PRACTICAL DEMONSTRATION OF SLOW LEAKAGE FROM A TAILINGS IMPOUNDMENT

by

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Abstract: Percolation from an unlined tailings impoundment in the Robinson District, east-central Nevada, was investigated by soil borings into the impoundment and adjacent background soils. The data obtained demonstrated the extent of water percolation and solute transport into the subsurface. After approximately 1 year of operation, water had percolated approximately 3 feet (91 cm) into the soil, and a solute front was detected at a depth of 2 feet (61 cm). The depths of the wetting and solute fronts were incorporated into fate and transport modeling to determine potential impacts to groundwater of the solute transport from the impoundment. The field measurements of the wetting and solute fronts agreed well with the theoretical water balance derived for the impoundment and with known hydraulic properties of the background soil. Hence, the borings validated the fate and transport model's prediction of the extent of solute transport through the vadose zone to the water table.

Additional Key Words: seepage, vadose zone, fate and transport

Introduction

Disposal of tailings in the unlined Giroux Wash tailings impoundment commenced in January 1996. The tailings solution present in the impoundment is alkaline (pH < 8) with an average TDS of 1820 mg/L. The major constituents in the TDS are calcium (averaging 600 mg/L) and sulfate (averaging 1200 mg/L). The 1800 acre ($7x10^6$ m^2) impoundment will ultimately hold approximately 280 million tons (2.5×10^{11} kg) of tailings (PTI 1994).

The objective of this investigation was to support a modeling effort (Anderson et al. 1997) to predict the impact, if any, that present and future tailings disposal at the Giroux Wash impoundment may have on water quality in the aquifers potentially affected by the facility. To achieve this objective, (1) background soil chemistry and hydraulic properties were evaluated at five locations in the impoundment area and (2) the vadose-zone infiltration rate and solute flux in the subsurface were directly measured at three locations in the portion of the impoundment where tailings were being actively deposited.

To quantify solute transport into the subsurface, chemical analyses of both solid soil and interstitial pore waters were obtained from samples collected within the deposited tailings and the subjacent background soils to a depth of approximately 40 feet (12 m) below the soil surface. Similar analyses were conducted on soil samples collected from outside the area of tailings deposition. The extent of solute mobility was determined by comparing the chemical profiles of the samples collected in the active impoundment area to the background profiles.

Sample Collection Methodology

Three sets of continuous soil samples were collected from beneath the impoundment, by angle boring from the embankment crest through tailings, and completed into the native substrate material. Angle drilling was performed using a roto-sonic drill rig with a 6-inch core barrel. Continuous sample was recovered from the three bores and samples were analyzed at selected intervals. Casing used to retain the bore walls for each angle boring was retracted upon drilling completion, and the open borehole filled and sealed

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with bentonite-augmented grout. The roto-sonic drilling was performed by Boart Longyear Environmental Drilling Co. (Peoria, Arizona).

Five vertical borings (background borings) were drilled to collect background material samples in locations outside of the impoundment footprint. Two borings were drilled by using roto-sonic drill techniques, and three vertical borings were drilled by using a 6-inch (15cm) diameter hollow-stem auger and sampled at 2-foot (61 cm) intervals from the ground surface with a split-spoon sampler. The hollow-stem auger drilling was performed by Andresen Drilling Co. (Reno, Nevada).

During drilling, pH and specific conductivity (SC) measurements were obtained from soil slurry samples. Field measurements were performed by collecting a subsample of the recovered soil and creating a slurry of one part soil to two parts distilled water (by volume) in precleaned plastic cups. The distilled water used in the process consistently registered pH between 6.0 and 6.3 and a SC below 10 $\mu S/cm^2$. The slurry was thoroughly stirred and homogenized using precleaned plastic spoons and immediately measured for pH and SC using Orion 920A and Fischer Conductivity meters, respectively. These field measurements were used as indicator measurements for determining the approximate location of the solute front to guide drilling activities.

