In Cooperation with the World Bank, Romanian National Agency for Mineral Resources, and Futures Group

Reconnaissance Study of Water Quality in the Mining-Affected Aries River Basin, Romania

By Michael J. Friedel, James A. Tindall, Daniel Sardan, David L. Fey, and G. L. Poputa

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
Length		
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
yard (yd)	0.9144	meter (m)
Volume		
ounce, fluid (fl. oz)	0.02957	liter (L)
pint (pt)	0.4732	liter (L)
quart (qt)	0.9464	liter (L)
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
cubic inch (in^3)	0.01639	liter (L)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
cubic yard (yd^3)	0.7646	cubic meter (m^3)
Flow rate		
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
Mass		
ounce, avoirdupois (oz)	28.35	gram (g)
pound, avoirdupois (lb)	0.4536	kilogram (kg)
Pressure		
atmosphere, standard (atm)	101.3	kilopascal (kPa)

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:
°C=(°F-32)/1.8

SI to Inch/Pound

Multiply	By	To obtain
Length		
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
meter (m)	1.094	yard (yd)
Volume		
liter (L)	33.82	ounce, fluid (fl. oz)
liter (L)	2.113	pint (pt)
liter (L)	1.057	quart (qt)
liter (L)	0.2642	gallon (gal)
cubic meter (m^3)	264.2	gallon (gal)
liter (L)	61.02	cubic inch (in^3)
cubic meter (m^3)	35.31	cubic foot (ft^3)
cubic meter (m^3)	1.308	cubic yard (yd^3)
Flow rate		
meter per second (m/s)	3.281	foot per second (ft/s)
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
Mass		
gram (g)	0.03527	ounce, avoirdupois (oz)
kilogram (kg)	2.205	pound avoirdupois (lb)
Pressure		
kilopascal (kPa)	0.009869	atmosphere, standard (atm)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:
°F=(1.8×°C)+32

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Abstract

The Aries River basin of western Romania has been subject to mining activities as far back as Roman times. Present mining activities are associated with the extraction and processing of various metals including Au, Cu, Pb, and Zn. To understand the effects of these mining activities on the environment, this study focused on three objectives: (1) establish a baseline set of physical parameters, and water- and sediment-associated concentrations of metals in river-valley floors and floodplains; (2) establish a baseline set of physical and chemical measurements of pore water and sediment in tailings; and (3) provide training in sediment and water sampling to personnel in the National Agency for Mineral Resources and the Rosia Poieni Mine. This report summarizes basin findings of physical parameters and chemistry (sediment and water), and ancillary data collected during the low-flow synoptic sampling of May 2006.

Introduction

Reconnaissance surveys were conducted to evaluate water quality in the Tisza River basin. Reconnaissance surveys previously conducted by Forray and Hallbauer (2000) and Bird and others (2003a, 2003b, 2005) focused on the geochemistry and spatial extent of sediment-bound metal pollution in mining-affected tributaries (Aries, Lapus, Somes, and Tisza) of the Tisza River basin. These studies focused on the identification of sediment-associated metal sources that originate from upstream mining activities in the Tisza River basin. Flood events play an important role in the redistribution of sediment-bound metals in channels and floodplains. Catastrophic releases of metals stored in tailings-pond sediment occurred as a result of failure of tailings dams (Macline and others, 2003); however, the mechanisms for dam failure were not fully understood at the time of this study.

To enhance our ability to understand the physical and chemical interaction of metal-mine activities on the environment, this study had three data-collection objectives. The first was to determine the redistribution, storage sites, and mobility of metal contaminants in river valley floors by sampling: (1) a previous water-quality survey of the Aries River basin, (2) floodplains under changing hydrological conditions, and (3) previously unsampled tailings and ground-water sources. The second objective was to collect samples and analyze the metal content of tailings water and sediment for future computer-model evaluation of geochemical interactions leading to tailings dam failure. The third objective was to provide technical training in sediment and water sampling to employees of the National Agency for Mineral Resources (NAMR) and Rosia Poieni mine personnel through field participation with USGS scientists during the surveys. The following sections describe findings of the water and sediment chemistry surveys conducted in the Aries River basin.

Description of Study Areas

The Aries River basin is underlain by bedrock consisting of igneous, metamorphic, and sedimentary assemblages. The igneous rocks are associated with volcanic activity within the Carpathian region (Alderton and Fallick, 2000). Calc-alkaline igneous rocks, particularly porphyritic andesites, are the most abundant rock types, and they host ores of base metals (Cu, Zn, and Pb) and precious metals (Au and Ag). Carbonate-rich bedrock is present in the upper reaches of the Aries valley, upstream of Campeni, and also within the ore deposits at Baia de Aries (Forray and Hallbauer, 2000).

The Aries River basin contains both inactive and active metal mines that may contribute to existing and future pollution. Past mining activity occurred at a number of mines including the EM Bucium, located on a tributary to the Abrudel River that drains into the Aries River (fig. 1). Current mining activity takes place at a number of sites in the Aries River basin, most notably at the Rosia Poieni mine, where a porphyry copper deposit containing 0.4% Cu is exploited through open-pit mining. Mine-waste slurry previously and currently deposited at the respective Stefancei and Valea Sesei tailings dam facilities constitute a potential source of solute and sediment-associated metal contaminants to the Aries River. The Rosia Montana deposit comprises a 20 km^2 concession that is believed to contain 100-150 million tonnes of ore, with Au and Ag contents of 1.9 g $tonne^{-1}$ and 10 g $tonne^{-1}$, respectively. Since the study by Bird and others

(2005), the Rosia Montana mine has become operational using cyanide (CN)-leach methods to process about 13 Mt of ore each year. The Rosia Montana mine also is linked hydrologically to the Aries River system, and therefore its mine waste constitutes a potential source of solute and sediment-associated contaminants to that system.

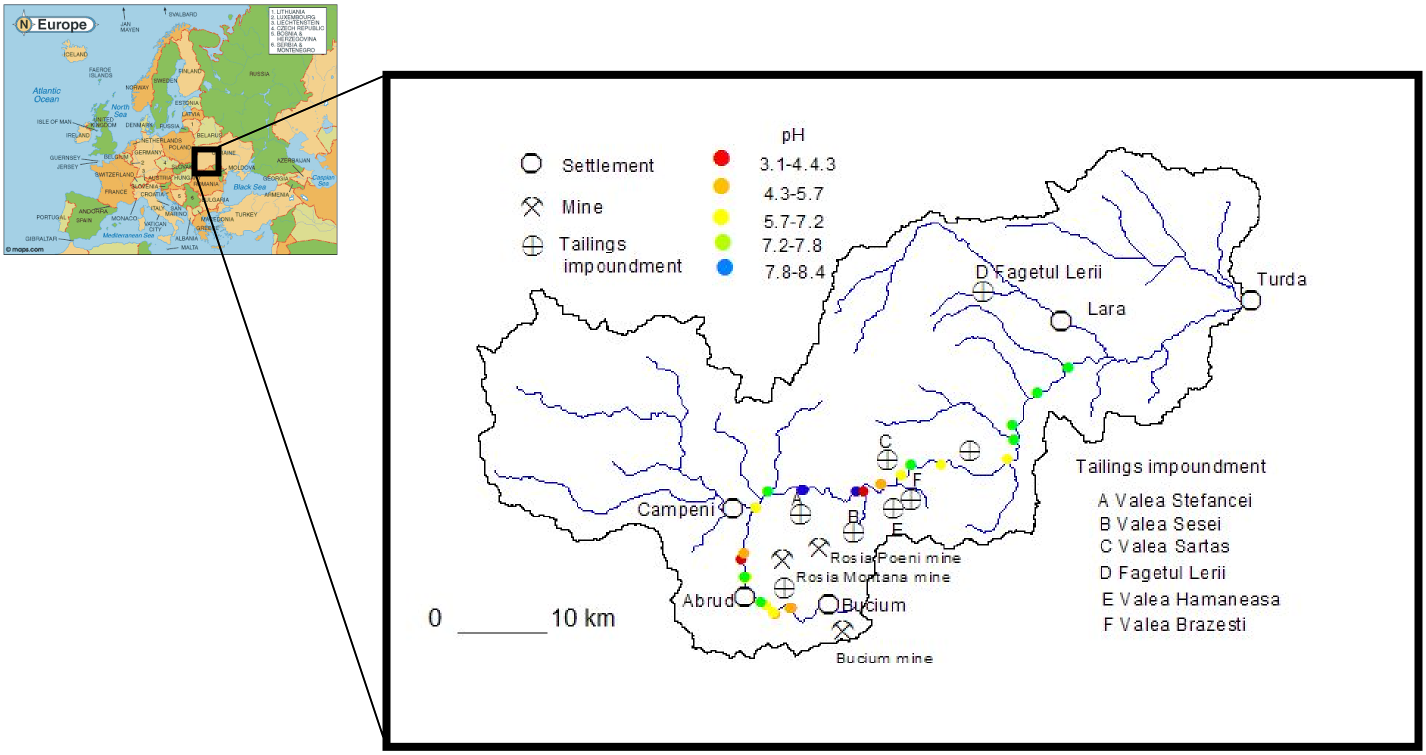


Figure 1. Map of the Aries River basin including studied rivers and tributaries, mines, tailing impoundments (ponds), and location of sampling sites (numbers indicate sample station). The dark line is the boundary of the Aries Basin.

The two tailings dam facilities (TDFs) being studied are the upper Valea Stefancei (fig. 2a-f) and Valea Sesei (fig. 2g-j). Both TDFs are hydrologically connected to the Aries River, with average allowable designed releases of 0.108 $m^3 sec^{-1}$ and 0.263 $m^3 sec^{-1}$ for the Valea Stefancei and Valea Sesei, respectively. Although both TDFs are hydrologically connected to the Aires River, they differ in age, depositional activity, and risk of dam failure.

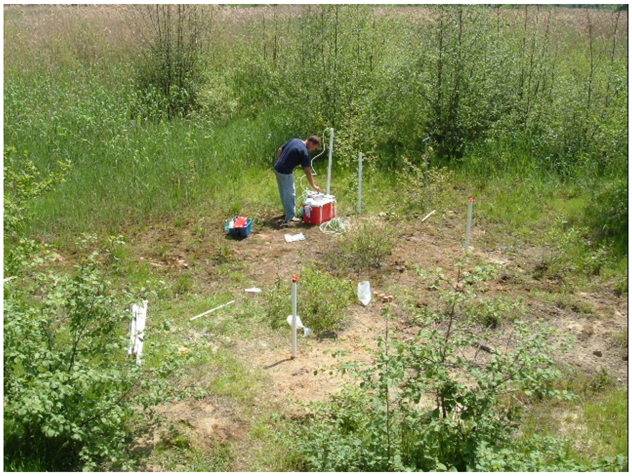
The Valea Sesei TDF is younger (1988-present), active, and has surface desiccation-induced cracks (60 to 80 cm deep and 0.5 to 2 m long). As of May 1, 2006, the 79-m-high Valea Sesei dam was retaining about 30.1 million tons of acid water and metal-associated sediment, covering about a 127-ha area. Early in 2007, the Valea Sesei TDF was expected to reach design capacity, with a 100-m-high dam that retains about 66 million tons of acid water and metal-associated sediment over about a 221-ha area.

The Valea Stefancei TDF is essentially semi-inactive (1980-1998), overgrown with vegetation (riparian-like), and has a dam stability that is of primary concern. The older Valea Stefancei TDF is considered semi-inactive because tailings sediment is deposited here only when problems arise with the processing plant, during extreme weather conditions, or when capacity with the upstream Valea Sesei TDF is exceeded. The inactive, 35-m-high Valea Stefancei dam retains about 9 million tons of acid water and metal-associated sediment (Poputa, personal comm., 2006). At the surface, the Valea Stefancei TDF is at about 750 m elevation and covers about 26 ha.

