

Metal leaching through a fluvial tailings deposit along the upper Arkansas River, Colorado

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ABSTRACT: Fluvial deposits of mine tailings occur along the upper Arkansas River south of Leadville, Colorado, as a result of historical mining activities. We excavated an intact 8-inch diameter core from a small fluvial tailings deposit (approximately 0.1 km²) located about 13 km downstream from Leadville. To simulate leaching of metals from the fluvial tailings deposit to shallow ground water, we performed column-leaching experiments and examined the amount of metals leaching from the core. We applied deionized water to the top of the core and collected leachates from ports at the base of the core. Unsaturated, partially saturated, and fully saturated conditions were simulated. Leachates were analyzed for pH, metal concentrations, and specific conductance. For approximately the first 100 hours of unsaturated flow through the core (12 L of deionized water), conductivity and metal concentrations rose steadily and pH fell to values below 3. Metal concentrations peaked at about 170 mg/L Zn, 110 mg/L Al, 35 mg/L Fe, 8.7 mg/L Mn, 4.0 mg/L Cd, 1.9 mg/L Cu, and 0.1 mg/L Pb. The results demonstrate that large amounts of acidity and metals can be readily leached from these fluvial tailings deposits. The pH remained fairly stable under partially and fully saturated conditions, and Zn, Al, Mn, Cd, and Cu concentrations declined. Iron concentrations showed a slight increase during the partially and fully saturated conditions. Lead exhibited unique behavior throughout the leaching experiment and spiked when partially and fully saturated conditions were achieved. This behavior indicates that there is a readily available reservoir of Pb throughout the core. In light of these data, flooding of the fluvial tailings deposits along the upper Arkansas River may result in increased Pb concentrations locally in the shallow ground water. However, since Pb is fairly immobile in iron-rich systems at pH > 4, this situation probably does not represent a threat to the Arkansas River.

1 INTRODUCTION

The floodplain of the upper Arkansas River, south of Leadville, Colorado, contains several fluviually deposited mine tailings from historic mining operations in the Leadville area. These deposits are a possible nonpoint source of acid and metal contamination to surface and ground water. Studies at other fluvial tailings sites document that stormwater runoff from tailings can be a source of acidity and metals to surface and ground water (Nimick & Moore 1991; Bayless & Olyphant 1993).

Our study site is in the upper Arkansas River basin approximately 13 km south of Leadville, Colorado (Figure 1). The size of the site is about 0.1 km² and it is predominantly barren of living vegetation. Recently the land use in the surrounding area has been cattle grazing. There is a distributary channel that flows through the study site and the tailings mainly are deposited between the Arkansas River channel and this distributary channel.

The fluvial tailings deposits at the site are generally fine-grained, overbank deposits containing mixtures of tailings and other sediment. The tailings themselves are composed of mine waste washed downstream from the Leadville Mining District, which contains gold, silver, lead, and

