	µg/L	ICP-MS	2.5	7	5.8	12.4
Dy	µg/L	ICP-MS	0.1	0.14	0.16	0.43
Er	µg/L	ICP-MS	0.051	0.076	0.078	0.21
Eu	µg/L	ICP-MS	0.033	0.051	0.052	0.2
Fe	µg/L	ICP-MS	12000	760	14700	46600
Ga	µg/L	ICP-MS	0.039	< 0.02	0.09	0.41
Gd	µg/L	ICP-MS	0.13	0.19	0.23	1.01
Ge	µg/L	ICP-MS	< 0.02	< 0.02	< 0.05	0.09
Ho	µg/L	ICP-MS	0.02	0.027	0.03	0.066
K	mg/L	ICP-MS	1500	1100	1.2	5.34
La	µg/L	ICP-MS	0.76	0.99	1.18	4.95
Li	µg/L	ICP-MS	< 0.3	< 0.3	0.7	2.4
Lu	µg/L	ICP-MS			< 0.1	< 0.1
Mg	mg/L	ICP-MS	1.6	0.77	1.69	5.56
Mn	µg/L	ICP-MS	700	70	416	1030
Mo	µg/L	ICP-MS	0.079	0.073	< 2	< 2
Na	mg/L	ICP-MS	3.6	2.7	4.11	5.45
Nb	µg/L	ICP-MS			< 0.2	< 0.2
Nd	µg/L	ICP-MS	0.74	1.1	1.17	6.94
Ni	µg/L	ICP-MS	0.94	0.98	0.9	2.1
P	mg/L	ICP-MS	490	7.5	0.03	0.05
Pb	µg/L	ICP-MS	7.7	8.9	14.1	44
Pr	µg/L	ICP-MS	0.19	0.28	0.3	1.66
Rb	µg/L	ICP-MS	3	2.4	3.5	18.2
Sb	µg/L	ICP-MS	<0.02	<0.06	<0.3	<0.3
Sc	µg/L	ICP-MS			2.9	3.9
Se	µg/L	ICP-MS	< 0.2	< 0.4	< 1	< 1
SiO_2	mg/L	ICP-MS	12	5.7	18.7	26.6
Sm	µg/L	ICP-MS	0.15	0.24	0.22	1.4
SO_4	mg/L	ICP-MS	0.67	3.1	< 2	91
Sr	µg/L	ICP-MS	17	7.3	14.5	36.6

Appendix 1 (cont.). Field and laboratory data for post reclamation surface water samples at Valzinco.

Field No.	Units	Method	VLZN 13-10	VLZN 13-11	VLZN 13-12	VLZN 14-12
Ta	µg/L	ICP-MS	0.017	0.026	0.03	< 0.02
Tb	µg/L	ICP-MS			0.03	0.12
Th	µg/L	ICP-MS	0.24	0.12	0.23	0.21
Tl	µg/L	ICP-MS	<0.05	<0.05	<0.1	<0.1
Tm	µg/L	ICP-MS	0.0068	0.01	0.01	0.03
U	µg/L	ICP-MS	0.05	0.044	< 0.1	0.15
V	µg/L	ICP-MS	2.2	0.4	2.9	2.8
W	µg/L	ICP-MS	< 0.02	0.03	< 0.5	< 0.5
Y	µg/L	ICP-MS	0.47	0.76	0.86	2.15
Yb	µg/L	ICP-MS	0.04	0.061	0.07	0.18
Zn	µg/L	ICP-MS	15	41	21.5	260
Ag	µg/L	ICP-AES	<1	<1	<5	<5
Al	mg/L	ICP-AES	0.19	0.45	0.209	0.767
As	µg/L	ICP-AES	<100	<100	<200	<200
B	µg/L	ICP-AES	<5	<5	<5	<5
Ba	µg/L	ICP-AES	41	33	31	33
Be	µg/L	ICP-AES	<10	<10	<10	<10
Ca	mg/L	ICP-AES	2.9	1.3	2.01	8.39
Cd	µg/L	ICP-AES	<5	<5	<5	<5
Co	µg/L	ICP-AES	<10	<10	<10	<10
Cr	µg/L	ICP-AES	<10	<10	<10	<10
Cu	µg/L	ICP-AES	<10	<10	<10	<10
Fe	mg/L	ICP-AES	12.2	0.98	12	32
K	mg/L	ICP-AES	1.4	1.3	0.96	3.65
Li	µg/L	ICP-AES	<1	<1	<5	<5
Mg	mg/L	ICP-AES	1.7	0.92	1.45	3.36
Mn	µg/L	ICP-AES	682	81	384	783
Mo	µg/L	ICP-AES	<20	<20	<20	<20
Na	mg/L	ICP-AES	3.8	3.3	3.63	3.48
Ni	µg/L	ICP-AES	<10	<10	<10	<10
P	mg/L	ICP-AES	<0.1	<0.1	<0.5	<0.5
Pb	µg/L	ICP-AES	<50	<50	<50	<50
Sb	µg/L	ICP-AES	<50	<50	<50	<50
SiO_2	mg/L	ICP-AES	12.6	7.3	13.2	15.5
SO_4	mg/L	ICP-AES			2.1	64.3
Sr	µg/L	ICP-AES	18	7.8	12	28
Ti	µg/L	ICP-AES	<50	<50	<50	<50
V	µg/L	ICP-AES	<10	<10	<10	<10
Zn	µg/L	ICP-AES	12	52	<20	192