Background Geochemical Characterization

Five background soil borings (B-1 through B-5) were drilled in Giroux Wash at locations outside of the tailings impoundment area. The background borings were drilled and sampled to establish ambient pH, SC profiles, and soil chemistry for areas known to be unaffected by the deposition of tailings. In general, the soil chemistry of background samples collected from different locations appears to be similar and moisture contents in the soils varied from 0.04 to 0.15. The measured pH values range between 7.3 and 9.3, and most of the SC values range between 60 and 300 $\mu S/cm^2$. The exception to this is the 6- to 12-foot (1.8 to 3.6 m) depth interval of B-1. Physical and chemical characteristics of background soils in the boreholes are described below.

The first background boring (B-1) was located approximately 50 feet (15 m)west of the main drainage through Giroux Wash and about 165 feet (50 m) south of the impoundment embankment. The upper interval of core obtained from B-1 was characterized as dry, unconsolidated, and well-sorted brownish-tan, silty sand with minor secondary calcite ($CaCO_3$). The sand unit was continuous from the surface to a depth of 11 feet (3.4 m), where a semiconsolidated and resistant gravel layer was encountered. Drilling and sampling continued until the 16.5-foot (5 m) depth interval at which point the resistance of the gravel layer resulted in auger refusal and precluded further sample recovery. As a result, the B-1 boring was terminated, backfilled with soil cuttings, and respudded approximately 10 feet (3 m) east of the original location. Drilling at the new location was successful in penetrating the gravel layer, and soil sample collection was resumed at the 16- to 18-foot (4.9 to 5.5 m) depth interval to a total depth of 20 feet (6 m).

SC values ranged from 175 $\mu S/cm^2$ in the top 2 feet (61 cm) of soil, where natural surficial leaching processes act to remove soluble soil salts, to 1910 $\mu S/cm^2$ at a depth of 12 feet (3.7 m). SC values steadily declined below the 12-foot (3.7 m) depth to the 20-foot (6 m) depth (600 $\mu S/cm^2$) where drilling ended. A pronounced "conductivity spike" was measured in the 10- to 14-foot (3 to 4.3 m) depth interval, which coincides with the gravel zone.

As with the SC measurements, soil chemistry changed around the 12-foot (3.7 m) interval, where high concentrations of chloride (483 mg/kg) and sulfate (5930 mg/kg) were encountered. These concentrations are considerably higher than those at the other background locations. Because there are also increased concentrations of aluminum and sodium at this depth, it is hypothesized that this "concentration and conductivity spike" reflects a normal buildup of salts (localized hardpan) that has accumulated at the sand-gravel interface.

Background boring B-2 was located approximately 0.5 mile (0.8 km) south of the impoundment, approximately 20 feet (6 m) north of the BHP property fence, which runs east-west across Giroux Wash, and is located approximately 50 feet (15 m) west of the main drainage in Giroux Wash. Soil core in B-2 was dry, unconsolidated, light brown, gravelly sand extending from the ground surface to the total boring depth at 18 feet (5.5 m). An increase in gravel content was observed at a depth of 10 to 12 feet (3 to 3.7 m). Unlike boring B-1, this gravel layer did not impede drilling; however, owing to the increased grain size and loose nature of the soil, there was no sample recovery from the 14- to 18-foot (4.3 to 5.5 m) depth interval. The hole was subsequently abandoned and backfilled with soil cuttings.

Field measurements of SC were relatively uniform along the entire depth of B-2, ranging from 89 μS/cm^2 at a depth of 4 feet (1.2 m), increasing to a maximum of 131 μS/cm^2 at 8 feet (2.4 m), and decreasing to 116 μS/cm^2 at 14 feet (4.3 m). As with B-1, the highest SC values recorded in boring B-2 are associated with increasing gravel content at the 8- to 12-foot (2.4 to 3.7 m) depth interval, suggesting that similar geochemical mechanisms, such as precipitation of calcite and other hardpan solid phases, may be occurring at the sand-gravel contact.