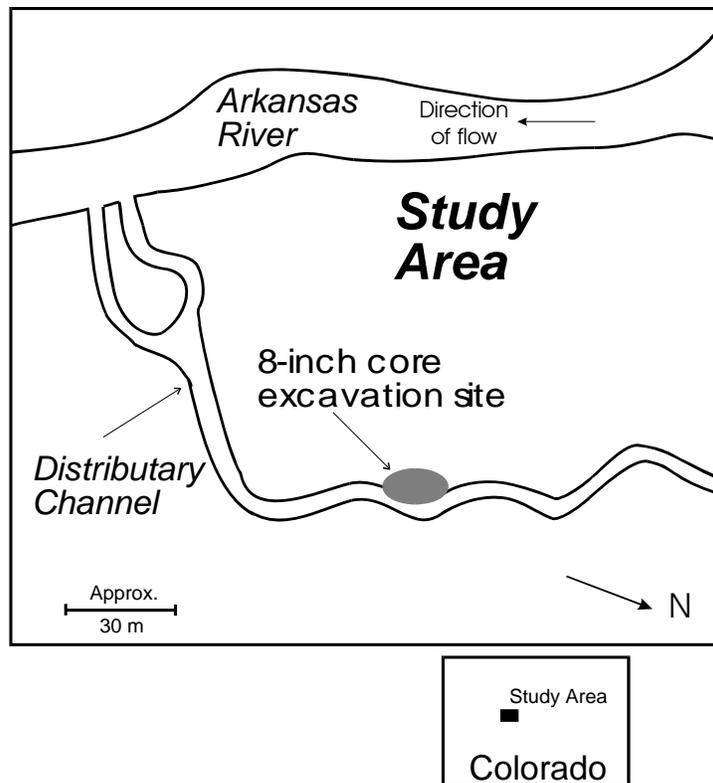


Figure 1. Schematic of the study area showing location of core excavation site.

zinc ores mined over the last 100+ years. Cored material from the fluvial tailings deposit is very heterogeneous. Generally the top of the deposit 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 is organic-rich underlain by a sand and gravel shallow aquifer. The dominant minerals are quartz, feldspar, and mica (Jerz 1998; Smith et al. 1998b).

In this study we examined the leaching behavior of an intact 8-inch core excavated from the fluvial tailings deposit. We investigated the leaching behavior under unsaturated, partially saturated, and fully saturated conditions to simulate leaching behavior of the fluvial tailings deposit under a variety of naturally occurring and hypothetical hydrologic states. Previous work at this site shows that metals and acidity can be readily leached from the fluvial tailings material (Walton-Day et al. 1996; Jerz 1998; Smith et al. 1998b).

2 METHODS

An 8-inch core was excavated intact from the bank of the distributary channel that cuts through the tailings deposit. 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. This 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 cap and the joint sealed with silicone cement. The cap contained drainage ports that were designed to separate water draining along the interface between the cored material and the inner edge of the tube (side-wall flow; edge port) from the water draining through the center of the cored material (center port). A polypropylene cloth prevented fine

material from passing from the cored material into the cap. The cap was filled with quartz sand to minimize dead volume.

Deionized water was applied to the top of the core at a rate of 2 mL/min using a peristaltic pump and was allowed to gravity drain through the core. This resulted in unsaturated flow conditions. Leachate samples were collected from ports at the bottom of the core (in this paper we discuss only samples collected from the center port). Leachate was collected at varying times and sample weight, pH, and specific conductance were measured. Subsamples of the leachate were taken and saved for chemical analyses. Results presented here are for unfiltered samples. Filtered samples (0.45 μm) were also collected, but little difference was noted between filtered and unfiltered results.

After approximately 20 days, the application rate was reduced to 1 mL/min for 3 days. About 23 days after the beginning of the experiment the core was allowed to partially fill from the bottom to about half full. This partially saturated state is intended to simulate rising of the underlying shallow ground water table into the fluvial tailings deposit. Partial saturation was maintained for about 29 days with continual application at 1 mL/min. After that time, the core was allowed to completely saturate and saturation was maintained for 9 days with continual application of deionized water at the same rate. During saturation, ferrous iron and dissolved oxygen were monitored in addition to pH and specific conductance. Acidified samples were analyzed by inductively coupled argon plasma - mass spectroscopy (ICP-MS).

3 RESULTS AND DISCUSSION

3.1 *Unsaturated leaching conditions*

The near-surface area of the core contained obvious deposits of efflorescent salts that are readily soluble. We assume that the majority of the acidity and dissolved metals in the leachates originate from these salts at and near the top of the core. The salts were visibly depleted over the course of the leaching experiment. Initial pH and specific conductance measurements (Figure 2) and Cu, Cd, Zn, Al, Mn, Fe, and Pb concentrations (Figures 3-5) show that there is a reservoir of readily leachable material in the core that can be removed under unsaturated conditions.

The pH of the leachate (Figure 2) drops quickly over the first 100 hours to less than pH 3, remains low, and then slowly rises to pH > 3. The low pH corresponds to the slow tailing off of Fe (Figure 4) and probably is related to acid produced by the precipitation of hydrous Fe oxide minerals. After a rapid increase over the first 100 hours, the specific conductance slowly decreases over the course of the leaching experiment (Figure 2).