(a)

(b)

(c)



(d)

(e)

(f)

(g) (h)

(i) (j)

Figure 2. Tailings dam facilities, May 2006, Valea Stefancei tailings impoundment. (A) view of the pond looking north, (B) view of the pond looking south, (C) north view from cased piezometers at dam, (D) sampling piezometers at beach, (E) pH probe at dam piezometers, (F, left) collecting water samples at seep at dam face; Valea Sesei tailings impoundment, (F, right) close-up of seep, (G) beach subsidence pit with tension cracks at dam, (H) beach installation piezometers and lysimeters, (I) piezometers at far side of pond, (J) pond discharge into Aries River (a tributary of the Valea Sesei).

Sediment Chemistry

Field Sampling

Sampling of the Abrud-Aries River system and associated tributaries was conducted near low-flow conditions in May 2006. Samples and measurements were collected in the Abrud-Aries River system from Bucium to a point upstream of Turda to evaluate the dispersal, storage, and remobilization of sediment-associated metals derived from mine sites and to identify future water-quality sampling and monitoring points. In this field study, samples of river-channel sediment and water, and aqueous measurements of dissolved oxygen (DO), electrical conductivity (EC), pH, and temperature, were collected concurrently from twenty-four sites along a 75-km reach of the Abrud-Aries river system (fig. 1). In addition to these samples, river-channel sediment and surface-water samples were collected from six tributaries where mining activities were or are presently conducted upstream of the sampling point (table 1). The six tributaries and their associated mines (listed in order from the headwaters downstream) include the Valea Abuzel (Rosia Poieni mine), Valea Covina (EM Bucium mine), Valea Lalishei (Rosia Montana mine), Valea Rosei (Rosia Montana mine), Valea Stefancei (Rosia Poieni mine), and Valea Sesei (Rosia Poieni mine) at river distances of about 0, 4.0, 8.3, 10.6, 26.7, and 36.0 km, respectively, where the distance downstream is measured from the first sample station located at the Abruzel tributary (Rosia Poieni mine). In addition to in-stream sampling of these tributaries, floodplain and surface-sediment sampling was conducted at the Valea Sesei and Valea Stefancei tailings impoundments (fig. 3). At all sites, a 200–300 g (wet weight) sediment sample was collected using a stainless steel trowel.

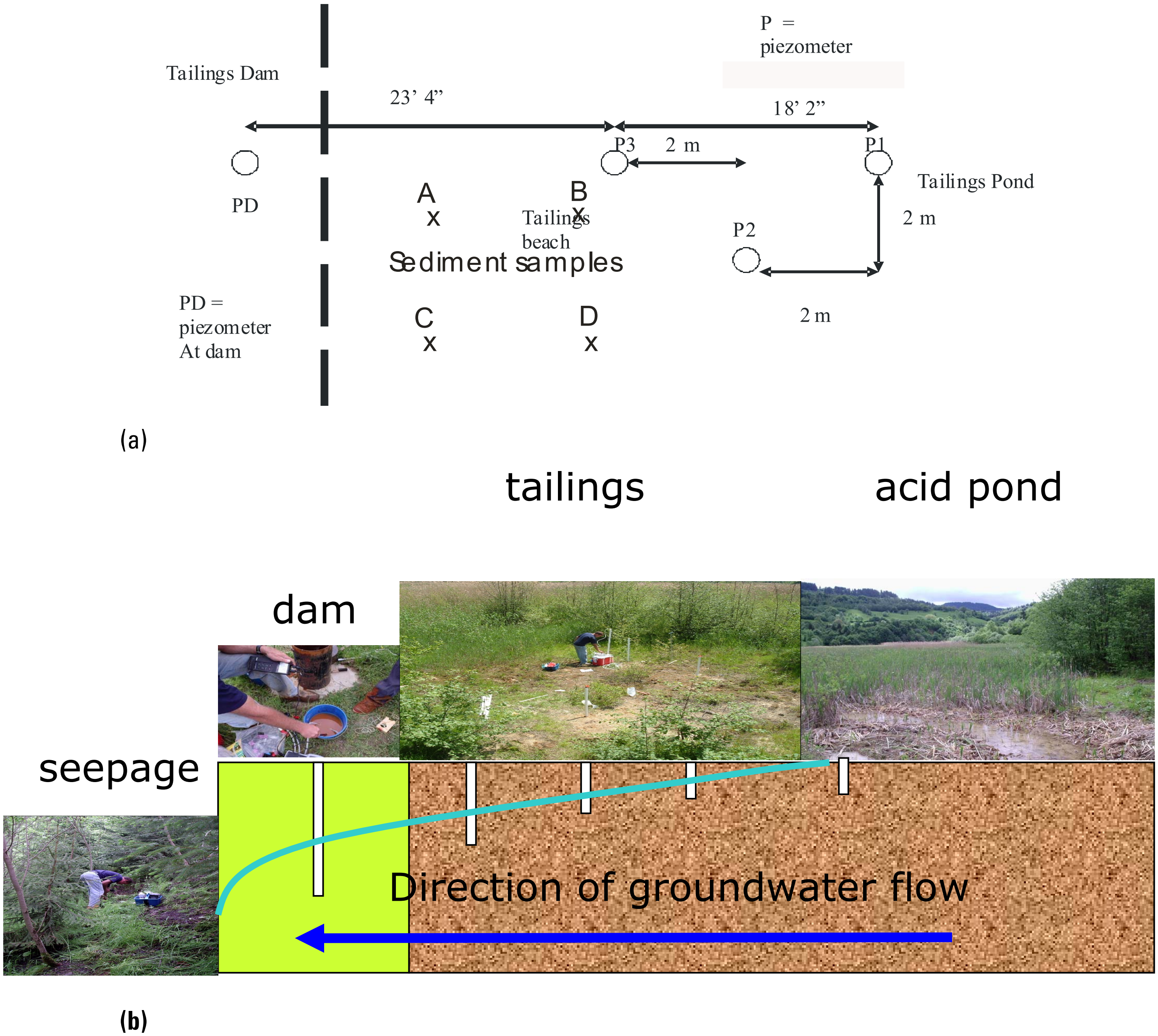


Figure 3. Schematic of (a) sediment and water sample locations, and (b) conceptual hydrologic model, at the Valea Stefancei tailings impoundment.

Table 1. Sample site information (coordinates, distances, elevation), aqueous measurements (conductivity, dissolved oxygen, pH, and temperature), and rivers (feature and names), sampled in the Aries River basin.

[km, kilometer; mg/L, milligrams per liter; µS/cm, microSiemens per centimeter; °C, degrees Celsius; < less than]

Sample Station	Distance downstream (km)	pH	Dissolved oxygen (mg/l)	Conductivity (µS/cm)	Temperature (°C)	River feature	River name	Mine
1	0.00	4.3	9.0	917	12.7	Tributary	Valea Abruzel	Rosia Poieni mine
2	0.08	5.6	8.3	313	12	Tributary	Bucium	EM Bucium mine
3	0.24	5.5	8.0	413	11.9	Tributary	Bucium	EM Bucium mine
4	2.43	5.7	8.1	255	12.3	Tributary	Abrudel	Upstream Bucium confluence
5	2.62	6.8	8.8	271	12.3	Tributary	Abrudel	
6	3.95	7.1	8.6	475	12.4	Tributary	Valea Covina	??? mine
7	4.71	7.4	8.5	368	12.5	Tributary	Abrudel	
9	8.19	7.1	6.4	355	15.1	Tributary	Abrudel	
10	8.29	6.7	8.0	688	13	Tributary	Valea Lalishei	Rosia Montana mine
11	8.58	7.5	6.9	633	14.5	Tributary	Abrudel	Rosia Montana mine
12	10.59	3.1	7.0	1866	13.9	Tributary	Valea Rosei	Rosia Montana min
13	11.49	5.4	6.9	929	14.2	Tributary	Abrudel	
14	17.26	5.4	7.5	916	13.8	Mainstem	Abrudel	
15	19.18	7.2	7.5	111	13.4	Mainstem	Aries	Upstream Abrudel confluence
16	21.36	7.6	6.7	134	14	Mainstem	Aries	
17	26.64	8.4	7.0	122	14.3	Mainstem	Aries	
18	26.74	8.1	6.6	308	16.5	Tributary	Valea Stefancei	Rosia Poieni mine
19	34.87	8.1	6.4	125	24.4	Mainstem	Aries	
20	35.94	3.5	5.2	2195	14.1	Tributary	Valea Sesei	Rosia Poieni mine
21	40.62	5.3	5.8	193	15.4	Mainstem	Aries	
22	40.68	5.2	5.9	181	15.1	Mainstem	Aries	
23	43.34	7.0	5.1	194	12.9	Mainstem	Aries	
24	45.74	7.5	5.4	180	14.4	Mainstem	Aries	
25	50.23	6.9	7.5	177	14.7	Mainstem	Aries	
26	59.11	7.0	8.5	187	14.7	Mainstem	Aries	

27	63.54	7.4	6.3	160	13.8	Tributary	???	
28	66.06	7.8	6.5	161	15.2	Mainstem	Aries	
29	71.46	7.6	8.0	196	15.3	Mainstem	Aries	
30	76.85	7.7	6.6	195	15.2	Mainstem	Aries	

Physical Properties and Mineralogy of Tailings Sediment

To understand the geochemical interaction, fate, and transport that leads to deterioration and sometimes catastrophic failure of tailings dams, the physical properties of tailings sediment samples were analyzed for future input to vadose zone transport and geochemical models. Ten tailings sediment samples (5 samples per site) were collected at the Valea Sesei and Valea Stefancei tailings impoundments. The analysis of physical properties for these samples was accomplished through a variety of published laboratory and field methods.

