Considerations of Observational Scale when Evaluating the Effect of, and Remediation Strategies for, a Fluvial Tailings Deposit in the Upper Arkansas River Basin, Colorado

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ABSTRACT

We examined the water-quality effects of a fluvial tailings deposit along the flood plain of the upper Arkansas River south of Leadville, Colorado. Fluvial tailings deposits are a possible diffuse source of acid and metal contamination to surface and ground water. We used four different scales of observation to evaluate the potential effect of fluvial tailings on water quality. First, we collected surficial material and subjected it to batch water-leaching tests. Second, we excavated an intact 8-inch-diameter (60 centimeters in length) core, leached it under unsaturated conditions for 23 days, and collected the effluent. Third, we examined the water quality of the shallow ground water beneath the fluvial tailings deposit; and fourth, we monitored water quality along a 5-kilometer reach of the adjacent Arkansas River. Our results illustrate the importance of observational scale in the interpretation of the effect of the fluvial tailings deposit on water quality. Leaching of surficial samples indicates that there is a large reservoir of readily water-soluble material yielding elevated metal concentrations and high acidity that could degrade water quality. However, the river-water-quality data indicate that there is no measurable effect from the fluvial tailings deposit. It is important to note that this data set does not include any stormwater sampling. Natural attenuation processes (including dilution) appear to contribute to our different findings at different observational scales. Attention to the importance of observational scale can lead to informed remediation decisions.

INTRODUCTION

The flood plain of the upper Arkansas River south of Leadville, Colorado, contains numerous deposits of tailings from historical mining operations in the Leadville area (URS Operating Services, 1997). These deposits are a possible source of acid and metal contamination to surface and ground water. Our study site is at one of these fluvial tailings deposits, approximately 13 kilometers south of Leadville (fig. 1). The size of the site is about 0.1 square kilometer (km^2), and it is virtually devoid of living vegetation.

The fluvial tailings deposits are generally fine-grained overbank and pointbar deposits containing mixtures of tailings and other sediment. Cored material from the deposits is usually extremely heterogeneous. At our study site, the top of the fluvial tailings deposit commonly consists of a fine-grained pyrite-rich layer, the middle portion of the deposit is clay-rich with sand and silt lenses, and the bottom contains an organic-rich layer underlain by a sand and gravel shallow aquifer. The dominant minerals are quartz, feldspar, and mica.

We used four different approaches and observational scales to study and evaluate the effects of fluvial tailings on water quality at the study site. First, we collected surface and near-surface material from the fluvial tailings deposit and subjected it to batch water-leaching tests. Second, we excavated an intact 8-inch-diameter core from the deposit and determined its leaching behavior under unsaturated conditions. Third, we installed shallow ground-water wells at the site and collected ground-water-quality samples. Finally, we collected water-quality samples along a 5-kilometer reach of the adjacent Arkansas