Concentrations of all the metals, except Pb, increased to a maximum after about 100 hours (around sample number 10; 12 L of deionized water) since the beginning of the leaching experiment (Figures 3 and 4). Peak concentrations of some of the metals are slightly offset from each other and have different features before and after the peak (as illustrated in Figures 3 and 4). Most notable are Cu, Al, and Fe, whose migration through the core seems to be somewhat retarded compared with the other metals in Figures 3 and 4. It is likely that Fe is precipitating in the core as hydrous Fe oxides. The behavior of Pb (Figure 5) is different from the other metals in that there is a less obvious peak in concentration and a very broad tail. This may indicate that Pb is being retained in the core by mechanisms such as precipitation of anglesite (PbSO_4) or sorption onto hydrous iron oxide minerals in the core.

3.2 *Partially and fully saturated leaching conditions*

About 23 days after the beginning of the leaching experiment the core was allowed to partially fill from the bottom up to about half full by raising the exit tube from the center port. The fill line was well below the upper pyrite-rich layer of the core and below any zone of obvious salt formation. This partially saturated state is intended to simulate rising of the underlying shallow ground water table into the fluvial tailings deposit as might take place during the spring. Partial saturation was maintained for about 29 days with continual application at 1 mL/min. After that

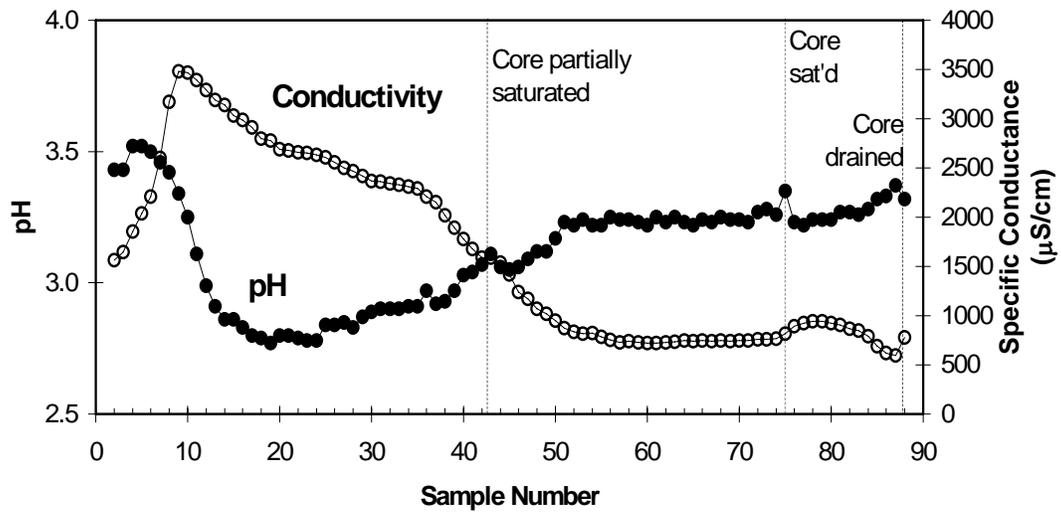


Figure 2. Conductivity and pH values of fluvial tailings core leachate samples collected under unsaturated, partially saturated, and fully saturated conditions.