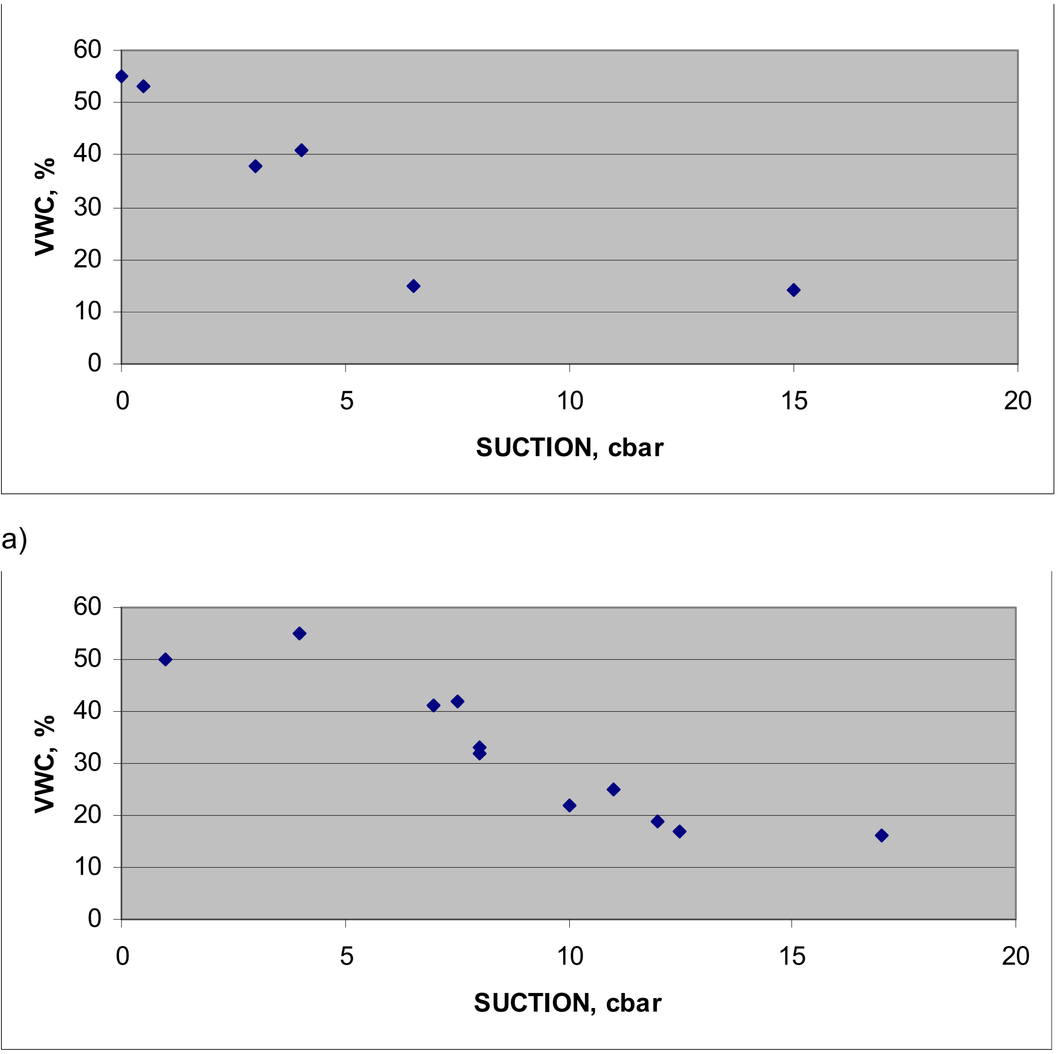
The ten tailings sediment samples were analyzed at the USGS Vadose Zone Laboratory (VZL). Analyses performed at the VZL included particle-size analysis, soil class, saturated hydraulic conductivity, bulk density, porosity, and moisture retention characteristics (table 2). All analyses were performed in accordance with standards developed by the American Society for Testing and Materials (ASTM) or other approved technical procedures (Blake and Hartge, 1986; Gee and Bauder, 1986; Klute, 1986; Klute and Dirksen, 1986). Classification of textural-size fractions uses the U.S. Department of Agriculture system (Tindall and Kunkel, 1999).

Table 2. Average physical properties of tailings sediment (10 samples).

Tailings Site	Soil Class	Percent sand-sized grains	Percent silt-sized grains	Percent clay-sized grains	Saturated hydraulic conductivity (m day^{-1})	Bulk density (Kg m^{-3})	Porosity
Valea Sesei	Sandy Loam	75	15	12	2.26×10^{-1}	1.24	0.54
Stefancei upper	Loamy Sand	80	10	9	3.73×10^{-1}	1.30	0.53

Field analysis of surface moisture retention was conducted using a combination of a Campbell Scientific time-domain reflectometer and a Soil Moisture Systems moisture suction probe. Pairs of moisture-suction measurements were recorded and plotted, revealing a complete profile of surface retention behavior for both the Stefancei and Sesei tailings beach sites (fig. 4). Construction of a complete retention profile underscores the heterogeneous nature of surface moisture. Because of the consistency in surface physical properties, the heterogeneous moisture content is attributed to gravitational potential associated with undulations in surface topography and lateral moisture migration toward surface tension cracks.

X-ray diffraction analyses of two sediment samples (one per tailings impoundment) show the most abundant mineral to be quartz, with subordinate albite and trace amounts of muscovite, pyrite, and other clay and silicate minerals (table 3). Two observations are pertinent here. First, the mineralogy suggests that at the surface, the trace-metal-bearing sulfide minerals have been mostly leached. Second, the infiltration of water through pyrite-laden tailings will likely result in the lowering of in situ pH. The changing pH of pore water caused by variations in oxygen and temperature results in a complex geochemical environment.



(a)

(b)

Figure 4. Comparison of surface moisture retention using volumetric water content (VWC) as a function of suction in centibar (cbar) in beach sediment associated with tailings dam facilities: (a) Valea Stefancei, and (b) Valea Sesei.

Table 3. Mineralogy of surface tailings sediment determined using x-ray diffraction.

Stefancei Upper mine tailings impoundment	
Phase – ID	
Quartz – SiO_2	Major
Albite – $Na(Si_3Al)O_8$	Minor
Muscovite - 2M1 - $KAl_2 (Si_3Al)O_{10}(OH,F)_2$	Trace
Nontronite - 15A - $NaO.3Fe_2Si4O_{10} (OH)_2*4H_2O$	Trace
Clinochlore - 1MIIb - $(Mg,Fe0_6(Si,Al)4O_{10} (OH)_8$	Trace
Jarosite - $(K,H_3O)Fe_3 (SO_4)_2 (OH)_8$	Trace
Kaolinite - 1A - $Al_2Si_2O_5(OH)_4$	Trace
Magnesiohornblende - $Ca_2 (M,g,Fe^{+2})_4Al(Si_7Al)O_{22}(Oh,F)_2$	Trace
Pyrite - FeS_2	Trace

Vale Sesei mine tailings impoundment	
Phase – ID	
Quartz, SiO_2	Major
Albite – $Na(Si_3Al)O_8$	Minor
Muscovite - 2M1 - $KAl_2 (Si_3Al)O_{10} (OH,F)_2$	Trace
Orthoclase - $KAlSi_3O_8$	Trace
Clinochlore - 1MIIb - $(Mg,Fe0_6(Si,Al)_4O_{10} (OH)_8$	Trace
Kaolinite - 1A - $Al_2Si_2O_5(OH)_4$	Trace
Pyrite - FeS_2	Trace

Sediment Processing and Analytical Chemistry

All sediment samples were air-dried, disaggregated, and sieved through a stainless steel mesh to isolate the <63 µm fraction. Sediment samples were then digested in concentrated (70%) HNO_3 at 100°C for 1 hour, and metal concentrations (Cd, Cu, Pb, Zn, and others) were determined using an ICP-MS (Lamothe and others, 1999). Although concentrated HNO_3 does not provide a complete sediment digestion, it has been widely used in previous studies investigating metal contamination in mining-affected river basins (Bird and others, 2003a, 2003b, 20005).

Sediment-Associated Metal Concentrations

In this section, sediment-associated metal concentrations for the Abrud-Aries river system, including the channel, floodplain, and Stefancei and Sesei tailings impoundments, are presented (table 4) together with multiple soil/sediment toxicological benchmarks. For example, the respective pairs of Dutch (Visser, 1995) and US toxicity benchmarks (MacDonald and others, 1994) include values for the target level (the lower value) and intervention level (the higher value), and the threshold effect level (the lower value) and probable effect level (the higher value). The threshold effect level is defined as the upper limit of the range of sediment contaminant concentrations dominated by no adverse biological effects. The probable effect level represents the lower limit of the range of contaminant concentrations that are associated with adverse biological effects (MacDonald and others, 1994). Because the Dutch guidelines are similar defined but not identical, both sets of benchmarks are presented for a more robust evaluation of the sediment chemical data. Both sets of standards have a long history of use in setting soil/sediment protection policies and guidelines based on eco-toxicological methods and human health considerations. These benchmark criteria were adopted and used in various European and US metal-mine-related pollution studies (Macklin and Klimek, 1992; Macklin and others, 2003; Jones and others, 1997) and are routinely used in basin studies to evaluate sediment quality.

Table 4. Downstream concentrations of selected metals in river channel and floodplain sediment of the Abrud-Aries River system. The distance downstream is measured from the first sample station located at the Abruzel tributary (Rosia Poieni mine).

[mg kg^{-1}, km - kilometer]

Downstream distance Km	As mg kg^{-1}	Cd mg kg^{-1}	Cu mg kg^{-1}	Pb mg kg^{-1}	Zn mg kg^{-1}	River Name	Mine
0.00	17.4	0.36	127	30.4	113	Abuzel	Rosia Poieni mine
0.08	16.6	2.6	325	45.4	609	Bucium	EM Bucium mine
0.24	19.9	0.72	264	45.5	249	Bucium	EM Bucium mine
2.43	15.1	1.2	332	76.8	285	Abrudel	Bucium confluence
2.62	10.7	0.46	116	34.7	157	Abrudel	
3.95	58.5	1.1	186	49.7	405	Valea Covina	
4.71	8.1	0.59	76.5	44.3	172	Abrudel	
8.19	11	1.5	165	31.3	325	Abrudel	
8.29	160	2.3	75.1	104	651	Valea Lalishei	Rosia Montana mine
8.58	21.2	2.1	330	49.7	552	Abrudel	Rosia Montana mine
10.59	234	0.38	77.2	49.1	177	Valea Rosei	Rosia Montana mine
11.49	49.9	3.2	265	70.6	820	Abrudel	
17.26	72.8	5.3	153	75.9	1050	Abrudel	
19.18	14.4	0.45	53.8	59.8	164	Aries	Abrudel confluence
21.36	25.5	1.8	108	157	365	Aries	
26.64	20.4	1.7	107	44.2	366	Aries	

26.74	37.1	0.4	431	35.1	94.6	Valea Stefancei	Rosia Poieni mine
34.87	29.3	2.4	302	63	484	Aries	
35.94	34.8	0.3	503	45.5	142	Valea Sesei	Rosia Poieni mine
40.62	37.4	1.5	924	107	338	Aries	
40.68	51.3	2.6	702	118	535	Aries	
43.34	38.4	0.7	40.4	52.4	198	Aries	
45.74	22.6	1.4	570	52.8	340	Aries	
50.23	47.8	1.6	451	84	364	Aries	
59.11	76.5	3.6	665	220	775	Aries	
63.54	16	0.19	27.3	18.9	87.7	???	
66.06	26.5	1.5	234	42.7	279	Aries	
71.46	44.9	4.5	794	50.8	756	Aries	
76.85	23	1.7	476	40.4	382	Aries	
63.54	20.5	0.39	73.2	33.9	144	Aries floodplain	
66.06	26.8	0.66	113	48.1	189	Aries floodplain	
71.46	**169**	2.3	94.3	117	449	Aries floodplain	
76.85	38.3	0.27	42.6	27.6	101	Aries floodplain	

Abrud-Aries River System

The basin sediment sampling campaign (30 locations) may be treated as a single population, and the metal concentrations vary over a wide range of statistical values (table 5). Of the selected sediment-associated metals, the only pair of metals characterized by a strong relation (with a correlation coefficient 0.97) is Cd and Zn (table 6). This strong correlation is typically apparent where Cd is substituted for Zn in the mineral sphalerite [(Zn,Fe) S]. This is particularly true where dissolution and/or precipitation of sphalerite is likely. Whereas either Cd or Zn can be used as a predictor for the other, the relations between other metals are weak. The weak correlations may have something to do with sorption, kinetics, and redistribution during flood events. For this reason, the probability of exceeding the benchmarks for the selected metals was computed (table 7). With the exception of Cu, the probability for exceeding the benchmarks differs between the US and Dutch systems. Using the US system, which is considered more conservative, the probability for exceeding the threshold effect level (low) for As, Cd, Cu, Pb, and Zn is 100, 100, 100, 91, and 87.5%, respectively, and the probability of exceeding the probable effects level (high) is 51.9, 4, 69, 11, and 60.5%. The relative likelihood for pollution by the selected metals is, from high to low: Cu>Zn>As>Cd.