An additional background boring was located close to B-1 to determine whether the conductivity spike observed in B-1 was a localized phenomenon or had horizontal continuity. Background boring B-3 was subsequently located approximately 300 feet south of the impoundment and 50 feet west of the main drainage. Background boring B-3 was drilled to a total depth of 24 feet (7.3 m), through coarse, gravely sand at the surface (0- to 2-foot depth interval) transitioning to a buff-colored fine to medium sand between 2 and 4 feet (0.6 and 1.2 m), and then to a reddish silt with clay and fine sand from 4 to 24 feet (1.2 to 7.3 m). Some secondary calcite was observed in the upper 8 feet (2.4 m). Highly developed "partings" dominated the structure of this soil probably because of the presence of clay minerals.

The soil chemistry in B-3 is fairly uniform through its depth except that, like B-2, there is approximately twice as much calcium (102,000 mg/kg) in the 2- to 4-foot (0.6 to 1.2 m) layer than at the other locations. Data collected from B-2 and B-3 indicate that the concentration and conductivity spike observed in B-1 was a localized phenomenon without significant horizontal continuity. Therefore, the conductivity spike observed in B-1 is not considered relevant for comparing background sample data to impoundment sample data.

Background sample B-4 was located approximately 600 feet (183 m) west of the tailings impoundment, near the tree line that marks the edge of the impoundment area and in an area that will be inundated with tailings in the next year. Hence, the surface soil had been removed from this area. Soil core from B-4 consisted of a dry, unconsolidated, white gravelly sand. Unlike the previous borings, the sample was relatively uniform throughout its entire 20-foot (6 m) depth and lacked a distinct gravel layer. Field measurements of pH and SC were uniform throughout the boring. The pH ranged between 9.0 and 9.3, and the SC ranged between 67 and 101 μS/cm^2.

Another 20-foot (6 m) vertical boring (B-5) was completed northeast of the tailings impoundment in an area outside the ultimate impoundment footprint. Unlike the other background samples, soil core in B-5 varies distinctly with depth from the surface. The surface soil is a dark brown sandy soil with visible organic material. Soil recovered from the 5-foot (1.5 m) depth was a lighter brown than the surface soil and contained secondary calcite. Below the 5-foot (1.5 m) depth and down to a depth of 10 feet (3 m), sample consisted of reddish-brown sand. Beneath the 10-foot (3 m) depth, the sample contained powdery fine gray material representing bedrock at this location.

Field measurements of pH and SC were heterogeneous, as were the observed physical characteristics of the sample recovered from B-5. The surface soil had a pH of 7.6 and an SC of 75 μS/cm^2. The SC increased at the 5-foot (1.5 m) depth to 220 μS/cm^2, probably because of the presence of secondary calcite, whereas the pH was measured to be 7.3. At the 10-foot (3 m) level, the pH increased to 8.2, and the SC decreased to 90 μS/cm^2. In the bedrock (below 10 feet in depth), pH and SC at the 15- and 20-foot (6 m) depths were 8.4 and 8.5, and 66 and 62 μS/cm^2, respectively.

Impoundment Geochemical Characterization

Three angle borings were drilled by the roto-sonic rig from the top of the embankment to collect samples from both the tailings deposited in the impoundment and the native material, underlying the tailings, for assessment of soil and pore-water quality underlying the Giroux Wash Tailings Impoundment. Drilling was discontinued when measured pH and SC were similar to background measurements collected from native soil samples.

The borings were drilled from the top of the embankment at an angle between 30 and 35 degrees to the horizontal. The bores were drilled from the embankment crest and emerged from the side of the embankment approximately half-way between the crest and the tailings surface; casing was then pushed through the embankment, into open air, and then through the tailings until it met refusal at the interface between tailings and native material. The sample within the casing was recovered with the core barrel. These samples consisted mainly of tailings and some of the native material at the interface. To collect samples below the interface, a second casing was advanced as the drilling proceeded. After completion of the bores, the casings were filled with bentonite grout and then removed.

Because these bores were drilled at roughly a 30 degree angle from the horizontal, the bore depth is approximately twice the vertical depth (the sine of 30 degrees is one half). To avoid confusion, this text will refer to vertical depth only. Physical and chemical characteristics of impounded tailings and underlying soils collected from each borehole are described below.