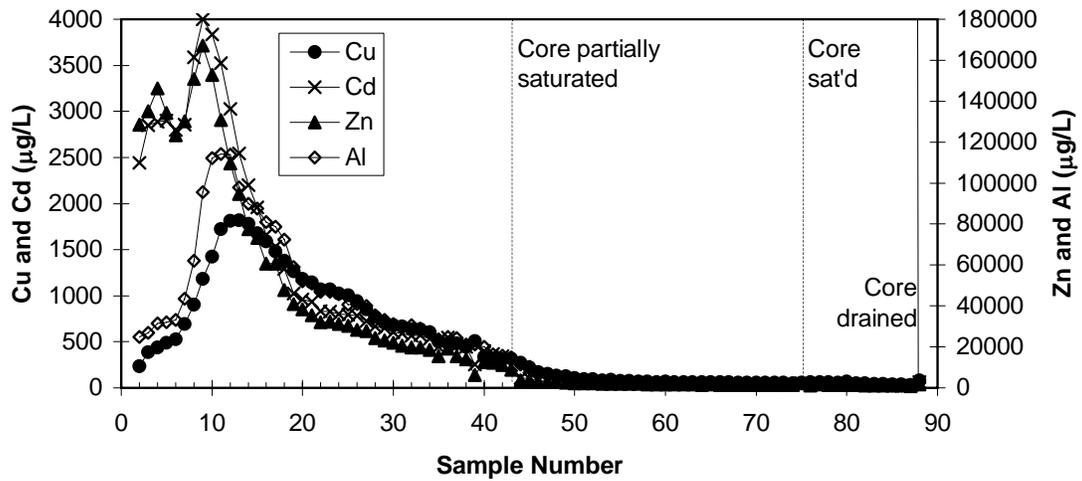


Figure 3. Copper, cadmium, zinc, and aluminum concentrations in fluvial tailings core leachate samples collected under unsaturated, partially saturated, and fully saturated conditions.

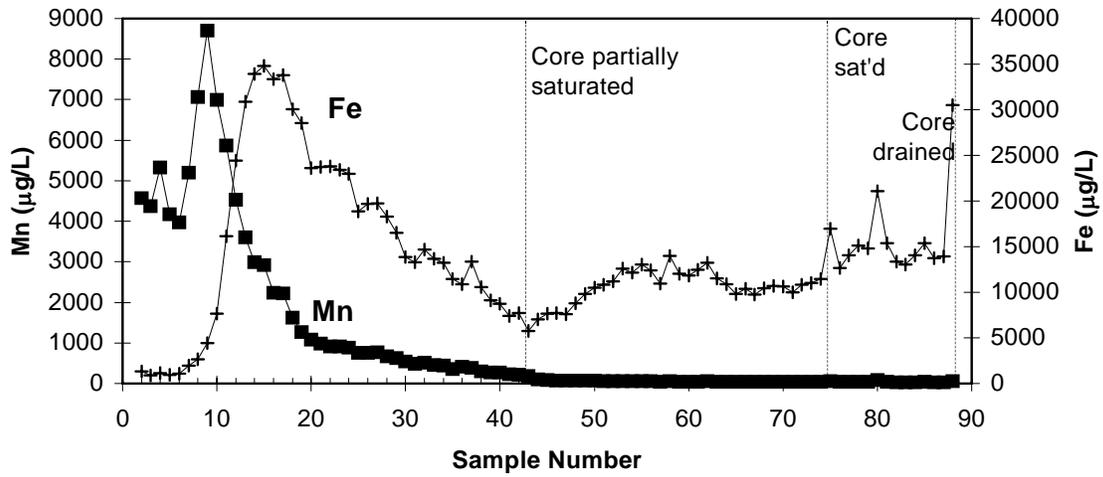


Figure 4. Iron and manganese concentrations in fluvial tailings core leachate samples collected under unsaturated, partially saturated, and fully saturated conditions.