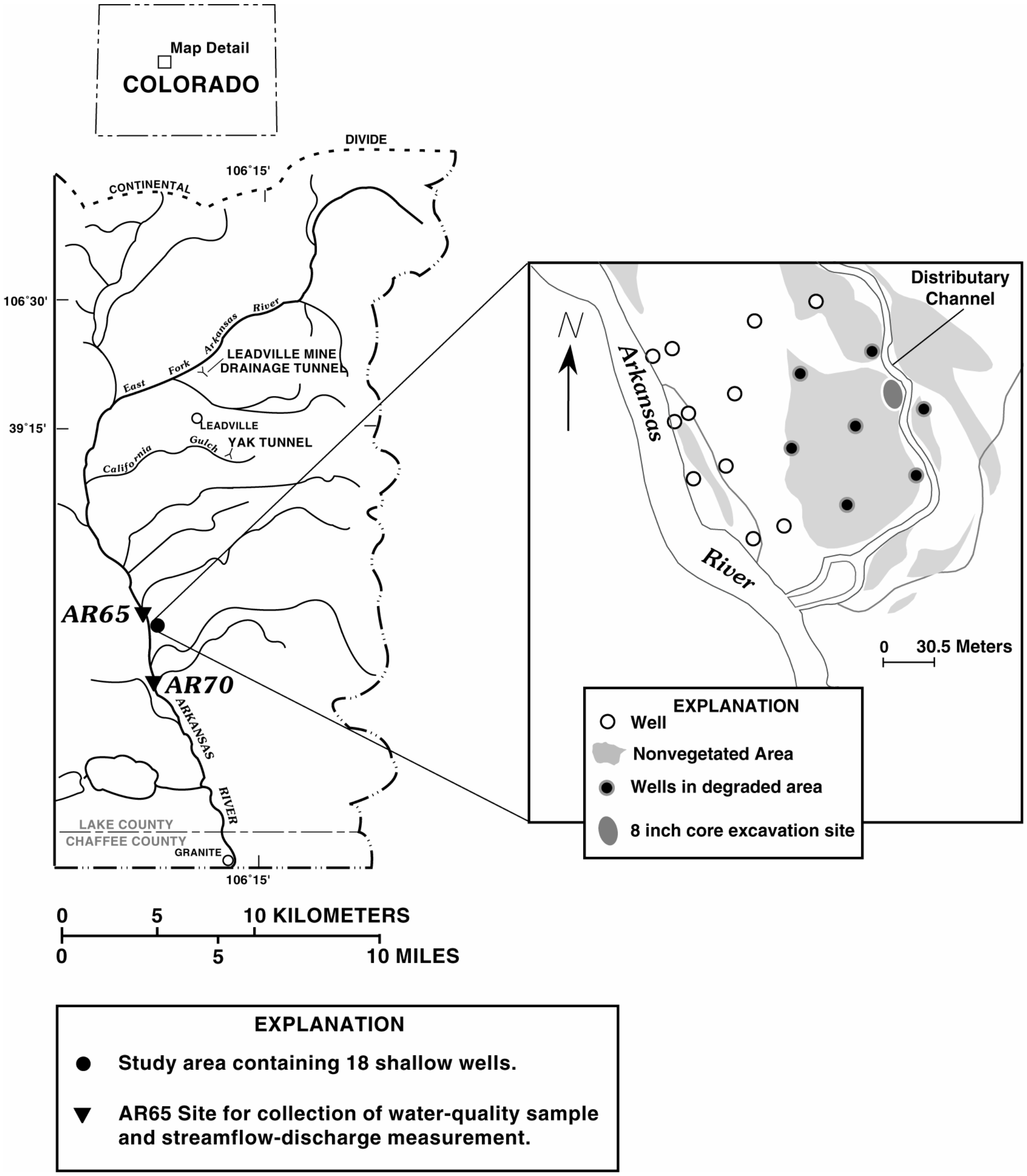

Figure 1. Schematic of the study site showing the main study area where shallow ground water wells were installed and surficial materials collected. Also shown are the excavation site of the 8-inch-diameter core, and the upstream and downstream sampling sites along the Arkansas River.

River. These four approaches represent different scales of observation of the potential effect of the fluvial tailings on water quality. In this paper, we compare results and interpretations among these different scales of observation. Related work at this study site is reported by Walton-Day and others (1996), Jerz (1998), and Smith and others (1998b, 1999).

METHODS

Collection and Leaching of Surficial Fluvial Tailings-Deposit Material

We used a one-inch stainless steel soil corer with plastic liners to collect five cores at the site. After air drying the cores, we separated the cored material into visually distinct stratigraphic segments on the basis of color and textural differences. Data for the top segments are given in this paper (top segments ranged from 5 to 15 centimeters [cm] in length). Batch water leaches of core segments were performed by combining 2 grams of sample with 40 grams of deionized water and shaking the mixture for 3 hours. After shaking, pH measurements were made and the leach suspension filtered through 0.45-µm (micrometer) filters. Filtered leachates were acidified with nitric acid and analyzed by inductively coupled argon plasma - mass spectroscopy (ICP-MS). A more detailed description of the collection and leaching methods is contained in Smith and others (1998b).