Appendix 2. Field and laboratory data for post reclamation ground water samples at Valzinco.

Field No.	**Units**	**Method**	**MW-1-12**	**MW-2-12**	**MW-3-12**	**MW-6-12**
Latitude			38.1778	38.1775	38.1784	38.1778
Longitude			-77.7985	-77.7974	-77.7966	-77.7936
Date			6/6/2007	6/6/2007	6/6/2007	6/6/2007
T water	C		14.3	15.5	17.8	18.2
Flow	L/s					
pH			5.7	5.5	5.3	5.9
Spec. Con.	µS/cm		16.5	15	96.1	45.4
DO	mg/L		5	7	3	5
ORP	mV		483.4	517.9	448.6	396.9
Fe^{2+}/Fe_{tot}						
Alkalinity	mg/L		8.2	3.9	7.8	17.1
Hardness	mg/L		3.5	2.5	44.6	10.8
Filtered (0.45 µm)						
Cl	mg/L	IC	2.1	2.7	2.3	2.2
SO_4	mg/L	IC	3.6	2	44	10
F	mg/L	IC	<.08	<.08	<.08	<.08
NO_3	mg/L	IC	<.08	0.26	0.13	<.08
Ag	µg/L	ICP-MS	<1	<1	<1	<1
Al	µg/L	ICP-MS	<2	3	64.9	6
As	µg/L	ICP-MS	<1	<1	<1	<1
Ba	µg/L	ICP-MS	9.94	19.6	29.3	40.8
Be	µg/L	ICP-MS	0.07	<0.05	<0.05	<0.05
Bi	µg/L	ICP-MS	< 0.2	< 0.2	< 0.2	< 0.2
Ca	mg/L	ICP-MS	0.24	<0.2	9.51	2.9
Cd	µg/L	ICP-MS	0.04	0.09	0.1	0.43
Ce	µg/L	ICP-MS	0.02	0.04	0.1	0.04
Co	µg/L	ICP-MS	0.04	0.06	0.32	11.8
Cr	µg/L	ICP-MS	<1	<1	<1	<1
Cs	µg/L	ICP-MS	< 0.02	< 0.02	< 0.02	< 0.02
Cu	µg/L	ICP-MS	<0.5	1.9	25.3	11.1
Dy	µg/L	ICP-MS	< 0.005	0.082	0.04	< 0.005
Er	µg/L	ICP-MS	< 0.005	0.04	0.02	< 0.005
Eu	µg/L	ICP-MS	< 0.005	0.04	0.02	0.01
Fe	µg/L	ICP-MS	<50	<50	<50	3660
Ga	µg/L	ICP-MS	< 0.05	< 0.05	< 0.05	< 0.05
Gd	µg/L	ICP-MS	< 0.005	0.22	0.08	< 0.005
Ge	µg/L	ICP-MS	< 0.05	< 0.05	< 0.05	< 0.05
Ho	µg/L	ICP-MS	< 0.005	0.02	0.009	< 0.005
K	mg/L	ICP-MS	0.2	0.3	5.4	5.64
La	µg/L	ICP-MS	0.04	0.93	0.33	0.02
Li	µg/L	ICP-MS	< 0.1	< 0.1	3	1.4
Lu	µg/L	ICP-MS	< 0.1	< 0.1	< 0.1	< 0.1

Appendix 2. (cont.) Field and laboratory data for post reclamation ground water samples at Valzinco.