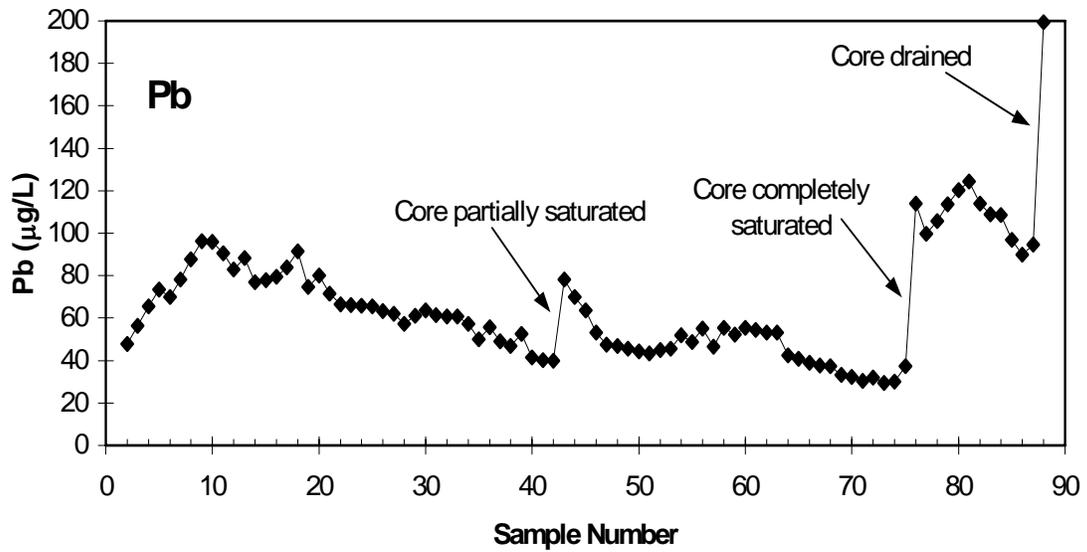


Figure 5. Lead concentrations in fluvial tailings core leachate samples collected under unsaturated, partially saturated, and fully saturated conditions.

time, the core was allowed to completely fill and complete saturation was maintained for 9 days with continual application at 1 mL/min.

During partial saturation, pH slowly increased from about 3.1 to 3.3, and specific conductance slowly decreased and leveled off (Figure 2). There was a slight jump in pH and in specific conductance when the core was completely filled. Specific conductance also jumped slightly when the core was drained, and pH decreased slightly (Figure 2). On the whole, partial and complete saturation of the core did not have a large effect on pH or specific conductance.

Partial and complete saturation also did not have much of an effect on Cu, Cd, Zn, Al, and Mn (Figures 3 and 4). After the initial peak of these metals under unsaturated conditions, they steadily decreased throughout the remainder of the leaching experiment as their source was depleted.

Iron concentrations slightly increased during partial and complete saturation of the core (Figure 4). Shortly after partial saturation of the core, dissolved oxygen dropped to near zero and ferrous iron rose from near zero to roughly 100% of the total iron. The increase in total Fe concentration may be due to dissolution of hydrous iron oxide minerals present in the core.

Lead concentrations spiked when the core was partially and completely saturated, and again when the core was drained (Figure 5). These spikes in concentration represent the presence of a readily available reservoir of Pb throughout the core. This Pb reservoir may be a soluble mineral phase present throughout the core or it may be lead sorbed onto hydrous iron oxides present in the core. In light of these data, flooding of fluvial tailings deposits along the upper Arkansas River may result in increased Pb concentrations locally in the shallow ground water. However, since Pb is fairly immobile in iron-rich systems at $\text{pH} > 4$ (Smith et al. 1998a), Pb will likely be immobilized prior to reaching the Arkansas River.

4 SUMMARY AND CONCLUSIONS

We performed column-leaching experiments with an intact 8-inch core excavated from a fluvial deposit of mine tailings along the upper Arkansas River south of Leadville, Colorado. For approximately the first 100 hours (12 L of deionized water) of unsaturated flow through the core, conductivity and metal concentrations rose steadily and pH fell to below 3. We attribute these peaks in metal concentrations and acidity to the leaching of readily soluble salts present at and near the top of the core. The pH slowly rose and leveled off under partially and fully saturated conditions, and Zn, Al, Mn, Cd, and Cu concentrations declined as the source material was depleted. Iron concentrations showed a slight increase during the partially and fully saturated conditions possibly due to the dissolution of hydrous iron oxide mineral phases under anoxic conditions. Lead exhibited unique behavior throughout the leaching experiment and spiked when partially and fully saturated conditions were achieved. This Pb behavior suggests that there is a readily available reservoir of Pb throughout the core, which could either be a soluble mineral phase or Pb sorbed onto hydrous iron oxide minerals in the core.

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