Collection and Leaching of an Intact 8-Inch-Diameter Core

An 8-inch-diameter core was excavated intact from the bank of a distributary channel that cuts through the fluvial tailings deposit (fig. 1). A clear polymethylmethacrylate tube was placed on top of the bank. The fluvial tailings around the tube were slowly excavated and the tube pushed down to encase the remaining material. The process was repeated until the shallow aquifer material was reached (approximately 60 cm of overlying material). The bottom of the tube was fitted with a polyvinylchloride (PVC) cap and the joint sealed with silicone cement. The cap contains sampling ports designed to separate water draining along the interface between the cored material and the inner edge of the tube from water draining through the center part of the core (center port). Deionized water was applied to the top of the core at a rate of 2 mL/min (milliliters per minute) by using a peristaltic pump. The deionized water was allowed to drain by gravity through the core. Effluent was collected from the center port at the bottom of the core at various times. Forty sequential effluent samples were collected under unsaturated conditions over a 23-day period. Specific conductance and pH measurements were made on the effluents, and a portion of the unfiltered effluents was acidified with nitric acid and analyzed by ICP-MS. A more detailed description of the core leaching method is in Smith and others (1999).

Installation and Sampling of Shallow Ground-Water Wells

Eighteen shallow ground-water wells were installed in a grid throughout the study area (see fig. 1). The 3.8-cm-diameter wells were designed to contain a screened interval within the zone of shallow water-table fluctuation. The annulus of each well was filled with sand to a depth approximately 15 cm above the screened interval. The annular fill of each well was completed with a bentonite seal topped by concrete containing a 7.5-cm-diameter PVC collar. The wells were developed by repeated surging and pumping until the well water was visibly clear. Prior to water-quality sampling, the wells were pumped until at least three well volumes of water had been pumped and pH and specific conductance remained steady. Values of pH and specific conductance were determined using a Hydrolab multiparameter sampling probe installed in a flow-through cell downstream from the peristaltic pump. Unfiltered samples were collected and acidified with concentrated nitric acid to pH less than 2.0 and analyzed by inductively coupled argon plasma - atomic emission spectroscopy (ICP-AES). All equipment that contacted sample water was cleaned using the procedure described by Horowitz and others (1994).

River Sampling

Water-quality samples were collected and streamflow discharge measurements made at two sites along the upper Arkansas River that were upstream and downstream from the study site. Sampling at each site was conducted from a bridge so that a composite water-quality sample could be obtained across the entire stream width and depth using the equal-width increment sampling technique (Shelton, 1994). Standard USGS (U.S. Geological Survey) techniques were used to collect water-quality samples and to conduct streamflow-discharge measurements (Rantz and others, 1982a, 1982b; Shelton, 1994). Field parameters, such as pH and specific conductance, were measured using a Hydrolab multiparameter sampling probe. Unfiltered samples were acidified with concentrated nitric acid to pH less than 2.0 and analyzed by ICP-AES. All equipment that contacted sample water was cleaned using the procedure described by Horowitz and others (1994). Instantaneous mass loads were computed for several elements and compared along the river reach. An instantaneous load for a particular element is the product of concentration and streamflow discharge and is expressed in units of mass per unit of time.

WATER-QUALITY RESULTS AT DIFFERENT OBSERVATIONAL SCALES

Average values for water-quality constituents and properties are presented in table 1 for the different scales of observation. Results for unfiltered samples are reported for core effluent, shallow ground water, and river water. Unfiltered samples represent the total amount of metal present in a given medium. More detailed results can be found in Smith and others (1998b, 1999) and Walton-Day and others (1996). A brief discussion of the interpretation for each observational scale follows.

Leachates of Surficial Fluvial Tailings-Deposit Material

Leaching of the surficial fluvial tailings-deposit material produces elevated metal concentrations and a median pH value of 2.3 (table 1). These results indicate that waters draining from the fluvial tailings deposit should degrade the quality of receiving waters. Maximum degradation would likely be from surface runoff and subsurface flow following snowmelt and periodic rainfall.