Table 5. Summary statistics for selected sediment-associated metals in the Aries River basin.

[mg kg^{-1}, milligrams per kilogram]

Statistics	**As** mg kg^{-1}	**Cd** mg kg^{-1}	**Cu** mg kg^{-1}	**Pb** mg kg^{-1}	**Zn** mg kg^{-1}
0%	8.1	0.2	27.3	18.9	87.7
5%	10.9	0.3	41.7	29.3	98.4
50%	26.8	1.5	186	49.7	338
95%	164	4.0	743	136	795
100%	234	5.3	924	220	1050
Average	45.3	1.6	279	64.4	367
Standard deviation	26.7	1.5	210	49.7	339
Range	226	5.1	897	201	962

Table 6. Correlation matrix for selected sediment-associated metals in the Aries River basin.

[As – arsenic, Cd – cadmium, Cu – copper, Pb – lead, Zn – zinc.]

	As	*Cd*	*Cu*	*Pb*	*Zn*
As	1.00				
Cd	0.13	1.00			
Cu	-0.08	0.36	1.00		
Pb	0.24	0.44	0.36	1.00	
Zn	0.22	**0.97**	0.29	0.46	1.00

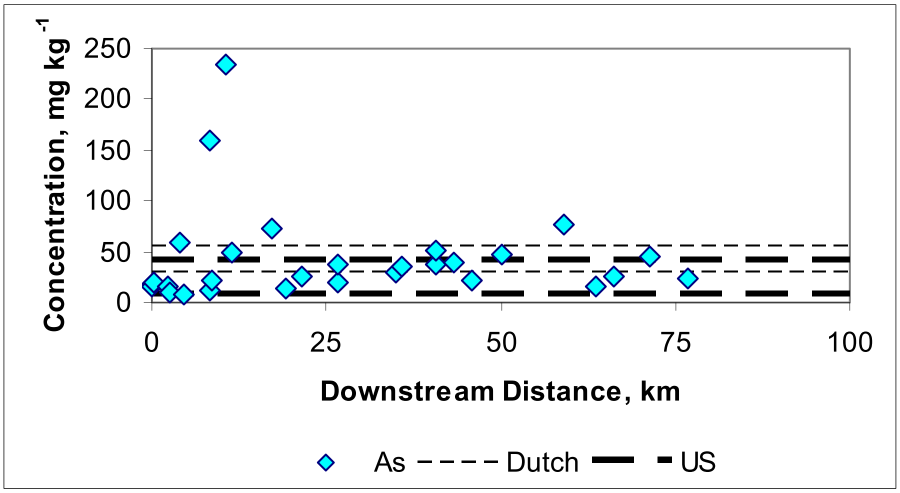
The concentration of selected metals (As, Cd, Cu, Pb, and Zn) found in the Abrud-Aries river channel sediment is shown in figure 5, together with the associated benchmarks. In all cases, concentrations of these five metals exceed the low benchmarks, showing the likelihood for some adverse effects on in-stream biota and the potential for human-health concerns where these biota, such as fish, are consumed. In many cases, downstream metal concentrations exceed both of the high benchmarks, which again indicates probable adverse effects on in-stream biota and human health. Of the selected metals, As is the only metal that occurs at sample locations of mining-associated tributaries. For example, the greatest As concentrations of 160 and 234 mg kg^{-1} were measured downstream from the mouths of the Valea Lalishei and Valea Rosei, both sampling points associated with the Rosia Montana mine. The four largest observed Cu concentrations also all occur downstream from the confluence of mining-associated tributaries. In contrast, the largest five Cd concentrations appear to be spread out over the complete study reach from distances of 0.08 to 71.5 km, and none of the locations are directly associated with mining-related tributaries. Like Cd, the largest sediment concentrations of Pb also span the study reach and show no direct correlation to mining-related tributaries.

Table 7. Exceedance probabilities for selected sediment-associated metals in the Aries River basin.

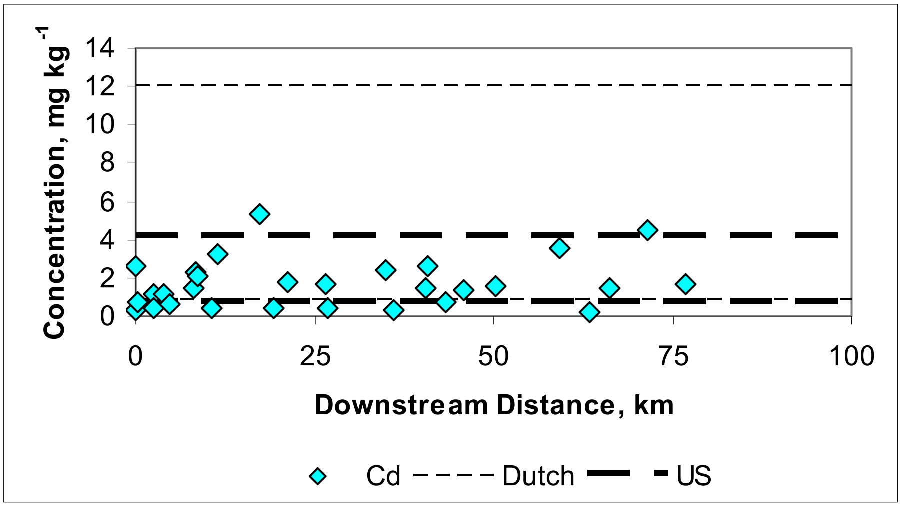
[% percent.]

Country	Guidelines	Probability of exceedance in Aries River basin,%				
		As	**Cd**	**Cu**	**Pb**	**Zn**
Netherlands	Target (low)[1]	47	62	97.5	18.5	87.5
Netherlands	Intervention (high)[1]	17.5	0	52	0	10.5
United States	Threshold effect level (low)[2,3]	100	100	100	91	87.5
United States	Probable effects level (high)[2,3]	51.9	4	69	11	60.5

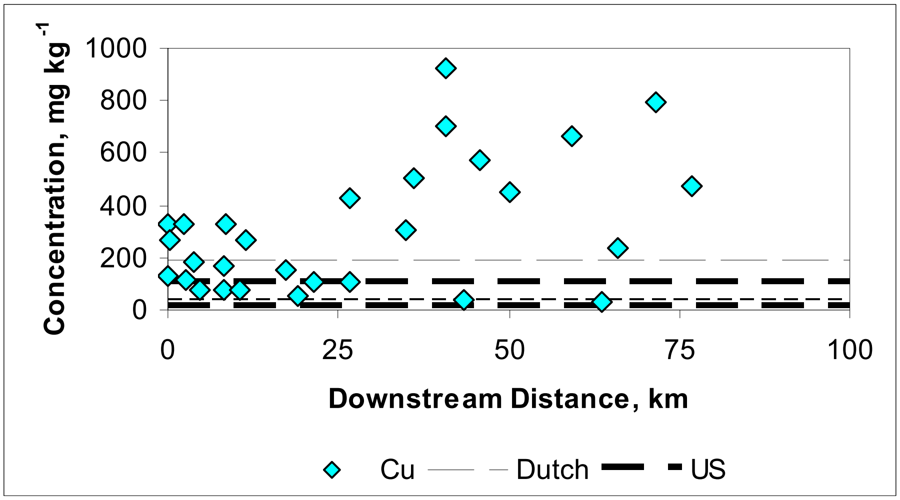
[2]MacDonald and others, 1994; [3]Jones and others, 1997



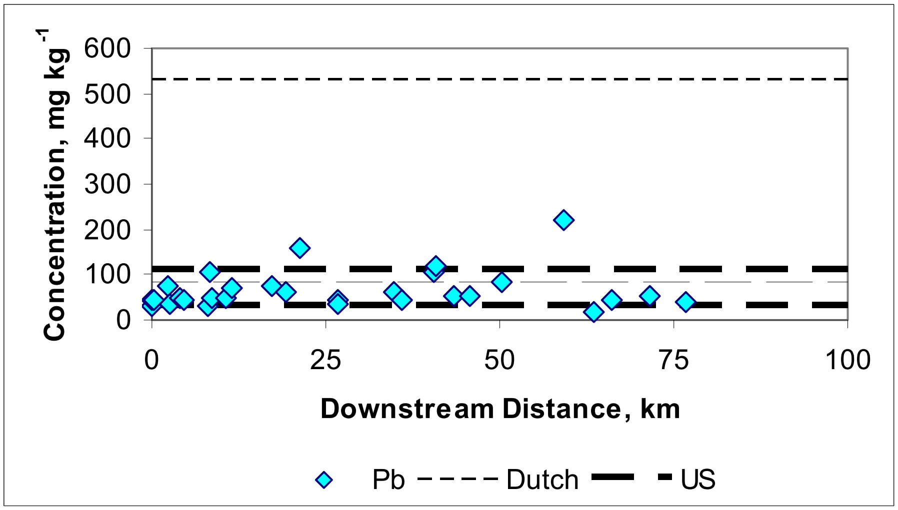
(a)


Concentration, mg kg^{-1}
14
12
10
8
6
4
2
0
0
25
50
75
100
Downstream Distance, km
Cd
Dutch
US

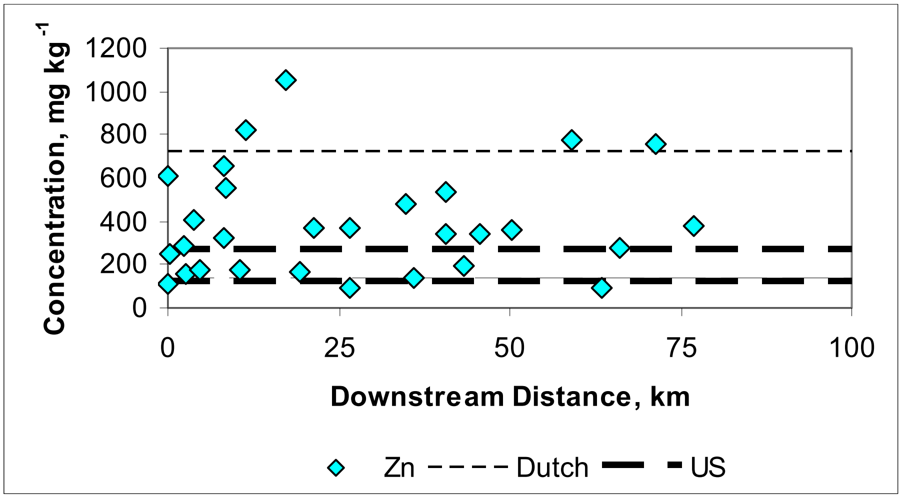
(b)


Concentration, mg kg^{-1}
1000
800
600
400
200
0
0
25
50
75
100
Downstream Distance, km
Cu
Dutch
US

(c)


Concentration, mg kg^{-1}
600
500
400
300
200
100
0
0
25
50
75
100
Downstream Distance, km
Pb
Dutch
US