Field No.	**Units**	**Method**	**MW-1-12**	**MW-2-12**	**MW-3-12**	**MW-6-12**
Mg	mg/L	ICP-MS	0.25	0.18	12.6	1.63
Mn	µg/L	ICP-MS	3.8	3.4	170	706
Mo	µg/L	ICP-MS	< 2	< 2	< 2	< 2
Na	mg/L	ICP-MS	1.07	0.73	3.6	1.67
Nb	µg/L	ICP-MS	< 0.2	< 0.2	< 0.2	< 0.2
Nd	µg/L	ICP-MS	0.02	1.07	0.27	0.02
Ni	µg/L	ICP-MS	<0.4	<0.4	1.1	28
P	mg/L	ICP-MS	< 0.01	< 0.01	< 0.01	< 0.01
Pb	µg/L	ICP-MS	1	0.72	0.06	3.3
Pr	µg/L	ICP-MS	< 0.01	0.27	0.07	< 0.01
Rb	µg/L	ICP-MS	1.63	1.98	13.5	12.8
Sb	µg/L	ICP-MS	<0.3	<0.3	<0.3	<0.3
Sc	µg/L	ICP-MS	1	< 0.6	2.5	3.7
Se	µg/L	ICP-MS	< 1	< 1	< 1	< 1
SiO_2	mg/L	ICP-MS	9.8	5.8	18.5	26
Sm	µg/L	ICP-MS	< 0.01	0.24	0.06	< 0.01
SO_4	mg/L	ICP-MS	< 2	< 2	63	10
Sr	µg/L	ICP-MS	3.34	1.8	30.1	19.7
Ta	µg/L	ICP-MS	< 0.02	< 0.02	< 0.02	0.02
Tb	µg/L	ICP-MS	< 0.005	0.02	0.01	< 0.005
Th	µg/L	ICP-MS	< 0.2	< 0.2	< 0.2	< 0.2
Tl	µg/L	ICP-MS	<0.1	<0.1	<0.1	0.1
Tm	µg/L	ICP-MS	< 0.005	< 0.005	< 0.005	< 0.005
U	µg/L	ICP-MS	< 0.1	< 0.1	< 0.1	< 0.1
V	µg/L	ICP-MS	<0.5	<0.5	<0.5	<0.5
W	µg/L	ICP-MS	< 0.5	< 0.5	< 0.5	< 0.5
Y	µg/L	ICP-MS	< 0.01	0.27	0.48	0.02
Yb	µg/L	ICP-MS	< 0.005	0.04	0.01	< 0.005
Zn	µg/L	ICP-MS	15.7	13.2	20	203
Ag	µg/L	ICP-AES	<5	<5	<5	<5
Al	mg/L	ICP-AES	<20	<20	49	<20
As	µg/L	ICP-AES	<200	<200	<200	<200
B	µg/L	ICP-AES	<5	<5	<5	<5
Ba	µg/L	ICP-AES	8.3	17	36	46
Be	µg/L	ICP-AES	<10	<10	<10	<10
Ca	mg/L	ICP-AES	0.46	0.27	5.75	2.21
Cd	µg/L	ICP-AES	<5	<5	<5	<5
Co	µg/L	ICP-AES	<10	<10	<10	13
Cr	µg/L	ICP-AES	<10	<10	<10	<10
Cu	µg/L	ICP-AES	<10	<10	18	<10
Fe	mg/L	ICP-AES	<0.020	<0.020	<0.020	3.01
K	mg/L	ICP-AES	0.53	0.59	3.27	4.45
Li	µg/L	ICP-AES	<5	<5	<5	<5

Appendix 2. (cont.) Field and laboratory data for post reclamation ground water samples at Valzinco.