Effluents from Cored Fluvial Tailings-Deposit Material Under Unsaturated Conditions

Effluents obtained by leaching an 8-inch-diameter core with deionized water contained elevated metal concentrations and pH values ranging from 2.8 to 3.5. Results presented in table 1 represent average metal concentrations of 40 samples collected under unsaturated leaching conditions of the core over a period of approximately 23 days. Most metals exhibit a large spike in concentration early in the leaching process followed by a gradual decrease in concentration (Smith and others, 1999). The elevated metal concentrations and acidity released from the core indicate that uncontaminated shallow ground water should be degraded by infiltration of water through the tailings. Average iron and lead concentrations are higher in the most degraded shallow ground-water wells than in the core effluent (table 1).

Shallow Ground Water

The quality of shallow ground water beneath the fluvial tailings deposit is clearly degraded by the overlying tailings, as exhibited by depressed pH values (pH less than 3.0 in as many as four wells) and elevated specific conductance and unfiltered metal concentrations in some wells. Shallow ground-water quality shows some seasonal variability that affects the number of wells exhibiting degradation of water quality. Degradation of most water-quality constituents and properties is geographically restricted to wells located directly beneath tailings deposits (seven wells). Table 1 presents results for these wells and for all 18 wells. Zinc contamination is most pervasive and is present in almost all wells. At this scale of observation, degraded water quality is demonstrated in the shallow ground water, but no conclusions can be drawn about the adjacent river water.

Table 1. Average values and ranges of various constituents and properties in 20:1 water leachates of surficial material, core effluent, shallow ground water for 7 wells in the most degraded area, shallow ground water for all 18 wells, and adjacent river water [pH values are median values; n, number of measurements; ND, not determined; µS/cm, microsiemens per centimeter; µg/L, micrograms per liter; mg/L, milligrams per liter; <, less than].

Constituents and properties	Surficial leachate	Core effluent	Ground water (7 wells)	Ground water (18 wells)	River water
pH					
n	5	40	34	85	58
range	2.1 - 2.9	2.8 - 3.5	2.3 - 6.1	2.3 - 8.1	7.2 - 8.2
median value	2.3	2.9	3.3	6.0	7.8
Specific conductance (µS/cm)					
n	ND	40	34	85	57
range	ND	1,560 - 3,480	210 - 2,760	90 - 2,760	79 - 230
average value	ND	2,530	850	500	150
Cadmium (µg/L)					
n	5	40	39	97	4
range	22 - 280	250 - 4,000	< 5 - 410	< 5 - 410	< 5 - 6
average value	95	1,520	55[*]	32[*]	< 5
Copper (µg/L)					
n	5	40	39	97	60
range	120 - 1,400	240 - 1,860	< 50 - 1,150	< 50 - 1,150	< 50
average value	570	940	120[#]	65[#]	< 50
Iron (mg/L)					
n	5	40	39	97	60
range	3.6 - 490	0.89 - 35	0.050 - 112	< 0.02 - 110	0.27 - 4.0
average value	180	16	24	10[+]	1.0
Lead (µg/L)					
n	5	40	39	97	38
range	140 - 3,500	40 - 96	< 5 - 2,100	< 5 - 2,100	6.0 - 120
average value	1,660	68	170[*]	74[*]	25
Manganese (mg/L)					
n	5	40	39	97	60
range	0.23 - 4.1	0.23 - 8.7	0.011 - 7.0	< 0.005 - 12	0.076 - 0.97
average value	1.2	2.3	1.6	1.6[*]	0.27
Zinc (mg/L)					
n	5	40	39	97	60
range	2.1 - 34	6.2 - 170	0.016 - 29	0.016 - 29	0.085 - 0.99
average value	11	62	4.8	3.4	0.31

[*] Detection limit = 5 µg/L; substituted 2.5 µg/L for all samples < 5 µg/L.

[+] Detection limit = 0.020 mg/L; substituted 0.010 mg/L for all samples < 0.020 mg/L.

[#] Detection limit = 50 µg/L; substituted 25 µg/L for all samples < 50 µg/L.