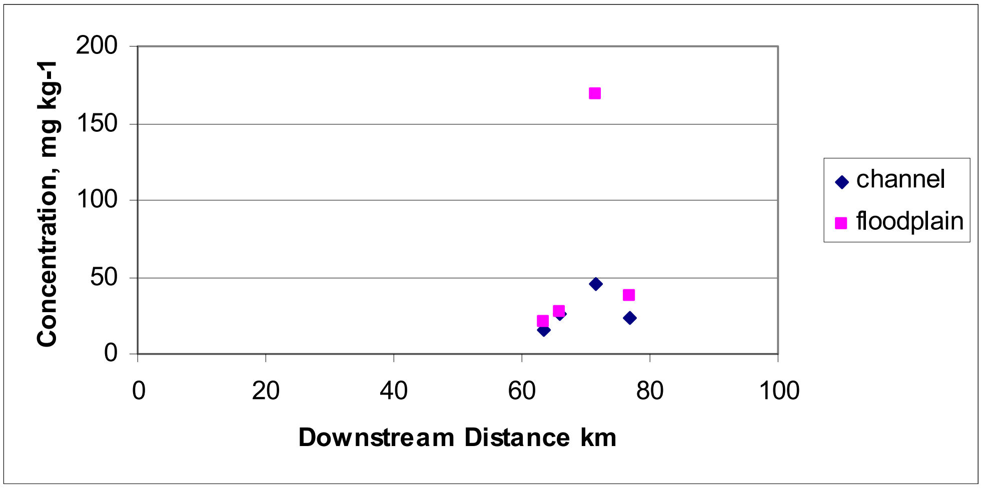
(d)



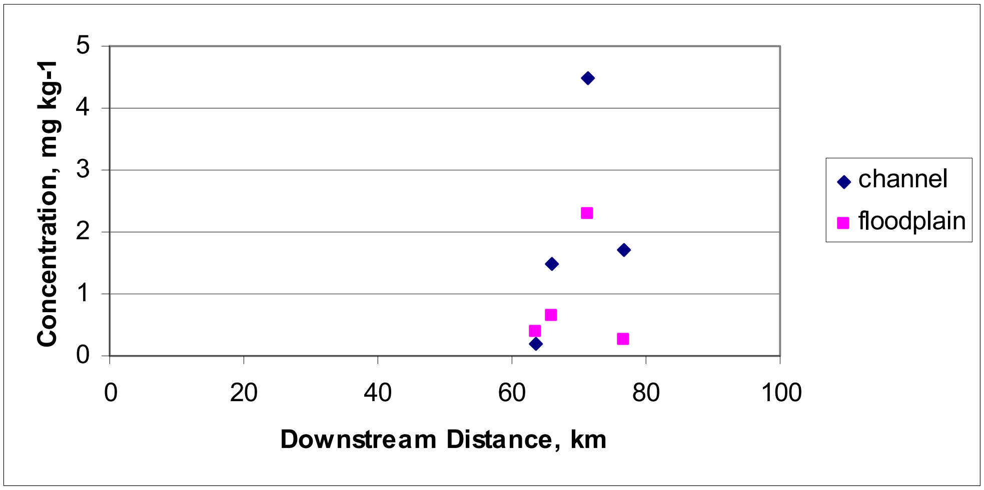
(e)

Figure 5. Concentrations of selected metals in river-channel sediment in the Abrud-Aries River system: (a) As, (b) Cd, (c) Cu, (d) Pb, and (e) Zn. The distance downstream is measured from the first sample station located at the Abruzel tributary (Rosia Poieni mine). The lower benchmark is called the threshold effect level and is defined as the upper limit of the range of sediment contaminant concentrations dominated by no adverse biological effects. The upper benchmark is called the probable effect limit and is defined as the lower limit of the range of contaminant concentrations that are associated with adverse biological effects.

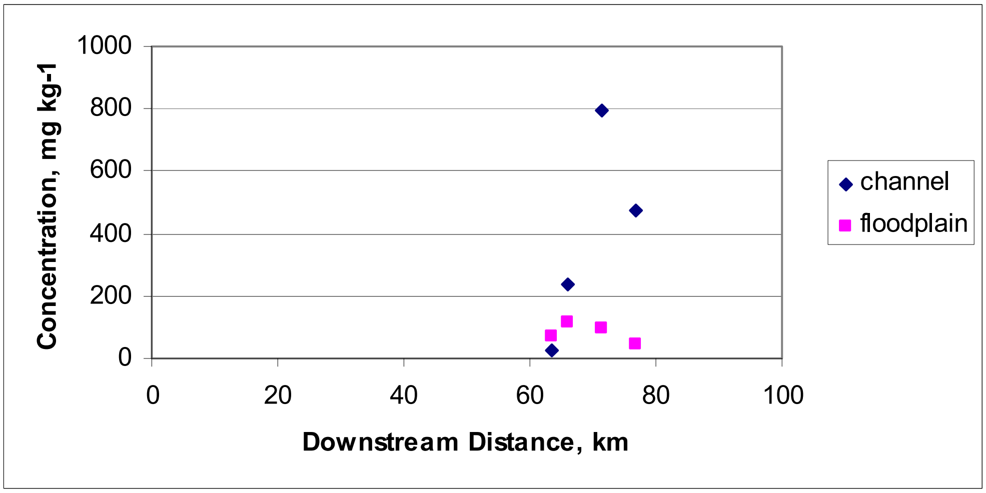
At the time of this survey, the upper portion of the sampled reach did not have a well-defined floodplain. For this reason, only limited sampling was conducted, beginning about 60 km downstream from the first sample location (table 4). Sediment concentrations for both the channel and floodplain are variable, with peak metal values occurring at about 71.5 km (fig. 6). These peak concentrations occur about 7.9 km downstream from the confluence of an unnamed tributary with the Aries River. The relation between sediment concentrations sampled in the channel to those of the floodplain are strong and positive for As, Cd, and Zn, with respective correlation coefficients of 0.95, 0.92, and 0.84. Less prominent is the relation between Pb concentrations as shown by an intermediate correlation coefficient of 0.65. Interestingly, there was no correlation found between Cu concentrations in the channel and in floodplain sediment, despite the fact that Cu concentrations in the channel sediment displayed the strongest exceedance characteristics for both the US and Dutch guidelines.


Concentration, mg kg-1
200
150
100
50
0
0
20
40
60
80
100
Downstream Distance km
◆ channel
■ floodplain

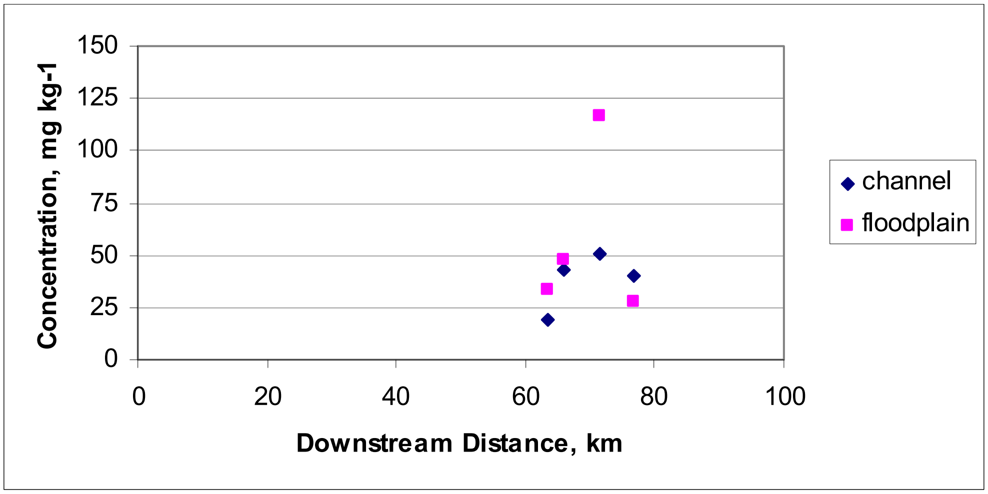
(a)


Concentration, mg kg-1
5
4
3
2
1
0
0
20
40
60
80
100
Downstream Distance, km
◆ channel
■ floodplain

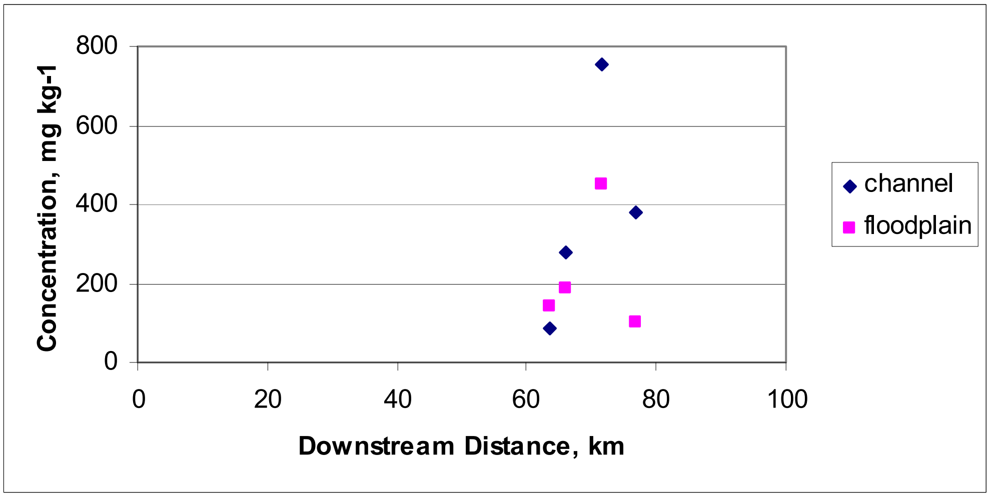
(b)


Concentration, mg kg-1
1000
800
600
400
200
0
0
20
40
60
80
100
Downstream Distance, km
◆ channel
■ floodplain

(c)



(d)



(e)

Figure 6. Concentrations of selected metals in downstream sediments from the channel bed and floodplain of the Aries River, Romania: (a) As, (b) Cd, (c) Cu, (d) Pb, and (e) Zn.

Water Chemistry

Water samples and measurements of physical parameters in the Aries River basin were collected to evaluate the occurrence and distribution of solute metals in relation to mine sites and to identify future water-quality sampling and monitoring points. Samples of river water were collected during low-flow conditions in May 2006 from Bucium to a point upstream of Turda (fig. 2), as well as from various mining-affected tributaries (table 2). Surface and ground-water samples were also collected from the Stefancei and Sesei tailings impoundment sites (fig. 3). Measurements of physical parameters, such as dissolved oxygen (DO), electrical conductivity (EC), pH, and temperature (T), were collected simultaneously with the water samples.

Water Collection and Analytical Methods

Surface water samples were collected from sites having flowing water, and subsurface water samples were collected following the purging of up to three volumes of water from lysimeters (4.8 cm in diameter and 60 cm in length, with 2-bar ceramic cups) and piezometers (flush-threaded, 5-cm-diameter, schedule-40 polyvinyl chloride casing and screen). During purging, measurements of specific conductance, pH, water temperature, and dissolved oxygen were monitored using a flow-through chamber until consecutive stable readings were obtained, then water samples were collected. Water in the unsaturated zone (soil water) was collected from suction-cup lysimeters installed at the tailings sites. A 60-centibar vacuum was applied to the sample-chamber/ceramic-cup assembly to move soil water into the lysimeter. Ground water in the saturated zone was collected from existing or newly installed piezometers at the tailings sites. Either a suction or peristaltic pump was used to draw water from the piezometers.

All waters were filtered in the field through a 0.45-μm disposable capsule filter and captured in clean polyethylene or amber glass bottles that were rinsed on-site with filtered native water. Water samples for anion analysis were filtered and deacidified, whereas water samples for trace elements and iron speciation (redox pairs) were filtered and preserved with about 2 mL of 7.5–7.7 N nitric acid and 2 mL of 50% sulfuric acid, respectively. All water samples were kept chilled in a cooler with ice.