Field No.	**Units**	**Method**	**MW-1-12**	**MW-2-12**	**MW-3-12**	**MW-6-12**
Mg	mg/L	ICP-AES	0.58	0.44	7.37	1.29
Mn	µg/L	ICP-AES	<10	<10	122	618
Mo	µg/L	ICP-AES	<20	<20	<20	<20
Na	mg/L	ICP-AES	2.6	1.91	2.09	1.4
Ni	µg/L	ICP-AES	<10	<10	<10	26
P	mg/L	ICP-AES	<0.5	<0.5	<0.5	<0.5
Pb	µg/L	ICP-AES	<50	<50	<50	<50
Sb	µg/L	ICP-AES	<50	<50	<50	<50
SiO_2	mg/L	ICP-AES	14.3	9.0	9.6	18.2
SO_4	mg/L	ICP-AES	1.4	< 1	40.7	9.2
Sr	µg/L	ICP-AES	3.8	2.1	25	16
Ti	µg/L	ICP-AES	<50	<50	<50	<50
V	µg/L	ICP-AES	<10	<10	<10	<10
Zn	µg/L	ICP-AES	24	21	<20	170

Appendix 2. (cont.) Field and laboratory data for post reclamation ground water samples at Valzinco.

Field No.	**Units**	**Method**	**MW-1-12**	**MW-2-12**	**MW-3-12**	**MW-6-12**
Unfiltered						
Ag	µg/L	ICP-MS	<1	<1	<1	<1
Al	µg/L	ICP-MS	46.3	8.4	221	427
As	µg/L	ICP-MS	<1	<1	<1	<1
Ba	µg/L	ICP-MS	11.6	20	29.7	47
Be	µg/L	ICP-MS	<0.05	<0.05	0.07	0.09
Bi	µg/L	ICP-MS	< 0.2	< 0.2	< 0.2	0.26
Ca	mg/L	ICP-MS	0.26	<0.2	9.37	3.13
Cd	µg/L	ICP-MS	0.05	0.08	0.1	0.45
Ce	µg/L	ICP-MS	0.53	0.18	0.19	0.82
Co	µg/L	ICP-MS	0.08	0.07	0.48	13
Cr	µg/L	ICP-MS	<1	<1	<1	<1
Cs	µg/L	ICP-MS	< 0.02	< 0.02	< 0.02	< 0.02
Cu	µg/L	ICP-MS	0.73	2.1	26.7	24.4
Dy	µg/L	ICP-MS	0.055	0.13	0.052	0.03
Er	µg/L	ICP-MS	0.02	0.059	0.02	0.02
Eu	µg/L	ICP-MS	0.03	0.066	0.02	0.02
Fe	µg/L	ICP-MS	<50	<50	227	5590
Ga	µg/L	ICP-MS	< 0.05	< 0.05	< 0.05	0.2
Gd	µg/L	ICP-MS	0.11	0.36	0.1	0.075
Ge	µg/L	ICP-MS	< 0.05	< 0.05	< 0.05	< 0.05
Ho	µg/L	ICP-MS	0.007	0.02	0.01	0.009
K	mg/L	ICP-MS	0.3	0.3	5.44	6.24
La	µg/L	ICP-MS	0.77	1.61	0.39	0.36
Li	µg/L	ICP-MS	< 0.1	< 0.1	2.3	2.2
Lu	µg/L	ICP-MS	< 0.1	< 0.1	< 0.1	< 0.1
Mg	mg/L	ICP-MS	0.28	0.19	12.7	1.81
Mn	µg/L	ICP-MS	4.7	3.8	175	756
Mo	µg/L	ICP-MS	< 2	< 2	< 2	< 2
Na	mg/L	ICP-MS	1.1	0.77	3.58	1.84
Nb	µg/L	ICP-MS	< 0.2	< 0.2	< 0.2	< 0.2
Nd	µg/L	ICP-MS	0.58	1.88	0.32	0.35
Ni	µg/L	ICP-MS	<0.4	<0.4	1.3	30.2
P	mg/L	ICP-MS	< 0.01	< 0.01	< 0.01	< 0.01
Pb	µg/L	ICP-MS	2.8	0.84	0.2	36.4
Pr	µg/L	ICP-MS	0.16	0.47	0.08	0.09
Rb	µg/L	ICP-MS	1.87	2.02	14.3	14.5
Sb	µg/L	ICP-MS	<0.3	<0.3	<0.3	<0.3
Sc	µg/L	ICP-MS	1	< 0.6	2.4	4
Se	µg/L	ICP-MS	< 1	< 1	< 1	< 1
SiO_2	mg/L	ICP-MS	10.7	6.1	18.4	30.7
Sm	µg/L	ICP-MS	0.11	0.41	0.07	0.06
SO_4	mg/L	ICP-MS	< 2	< 2	63	12
Sr	µg/L	ICP-MS	3.56	1.86	29.4	21.2