River Water

With the possible exception of iron on one sampling date, there is no statistical difference between instantaneous loads for unfiltered metals upstream and downstream from the study site in the upper Arkansas River Basin. In addition, pH values are circumneutral, indicating minimal to no effect from the low-pH waters. This result indicates that there is no measurable evidence that the fluvial tailings deposits are degrading water quality along this river reach. It is likely that some metals from the study site reach the Arkansas River during certain times of the year, but these metals appear to be undetectable when conventional mass-loading techniques are used. The variation in these mass-loading techniques can be as high as 20 percent. Therefore, load changes of less than 20 percent probably will not be detected. It is important to note that this data set does not include any stormwater or snowmelt sampling, so we are not able to evaluate degradation of water quality during storm events. At this scale of observation, there is no apparent effect on water quality from the fluvial tailings deposit.

REMEDIATION IMPLICATIONS AT DIFFERENT OBSERVATIONAL SCALES

High concentrations of soluble metals at tailings-deposit surfaces have been explained by precipitation of hydrated metal sulfates resulting from soil moisture that is drawn to the surface and evaporated during warm, dry periods (Nimick and Moore, 1991; Bayless and Olyphant, 1993). We collected hydrated metal sulfate salts from the surface of the fluvial tailings deposit at the study site and dissolved them in deionized water (1:20 ratio). Iron concentrations were in the 1,000’s mg/L (milligrams per liter), zinc in the 10’s mg/L, manganese, copper, and lead in the 1,000’s µg/L (micrograms per liter), and cadmium in the 100’s µg/L. Dissolution of these salts probably is the source of most of the dissolved metals and acidity in leachates of tailings material from the site. These salts may degrade water quality during storm events. Water-quality data from shallow ground-water wells indicate localized areas of elevated metal concentrations and acidity, but there does not appear to be a measurable effect on the quality of the adjacent river water. Geochemical processes in the sediment column might attenuate metals as they migrate through the fluvial tailings deposit. Some possible attenuation processes include dilution, precipitation of saturated mineral phases, sorption onto hydrated metal-oxide minerals (Smith and others, 1998a) or organic material, and precipitation of sulfide phases in the organic-rich layer.

When studies such as ours are done, observational scale affects the results and interpretation at scientific, remediation strategy, and regulatory levels. The integration of the four scales of observation indicates that natural attenuation processes, including dilution, may decrease concentrations of some metals as the scale of observation goes from surficial samples to river-water monitoring. However, looking at any of these observational scales individually would not reveal any attenuation processes.

Remediation decisions depend on observational scale and on the remediation objectives. For example, if remediation objectives and the accompanying sampling plan only encompass water quality in the Arkansas River, our results indicate that the effects of the fluvial tailings are minimal to nonexistent, and no remediation may be necessary. However, if remediation objectives include the riparian ecosystem, it is clear that the effects of the tailings material on the sediment and riverbank are extreme and that remediation is necessary to improve sediment and vegetation quality. Since we did not evaluate storm events in our study, we do not know their short-term effects on water quality.

From a regulatory point of view, it appears that water-quality effects from the fluvial tailings would not be detected by monitoring water quality in the Arkansas River (unless perhaps storm events are monitored). However, if cleanup decisions were made on the basis of evaluation of the surficial tailings-deposit material, the material may be determined to be a hazardous waste. For example, the regulatory level that determines a hazardous waste under the Resource Conservation and Recovery Act (RCRA) Toxicity Characteristic Leaching Procedure (TCLP) is 5 mg/L for lead (U.S. Environmental Protection Agency, 1986). Some of the surficial leachates approached this level in our simple deionized water leach, and it is likely that some of these samples would exceed the regulatory level for lead in a TCLP test.

Our study illustrates that it is important to consider observational scale and remediation objectives when evaluating the effect of fluvial tailings on an ecosystem. Natural attenuation processes, including dilution, may play a role in metal transport from one observational scale to another. With an awareness of the importance of observational scale, land managers may take remediation actions that make use of the potential benefits of natural attenuation processes.

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