Chemical analyses of water collected from surface, soil, and ground water were conducted at the USGS Geologic Division Laboratory in Denver, Colorado, USA, using the methods of Fishman (1993) and Zaugg and others (1995). Analyses of dissolved major and trace elements were conducted using an elemental inductively coupled plasma–mass spectrometer (ICP-MS; Lamothe and others, 1999) and inductively coupled plasma–atomic emission spectrometry (ICP-AES, Briggs and Fey, 1996). Standard titration methods were used to determine bicarbonate concentrations, and arsenic and iron speciation concentrations were determined using atomic fluorescence spectrometry (AFS; Moreno and others, 2000) and the ferrozine method (Bangthanh T. and others, 1999). Blank and replicate samples also were collected and used to assess the combined effects of procedures on measurement variability (quality control). Laboratory measurements of conductivity and pH were recorded as a check against field measurements.

Physical Parameters

Findings for aqueous physical parameters and dissolved constituents in the water samples are shown as a statistical summary (table 8) and as correlation coefficients (table 9). Comparing these coefficients with the physical parameters for the Abrud-Aries River system (fig. 7), a strong negative correlation (-0.77) is present between EC and pH; that is, EC increases with decreasing pH. There also are weak positive and negative pairwise correlations between T and pH (0.32), and T and DO (-0.39). Pairwise correlation between T and EC is lacking, although there seems to be a temporal correlation, with about an apparent five-day lag. Of these relations, conductivity is the most obvious predictor of mine-affected solute concentrations.

Table 8. Summary statistics of aqueous physical parameters measured in the Abrud-Aries river system, May 2006 (N=30).

[mg/L, milligrams per liter; µS/cm, microsiemens per centimeter; °C, degrees Celsius; < less than]

Statistic	pH	Dissolved oxygen mg/l	Conductivity µS/cm	Temperature °C
minimum	3.1	5.1	111	11.9
maximum	8.4	9.0	2195	16.5
average	6.5	7.2	456	13.9
median	7.0	7.0	255	14.1
standard deviation	1.4	1.1	503	1.20

Table 9. Correlation matrix of aqueous physical parameters measured in the Abrud-Aries river system, May 2006 (N=30).

[mg/L, milligrams per liter; µS/cm, microSiemens per centimeter; °C, degrees Celsius; < less than]

	pH	Dissolved oxygen mg/l	Conductivity µS/cm	Temperature °C
pH	1			
Dissolved oxygen mg/l	-0.04	1		
Conductivity µS/cm	-0.77	-0.09	1	
Temperature °C	0.32	-0.39	-0.16	1

The physical parameters for the Abrud-Aries river system (fig. 7) reveal three primary anomalies at sample locations at downstream distances of 0, 10.6, and 35.9 km that are associated with the tributaries Valea Abruzel (Rosia Poieni mine), Valea Rosei (Rosia Montana mine), and Valea Sesei (Rosia Poieni mine), respectively. Downstream, the pH generally increases (becoming more basic), and conductivities decrease, probably due to stream dilution. There also are less prominent increases in conductivity downstream from these primary peaks that correspond to the confluence of two other tributaries. Specifically, the conductivity increases from a background value to 475 and 308 µS/cm at distances of 3.9 and 26.7 km that are associated with the Valea Stefancei (Rosia Poieni mine) and Valea Covina (unknown mine) tributaries.

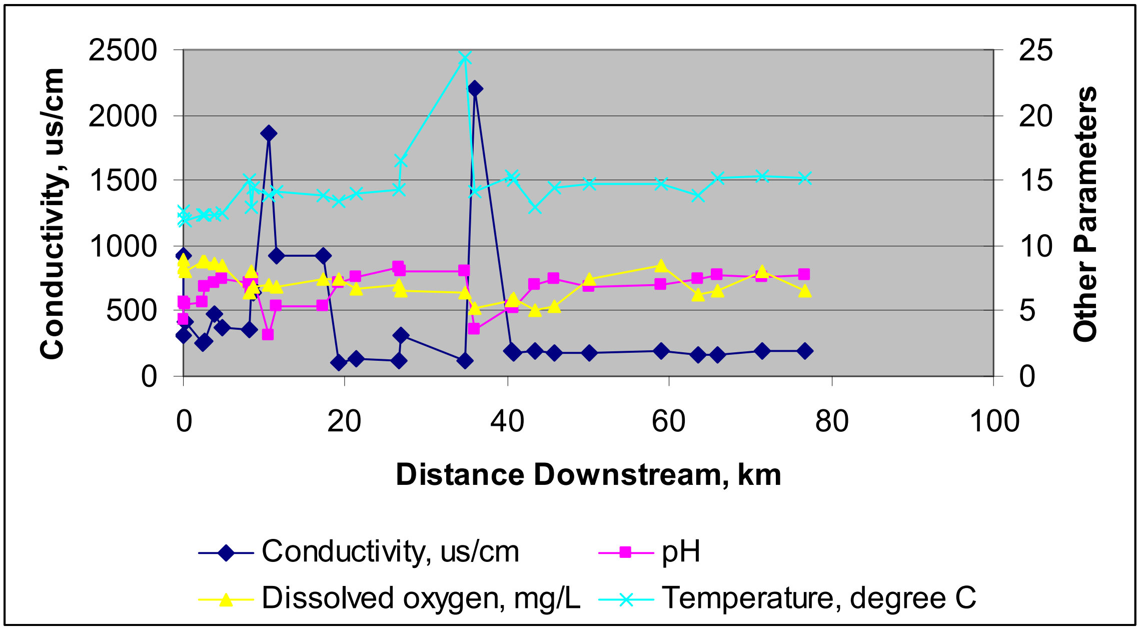


Figure 7. Aqueous physical-parameter measurements (conductivity, dissolved oxygen, pH, and temperature) for the Abrud-Aries river system. The distance downstream is measured from the first sample station located at the Abruzel tributary (Rosia Poieni mine).

Dissolved Constituents

A summary of solute concentrations for the dissolved ions analyzed in surface and ground water samples and related physical parameters measured on-site during sample collection are given in tables 8-9. Statistical summaries of dissolved constituents (major, trace, and rare elements) in surface and ground water at the tailings sites are provided in tables 10-16. In each of these tables, the U.S. Environmental Protection Agency (USEPA) national drinking-water standards (*http://www.epa.gov/safewater /mcl.html*) are provided as a frame of reference for the relative quality of collected samples.

Abrud-Aries River System

The major dissolved ions Al, Ca, Cu, Fe, K, Mg, Mn, Na, P, SiO_2, SO_4, and Zn account for the bulk of dissolved constituents in water sampled. In natural environments unaffected by anthropogenic sources, these dissolved constituents generally are derived from rock/water interactions; however, reuse of water can increase constituent concentrations through repeated exposure to weathered minerals or through evaporation that removes water but leaves dissolved metallic ions behind. Evaporative concentration would tend to increase the concentration of all dissolved ions, whereas exposure to weathered rock would affect only selected constituents. Many of these dissolved constituents exceed the USEPA maximum contaminant levels at tributaries associated with upstream mining activities, which suggests a strong anthropogenic influence.

Stefancei and Sesei Tailings Impoundments

The major dissolved ions Al, Ca, Cu, Fe, K, Mg, Mn, Na, P, SiO_2, SO_4, and Zn account for the bulk of dissolved constituents in water sampled at the Valea Sesei and Valea Stefancei tailings impoundment sites (tables 10-12). At these two sites, the elevated major-ion chemistry of the collected water samples indicates a drinking water resource of generally poor quality. Although some water samples had sufficient dissolved ions to be considered "hard" water, the U.S. drinking-water standards for dissolved solids (the sum of major dissolved ions dissolved in water; Boyd, 1999) were, for the most part, not exceeded (United States Environmental Protection Agency, 1986).

Notable exceptions include the large concentrations of Al, Ca, and sulfate in the piezometers and Valea Sesei tributary exiting the tailings impoundment and flowing toward the Aries River. More problematic from a human-health perspective are the number of samples that exceeded the maximum contaminant level for the dissolved trace elements As, Ba, Be, Cd, Co, Cr, Cu, Mo, Ni, Pb, Se, Sr, and U at both tailings impoundments (tables 13). While rare earth elements were present, none of their concentrations posed a potential ecological or human-health hazard (table 14).

The physical parameter measurements, redox environment (table 11), and pore fluid chemistry from samples along a flowpath (fig. 3b) through the Stefancei tailings impoundment are geochemically noteworthy (tables 12-13). For example, whereas the ground water is generally well-oxygenated at both tailings impoundment sites, the oxygen content at the Stefancei tailings diminishes along a flowpath from the pond to the seep about 2/3 of the way down the dam face. Dissolved oxygen concentrations of two water samples near the dam seep are almost suboxic (less than 1.0 mg/L). Suboxic dissolved-oxygen conditions often affect the concentration of other dissolved constituents by altering the oxidation/reduction and dissolution/precipitation reactions in the groundwater environment. In a similar manner, the pH, redox, and chemistry of water also appear to change along the flowpaths. Quantifying the effect of changing redox conditions and their influence on reactions is important for understanding the deterioration of the earth dam structures and devising dam failure mitigation strategies.

Table 10. Station identification and location description of tailings water samples.

[m, meter]

Sample site ID	Location	Depth (m)
SU1P1R	Valea Stefancei upper tailings at beach piezometer 1	1
SU1PND	Valea Stefancei upper tailings at pond	0
SU1P1	Valea Stefancei upper tailings at beach piezometer 1	0.46
SU1LSM1	Valea Stefancei upper tailings at beach lysimeter 1	0.6
SU1P2	Valea Stefancei upper tailings at beach piezometer 2	1.29
SU1P3	Valea Stefancei upper tailings at beach piezometer 3	1.6
SU1PDM	Valea Stefancei upper tailings at dam piezometer	8
SU1SPL2	Valea Stefancei upper tailings at dam seep piezometer	1
SU1SPL1	Valea Stefancei upper tailings at dam seep	0
SU1D1	Valea Stefancei upper tailings discharge at spillway	0
VSTRB	Valea Sesei tributary - upper entering pond	0
VSPU	Valea Sesei piezometer (near dam)	1
VSDSNL1	Valea Sesei dam site lysimeter 1	0.5
VSDSNL2	Valea Sesei dam site lysimeter 2	0.5
VSTRBL	Valea Sesei tributary - lower exiting toward Aries River	0

Table 11. Dissolved elemental iron and physical parameters measured in ground water at the Stefancei and Sesei tailings impoundments.