Appendix 2. (cont.) Field and laboratory data for post reclamation ground water samples at Valzinco.

Field No.	**Units**	**Method**	**MW-1-12**	**MW-2-12**	**MW-3-12**	**MW-6-12**
Ta	µg/L	ICP-MS	< 0.02	< 0.02	< 0.02	< 0.02
Tb	µg/L	ICP-MS	0.01	0.04	0.01	0.008
Th	µg/L	ICP-MS	< 0.2	< 0.2	< 0.2	< 0.2
Tl	µg/L	ICP-MS	<0.1	<0.1	<0.1	0.1
Tm	µg/L	ICP-MS	< 0.005	0.007	< 0.005	< 0.005
U	µg/L	ICP-MS	< 0.1	< 0.1	< 0.1	0.11
V	µg/L	ICP-MS	<0.5	<0.5	<0.5	<0.5
W	µg/L	ICP-MS	< 0.5	< 0.5	< 0.5	< 0.5
Y	µg/L	ICP-MS	0.12	0.43	0.53	0.24
Yb	µg/L	ICP-MS	0.02	0.06	0.02	0.02
Zn	µg/L	ICP-MS	18.5	13.8	22.3	222
Ag	µg/L	ICP-AES	<5	<5	<5	<5
Al	mg/L	ICP-AES	0.076	<0.020	0.119	0.252
As	µg/L	ICP-AES	<200	<200	<200	<200
B	µg/L	ICP-AES	<5	<5	<5	<5
Ba	µg/L	ICP-AES	9.3	17	37	53
Be	µg/L	ICP-AES	<10	<10	<10	<10
Ca	mg/L	ICP-AES	0.51	0.27	5.75	2.26
Cd	µg/L	ICP-AES	<5	<5	<5	<5
Co	µg/L	ICP-AES	<10	<10	<10	11
Cr	µg/L	ICP-AES	<10	<10	<10	<10
Cu	µg/L	ICP-AES	<10	<10	20	19
Fe	mg/L	ICP-AES	0.105	<0.020	0.149	4.15
K	mg/L	ICP-AES	0.6	0.61	3.37	4.61
Li	µg/L	ICP-AES	<5	<5	<5	<5
Mg	mg/L	ICP-AES	0.63	0.44	7.43	1.32
Mn	µg/L	ICP-AES	11	<10	128	627
Mo	µg/L	ICP-AES	<20	<20	<20	<20
Na	mg/L	ICP-AES	2.64	1.92	2.12	1.43
Ni	µg/L	ICP-AES	<10	<10	<10	27
P	mg/L	ICP-AES	<0.5	<0.5	<0.5	<0.5
Pb	µg/L	ICP-AES	<50	<50	<50	<50
Sb	µg/L	ICP-AES	<50	<50	<50	<50
SiO_2	mg/L	ICP-AES	14.9	8.9	10.0	19.5
SO_4	mg/L	ICP-AES	1.5	< 1	41.4	9.6
Sr	µg/L	ICP-AES	4.4	2.1	25	17
Ti	µg/L	ICP-AES	<50	<50	<50	<50
V	µg/L	ICP-AES	<10	<10	<10	<10
Zn	µg/L	ICP-AES	37	20	<20	183