[mg/L, milligrams per liter; µS/cm, microSiemens per centimeter; °C, degrees Celsius; < less than]

Station Identifier	**Location description**	Total iron (mg/l)	Ferrous iron (mg/l)	Ferric iron (mg/l)	pH	Dissolved oxygen (mg/l)	Electrical conductivity (µS/cm)	Depth (m)
SU1D1	Stefancei upper tailings discharge at spillway	no sample	no sample	no sample	11.40	6.53	449	0
SU1PND	Stefancei upper tailings at pond	0.052	0.053	-0.001	9.19	13.9	323	0
SU1P1	Stefancei upper tailings at beach piezometer 1	no sample	no sample	no sample	5.60	no data	487	.46
SU1LSM1	Stefancei upper tailings at beach lysimeter 1	11.4	10.8	0.52	no data	no data	no data	.6
SU1P1R	Stefancei upper tailings at beach piezometer 1	41.2	0.00	41.2	5.45	5.53	476	1
SU1P2	Stefancei upper tailings at beach piezometer 2	0.00	0.00	0.00	4.30	no data	288	1.29
SU1P3	Stefancei upper tailings at beach piezometer 3	54.0	50.4	3.59	4.32	5.04	432	1.6
SU1PDM	Stefancei upper tailings at dam piezometer	1.50	0.35	1.15	6.12	5.12	301	8
SU1SPL2	Stefancei upper tailings at dam piezometer (between dam piezometers and seep)	2.10	2.01	0.10	7.00	2.0	570	1
SU1SPL1	Stefancei upper tailings at dam seep	8.39	5.43	2.96	6.70	1.5	604	0
VSTRB	Sesei tributary - upper entering from above	no sample	No sample	no sample	7.17	12.1	244	0
VSDSNL1	Sesei dam site lysimeter 1	0.00	-0.007	0.00	12.20	6	3.94	0.5
VSDSNL2	Sesei dam site lysimeter 2	0.00	-0.007	0.00	12.20	7.4	3.90	0.5
VSPU	Sesei piezometer (near dam)	0.007	0.002	0.004	7.00	8.2	145	1
VSTRBL	Sesei tributary - lower exiting toward Aries R.	64.5	50.4	14.01	3.40	7.16	2.24	0
VSTRBL	Replicate	65.9	50.5	15.4	3.40	7.16	2.24	0
VSTRBL	Replicate	64.3	49.9	14.4	3.40	7.16	2.24	0
VSTRBL	Replicate	66.6	50.3	16.3	3.40	7.16	2.24	0

Table 12. Dissolved major elements in ground water at the Stefancei and Sesei tailings impoundments.

[m, meter; mg/L, milligrams per liter; MCL, maximum contaminant level; nd, no data]

Constituent	Site ID	SU1P1R	SU1PND	SU1P1	SU1LSM1	SU1P2	SU1P3	SU1PDM	SU1SPL2	SU1SPL1	SU1D1	MCL, mg/L
	Depth, m	1	0	0.46	0.6	1.29	1.6	8	1	0	0	
	pH	5.45	9.19	5.60	No data	4.3	4.32	6.12	7	6.7	11.4	
	Dissolved oxygen, mg/L	5.13	13.9	No data	No data	No data	5.04	5.12	2.0	1.5	6.53	
Al, mg/L	Stefancei	0.34	0.023	0.078	1.24	0.451	2.65	0.139	0.0428	0.0125	0.212	0.2
Ca, mg/L	Stefancei	44.7	41.9	48.9	45.9	17.3	20.6	39.8	109	114	54.3	
Cu, mg/L	Stefancei	2.32	0.036	0.115	1.78	1.94	4.48	1.95	0.0033	0.0022	0.0323	1.3
Fe, mg/L	Stefancei	40.4	0	33.5	11.3	19.5	59.5	0.996	0.208	8.09	<50	0.3
K, mg/L	Stefancei	10.5	9.31	11.6	9	6.01	3.89	3.98	7.94	6.54	12.2	
Mg, mg/L	Stefancei	3.31	2.38	4.44	5.84	2.74	8.28	4.36	8.15	8.88	0.45	
Mn, mg/L	Stefancei	0.399	0.004	0.326	0.296	0.238	0.553	0.542	1.1	1.68	0.0013	0.05
Na, mg/L	Stefancei	8.84	11	11	16.1	6.82	8.07	7.02	9.57	9.58	11	
P, mg/L	Stefancei	< 0.01	0.04	< 0.01	0.05	0.06	0.04	< 0.01	0.04	0.1	0.04	0.0001
SiO2, mg/L	Stefancei	67.8	6.5	64	74.6	70.2	82.7	38.8	13.3	14.9	7.4	
SO4, mg/L	Stefancei	218	90	222	197	108	216	113	206	211	101	250
Zn, mg/L	Stefancei	0.509	0.004	1.02	0.885	1.41	0.4	0.518	0.0126	0.0234	0.0029	5
Solids, mg/L	Stefancei	397	161	397.0	364.0	234.7	407.2	211.1	355.4	374.8	186.6	500

Table 12—Continued. Dissolved major elements in ground water at the Stefancei and Sesei tailings impoundments.

[m, meter; mg/L, milligrams per liter; ; µg/L, micrograms per liter; MCL, maximum contaminant level]

Constituent	Site ID	VSTRB	VSPU	VSDSNL1	VSDSNL2	VSTRBL	MCL, mg/L
	Depth, m	0	1	0.5	0.5	0	
	pH	7.17	7.0	12.2	12.2	3.4	
	Dissolved oxygen mg/L	12.1	8.2	6	7.4	7.16	
Al, mg/L	Sesei	0.006	0.012	1.61	1.42	127	0.2
Ca, mg/L	Sesei	27.7	21.8	348	351	250	
Cu, mg/L	Sesei	0.001	0.005	0.001	0.0006	14.9	1.3
Fe, mg/L	Sesei	<50	<50	<50	<50	64.2	0.3
K, mg/L	Sesei	3.29	1.41	49.1	58	16.6	
Mg , mg/L	Sesei	9.9	1.55	0.03	0.02	33.8	
Mn, mg/L	Sesei	0.004	0.095	0.0004	0.0004	3.73	0.05
Na, mg/L	Sesei	4.12	3.77	51.4	62.5	14.1	
P, mg/L	Sesei	< 0.01	< 0.01	0.3	0.3	0.02	0.0001
SiO2, mg/L	Sesei	13.2	9.6	7.1	8.1	17	
SO4, mg/L	Sesei	15	10	16	22	1740	250
Zn, mg/L	Sesei	0.004	0.107	0.013	0.009	7.19	5
Solids, mg/L	Sesei	73.2	48.4	473	503	2288	500

Table 13. Dissolved trace elements in ground water at the Stefancei and Sesei tailings impoundments.

[m, meter; mg/L, milligrams per liter; µg/L, micrograms per liter; MCL, maximum contaminant level; <, less than]

Constituent	Site ID	SU1P1R	SU1PND	SU1P1	SU1LSM1	SU1P2	SU1P3	SU1PDM	SU1SPL2	SU1SPL1	SU1D1	MCL, µg/L
	Depth, m	1	0	0.46	0.6	1.29	1.6	8	1	0	0	
	pH	5.45	9.19	5.60	No data	4.3	4.32	6.12	7	6.7	11.4	
	Dissolved oxygen, mg/L	5.13	13.9	No data	No data	No data	5.04	5.12	2.0	1.5	6.53	
As, µg/L	Stafancei	5.9	0.7	5.9	2.1	0.4	1.2	1.2	4.4	6.2	<1	10
Ba, µg/L	Stafancei	4.81	32.4	6.11	18.6	23.5	15.9	45.6	33.3	30.2	19.7	2000
Be, µg/L	Stafancei	0.2	<0.05	<0.05	0.2	0.07	0.5	0.2	<0.05	<0.05	<0.05	4
Cd, µg/L	Stafancei	0.98	0.05	0.92	1.22	2.12	1.42	1.64	0.1	0.1	0.03	5
Co, µg/L	Stafancei	3.88	0.14	4.46	2.81	5.34	18.9	17.8	5.85	12.2	<0.02	Na
Cr, µg/L	Stafancei	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	100
Cu, µg/L	Stafancei	2320	35.7	115	1780	1940	4480	1950	3.3	2.2	32.3	1300
Mo, µg/L	Stafancei	< 2	16	6.9	18	< 2	< 2	3.9	55.7	51.1	21.4	80
Ni, µg/L	Stafancei	3	0.4	5.4	3	4.5	5.3	8	2.6	3.2	<0.4	0.1
Pb, µg/L	Stafancei	<0.05	0.1	0.09	0.1	0.87	0.09	0.07	0.3	0.1	0.06	15
Se, µg/L	Stafancei	2.5	1.6	3.2	3.2	1.8	1.7	< 1	< 1	< 1	2.5	50
Sr, µg/L	Stafancei	45.5	228	38.9	69.2	30.8	50.4	92.3	199	193	241	25000
U, µg/L	Stafancei	< 0.1	< 0.1	< 0.1	0.58	< 0.1	0.26	< 0.1	0.12	0.16	< 0.1	30
Solids, µg/L	Stafancei	2.39	0.32	0.19	1.90	2.01	4.58	2.12	0.30	0.30	0.32	500000

Table 13—Continued. Dissolved trace elements in ground water at the Stefancei and Sesei tailings impoundments

[m, meter; mg/L, milligrams per liter; µg/L, micrograms per liter; MCL, maximum contaminant level; <, less than]

Constituent	Site ID	VSTRB	VSPU	VSDSNL1	VSDSNL2	VSTRBL	MCL, µg/L
	Depth, m	0	1	0.5	0.5	0	
	pH	7.17	7.0	12.2	12.2	3.4	
	Dissolved oxygen mg/L	12.1	8.2	6	7.4	7.16	
As, µg/L	Sesei	<0.2	<0.2	<0.2	<0.2	<0.2	10
Ba, µg/L	Sesei	17.1	10.8	65.4	76.8	81.8	2000
Be, µg/L	Sesei	<0.05	<0.05	<0.05	<0.05	5.4	4
Cd, µg/L	Sesei	<0.02	0.18	0.1	0.1	50.6	5
Co, µg/L	Sesei	0.02	0.98	<0.02	<0.02	203	
Cr, µg/L	Sesei	<1	<1	<1	<1	3.3	100
Cu, µg/L	Sesei	1.3	4.7	1.1	0.55	14900	1300
Mo, µg/L	Sesei	< 2	< 2	61.8	58.5	3.6	80
Ni, µg/L	Sesei	0.9	2.3	<0.4	<0.4	56.7	0.1
Pb, µg/L	Sesei	<0.05	0.08	0.1	<0.05	88.2	15
Se, µg/L	Sesei	< 1	< 1	4	4.2	9.5	50
Sr, µg/L	Sesei	70	46	830	806	470	25000
U, µg/L	Sesei	0.24	< 0.1	< 0.1	< 0.1	6.96	30
Solids, µg/L	Sesei	0.09	0.07	0.96	0.95	15.88	500000

Table 14. Dissolved rare earth elements in ground water at the Stefancei and Sesei tailings impoundments.

[m, meter; mg/L, milligrams per liter; µg/L, micrograms per liter; MCL, maximum contaminant level; <, less than]

Constituent	Site ID	SU1P1R	SU1PND	SU1P1	SU1LSM1	SU1P2	SU1P3	SU1PDM	SU1SPL2	SU1SPL1	SU1D1	MCL, µg/L
	Depth, m	1	0	0.46	0.6	1.29	1.6	8	1	0	0	
	pH	5.45	9.19	5.60	No data	4.3	4.32	6.12	7	6.7	11.4	
	Dissolved oxygen, mg/L	5.13	13.9	No data	No data	No data	5.04	5.12	2.0	1.5	6.53	
Cd, µg/L	Stefancei	0.98	0.05	0.92	1.22	2.12	1.42	1.64	0.1	0.1	0.03	5
Ce, µg/L	Stefancei	0.48	0.02	0.14	5.61	0.64	2.64	0.14	0.21	0.04	< 0.01	
Cs, µg/L	Stefancei	1.7	0.04	0.73	0.16	2.7	1.68	1.31	0.04	0.1	0.2	
Dy, µg/L	Stefancei	0.13	< 0.005	0.03	0.32	0.066	0.3	0.02	0.01	< 0.005	< 0.005	
Er, µg/L	Stefancei	0.074	< 0.005	0.02	0.16	0.03	0.15	0.01	0.005	< 0.005	< 0.005	
Eu, µg/L	Stefancei	0.02	< 0.005	0.007	0.1	0.02	0.091	0.008	0.005	< 0.005	< 0.005	
Ga, µg/L	Stefancei	< 0.05	< 0.05	< 0.05	0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	0.1	
Gd, µg/L	Stefancei	0.11	< 0.005	0.03	0.44	0.072	0.38	0.02	0.02	< 0.005	< 0.005	
Ge, µg/L	Stefancei	0.06	< 0.05	0.08	0.1	0.2	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	
Ho, µg/L	Stefancei	0.03	< 0.005	0.008	0.059	0.01	0.061	0.005	< 0.005	< 0.005	< 0.005	
La, µg/L	Stefancei	0.24	< 0.01	0.06	2.57	0.31	1.07	0.12	0.11	0.03	< 0.01	
Lu, µg/L	Stefancei	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	
Nd, µg/L	Stefancei	0.23	0.01	0.08	2.25	0.34	1.5	0.09	0.09	0.02	< 0.01	
Pr, µg/L	Stefancei	0.05	< 0.01	0.02	0.59	0.07	0.35	0.01	0.02	< 0.01	< 0.01	
Rb, µg/L	Stefancei	47.4	13.4	36.1	12.9	57.6	35.5	10.3	7.85	6.16	17.2	
Sc, µg/L	Stefancei	5.9	< 0.6	5.2	4.8	6	6.4	2.6	0.8	1	< 0.6	
Sm, µg/L	Stefancei	0.06	< 0.01	0.03	0.42	0.07	0.29	0.01	0.02	< 0.01	< 0.01	
Tb, µg/L	Stefancei	0.02	< 0.005	0.007	0.057	0.01	0.053	0.005	< 0.005	< 0.005	< 0.005	
Th, µg/L	Stefancei	< 0.2	< 0.2	0.29	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	0.93	< 0.2	2
Ti, µg/L	Stefancei	2.3	1.2	2.3	2.8	3.2	2.2	1.4	3.2	2.6	1.1	
Tl, µg/L	Stefancei	0.4	<0.1	0.3	<0.1	0.78	0.59	0.2	<0.1	<0.1	<0.1	
V, µg/L	Stefancei	1.8	<0.5	<0.5	203	0.5	4.8	<0.5	<0.5	<0.5	0.7	
W, µg/L	Stefancei	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	
Y, µg/L	Stefancei	0.74	0.02	0.24	1.53	0.32	1.46	0.27	0.05	0.04	< 0.01	
Yb, µg/L	Stefancei	0.06	< 0.005	0.02	0.13	0.03	0.15	0.008	< 0.005	< 0.005	< 0.005	
Solids, µg/L	Stefancei	0.062	0.015	0.047	0.239	0.075	0.061	0.018	0.013	0.011	0.019	500000

Table 14—Continued. Dissolved rare earth elements in ground water at the Stefancei and Sesei tailings impoundments.

[m, meter; mg/L, milligrams per liter; µg/L, micrograms per liter; MCL, maximum contaminant level; <, less than]

Constituent	Site ID	VSTRB	VSPU	VSDSNL1	VSDSNL2	VSTRBL	MCL, µg/L
	Depth, m	0	1	0.5	0.5	0	
	pH	7.17	7.0	12.2	12.2	3.4	
	Dissolved oxygen mg/L	12.1	8.2	6	7.4	7.16	
Cd, µg/L	Sesei	<0.02	0.18	0.1	0.1	50.6	5
Ce, µg/L	Sesei	0.06	0.09	< 0.01	< 0.01	58.2	
Cs, µg/L	Sesei	0.28	< 0.02	1.58	1.13	0.91	
Dy, µg/L	Sesei	0.01	0.01	< 0.005	< 0.005	24.6	
Er, µg/L	Sesei	0.009	0.01	< 0.005	< 0.005	14.3	
Eu, µg/L	Sesei	0.005	< 0.005	< 0.005	0.006	5.2	
Ga, µg/L	Sesei	< 0.05	< 0.05	5.6	5.1	1.6	
Gd, µg/L	Sesei	0.03	0.02	< 0.005	< 0.005	22.1	
Ge, µg/L	Sesei	< 0.05	< 0.05	< 0.05	< 0.05	0.25	
Ho, µg/L	Sesei	< 0.005	< 0.005	< 0.005	< 0.005	5.08	
La, µg/L	Sesei	0.14	0.1	< 0.01	< 0.01	24.8	
Lu, µg/L	Sesei	< 0.1	< 0.1	< 0.1	< 0.1	1.6	
Nd, µg/L	Sesei	0.15	0.14	< 0.01	< 0.01	45.2	
Pr, µg/L	Sesei	0.04	0.03	< 0.01	< 0.01	8.66	
Rb, µg/L	Sesei	5.8	3.48	56.2	52.2	34.6	
Sc, µg/L	Sesei	0.6	< 0.6	< 0.6	< 0.6	35.4	
Sm, µg/L	Sesei	0.02	0.02	< 0.01	< 0.01	14.8	
Tb, µg/L	Sesei	< 0.005	< 0.005	< 0.005	< 0.005	3.86	
Th, µg/L	Sesei	< 0.2	< 0.2	< 0.2	< 0.2	4.01	2
Ti, µg/L	Sesei	< 0.5	< 0.5	< 0.5	< 0.5	16.7	
Tl, µg/L	Sesei	<0.1	<0.1	<0.1	<0.1	0.2	
Tm, µg/L	Sesei	< 0.005	< 0.005	< 0.005	< 0.005	1.91	
V, µg/L	Sesei	<0.5	1	228	80.9	<0.5	

W, µg/L	Sesei	< 0.5	< 0.5	4.12	2.06	< 0.5	
Y, µg/L	Sesei	0.1	0.11	0.01	0.01	151	
Yb, µg/L	Sesei	0.007	0.01	< 0.005	< 0.005	11.8	
solids, µg/L	Sesei	0.007	0.005	0.296	0.142	0.537	500000

Table 15. Summary statistics of dissolved major elements in ground water at the Stefancei and Sesei tailings impoundments.

[mg/L, milligrams per liter; MCL, maximum contaminant level; <, less than]

Location Statistic Constituent	Stefancei Minimum mg/L	Stefancei maximum mg/L	Stefancei average mg/L	Stefancei deviation mg/L	Sesei minimum mg/L	Sesei maximum mg/L	Sesei Average mg/L	Sesei deviation mg/L	MCL, mg/L
Al	0.01	2.65	0.512	0.83	0.007	127	26.1	56.5	0.2
Ca	17.3	114	53.6	32.7	21.8	351	200	164	
Cu	0.002	4.48	1.27	1.5	0.0006	14.9	2.98	6.66	1.3
Fe	0	59.5	19.3	21	64.2	64.2	64.2	Na	0.3
K	3.89	12.2	8.1	2.96	1.41	58	25.7	26.3	
Mg	0.45	8.88	4.88	2.84	0.02	33.8	9.06	14.4	
Mn	0.001	1.68	0.51	0.52	0.0004	3.73	0.77	1.66	0.05
Na	6.82	16.1	9.9	2.68	3.77	62.5	27.2	27.8	
P	0.04	0.1	0.052	0.022	0.02	0.3	0.21	0.16	
SiO2	6.5	82.7	44	31	7.1	17	11	4.07	
SO4	90	222	168	56.8	10	1740	361	771	250
Zn	0.003	1.41	0.48	0.5	0.004	7.19	1.46	3.2	5
Solids	161.2	407	308	98.1	48.3	2288	677	926	500

Table 16. Summary statistics of dissolved trace elements in ground water at the Stefancei and Sesei tailings impoundments.

[µg/L, micrograms per liter; MCL, maximum contaminant level; <, less than]

Location Statistic Constituent	Stefancei minimum µg/L	Stefancei maximum µg/L	Stefancei average µg/L	Stefancei deviation µg/L	Sesei minimum µg/L	Sesei maximum µg/L	Sesei average µg/L	Sesei deviation µg/L	MCL, mg/L
As	0.4	6.2	3.1	2.5	0	0	Na	na	0.01
Ba	4.8	45.6	23	12.7	10.8	81.8	50.4	33.9	2
Be	0.07	0.5	0.23	0.16	5.4	5.4	5.4	na	0.004
Cd	0.03	2.12	0.858	0.76	0.1	50.6	12.7	25.2	0.005
Co	0.14	18.9	7.93	6.7	0.02	203	68	117	
Cr	0	0	Na	na	3.3	3.3	3.3	Na	0.1
Cu	0.002	4.48	1.27	1.5	0.0006	14.9	2.98	6.66	1.3
Mo	3.9	55.7	24.7	20.6	3.6	61.8	41.3	32.7	
Ni	0.4	8	3.93	2.2	0.9	56.7	20	31.8	
Pb	0.06	0.87	0.2	0.26	0.08	88.2	29.5	50.9	0.001
Se	1.6	3.2	2.35	0.68	4	9.5	5.9	3.11	0.05
Sr	30.8	241	119	85.7	46	830	444	381	
U	0.12	0.58	0.28	0.2	0.24	6.96	3.6	4.75	0.03
Solids	0.19	4.57	1.44	1.43	0.07	15.9	3.6	6.9	500

Summary and Conclusions

Reconnaissance surveys were conducted for the purpose of evaluating water-quality in the Aries River basin, a subbasin of the Tisza basin. Basin surveys included sampling and analyzing physical aqueous parameters and concentrations of sediment-associated metals in river bed and floodplains, and establishing a baseline set of physical and chemical measurements of tailings water and sediment. The physical parameters (conductivity and pH) for the Abrud-Aries river system revealed three primary anomalies corresponding to the influence of upstream mining activities associated with the tributaries Valea Abruzel (Rosia Poieni mine), Valea Rosei (Rosia Montana mine), and Valea Sesei (Rosia Poieni mine). Downstream from these locations, the pH generally increased (becoming more basic) and conductivities decreased, probably due to stream dilution.

Of the selected bed-sediment metal concentrations, As was the only metal that coincided with mining-associated tributaries. The other bed-sediment metal concentrations fluctuated downstream from these tributaries and over a wide range of values, probably due to episodic flooding. Cd and Zn were highly correlated, but relations between the other metals were weak, probably due to sorption, kinetics, and redistribution during flood events. The respective probability for exceeding the probable effects threshold level for As, Cd, Cu, Pb, and Zn was 51.9, 4, 69, 11, and 60.5%. This finding indicated the relative importance of basin pollution by these selected metals (high to low: Cu>Zn>As>Cd) and the probable adverse effects to *all* in-stream biota and consequently to human health where in-stream biota are a source of food. The relation between metal concentrations in sediment from the channel to those of the floodplain were strong and positive for As, Cd, and Zn, whereas there was no relation between Cu concentrations, despite the fact that Cu concentrations in bed sediment displayed the strongest exceedance characteristics.

At the Sesei and Stefancei tailings impoundment sites, the major-ion chemistry of the collected water samples indicated a drinkable water resource of generally poor quality. From a human-health perspective, problems are related to exceedances of maximum contaminant levels for As, Ba, Be, Cd, Co, Cr, Cu, Mo, Ni, Pb, Se, Sr, and U at both tailings impoundments. Geochemical sample analysis revealed changes in physical and parameter measurements and chemistry along a flowpath from the pond, through the Stefancei tailings impoundment, to a seep located in the dam face. As a result of this study, sufficient physical and chemical sediment data and water information now exists to be used as input to a geochemical model for the evaluation of principal reactions and related mechanisms along flowpaths in the Stefancei tailings impoundment. Quantifying the effect of changing redox conditions and their influence on reactions is an important step toward understanding the observed deterioration (as shown by seepage) and possible future failure at the upper Stefancei (number 1) tailings dam. Other potential issues contributing to deterioration may include tree roots and animal burrows associated with the riparian wetland allowed to develop.

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