A first, 35 degree boring (TB-1) was drilled at a location approximately 1000 feet (305 m) from the east end of the tailings impoundment embankment on December 7, 1996. This boring was closest to the point where tailings are discharged into the impoundment. The vertical bore depth of TB-1 was 53 feet (16 m), of which 25 feet (7.6) were through the embankment, 8 feet (2.4 m) were through tailings, and 20 feet (6 m) were into the substrate consisting of underlying natural soils. Samples recovered from TB-1 consisted of 7 vertical feet (2.1 m) of wet black tailings, underlain by 1 vertical foot (0.3 m) of wet black tailings mixed with gravel and coarse sand. Below this level, 5 vertical feet (1.5 m) of wet gravelly sand were recovered. Samples recovered from beneath the wet gravelly sand consisted of a fairly uniform gravelly, sandy loam that was slightly damp.

Field measurements of SC were taken on each sample as it was collected to determine the depth at which to cease drilling. Drilling was ceased after collection of several successive samples whose the SC measurements resembled those of the background samples. On-site field measurements for pH were attempted but were abandoned as the meter malfunctioned owing to the extreme cold. After collection, field measurements of SC were confirmed in the field laboratory located in a BHP warehouse. Measurements of pH were also made at that time.

Eight soil samples were collected from TB-1 and submitted to a Nevada certified analytical laboratory for Nevada Division of Environmental Protection (NDEP) Profile I Analysis for Solids. From these analyses, it was determined that analytes in the tailings have been transported approximately 1 foot (0.3 m) into the subjacent soil. Below that depth, analyte concentrations were similar to those established in the background analyses.

Another angle boring (TB-2) was located near the middle of the tailings impoundment, directly above the deepest tailings deposit. The boring was sampled to a total vertical depth of 63 feet (19.2 m); 22 feet (6.7 m) through the embankment, 12 feet (3.7 m) through the tailings, and 52 feet (15.8 m) into the substrate. The boring was completed on December 6, 1996. The sample recovered from TB-2 consisted of 11 feet (3.4 m) of black tailings, 1 foot (0.3 m) of wet tailings and sand, 3 feet (0.9 m) of damp sand, and 16 feet (4.9 m) of very slightly damp, gravelly, sandy, clay loam. The interface between the tailings and native material was located 12 vertical feet (3.7 m) below the surface of the tailings.

Six soil samples were collected from TB-2 and submitted to a Nevada certified analytical laboratory for NDEP Profile I Analysis for Solids. From these analyses, it was determined that analytes in the tailings have been transported approximately 1 foot (0.3 m) into the subjacent soil. Below that depth, analyte concentrations were similar to those established in the background analyses.

A final angle bore (TB-3) was located approximately 1000 feet (305 m) from the west edge of the impoundment embankment and was completed on December 5, 1996. Samples were collected from 53 vertical feet (16 m) of material; 22 feet (6.7 m) through the embankment, 11 feet (3.4 m) through the tailings, and 20 feet (6 m) through the substrate. The sample recovered from TB-3 consisted of 9 feet (2.7 m) of black tailings, 2 feet (0.6 m) of mixed tailings and sand, and 20 feet (6 m) of very slightly damp, gravelly, sandy, clay loam. The interface between the tailings and native material was located 11 vertical feet (3.3 m) below the surface of the tailings.

Nine soil samples were collected from TB-3 and submitted to a Nevada certified analytical laboratory for NDEP Profile I Analysis for Solids. From these analyses, it was determined that analytes in the tailings have transported approximately 2 feet (0.6 m) into the subjacent soil. Below that depth, analyte concentrations were similar to those established in the background analyses.

Conclusions And Discussion

On the basis of the field and laboratory data generated from the borings and sample analysis summarized in this report, tailings solution infiltration into native materials below the impoundment is limited to a zone less than 2 vertical feet (0.6 m) below the interface between the tailings and native material at the tailings borehole locations (Figure 1). In addition, wetting of the native material by water in the impoundment has not been observed at depths of more than 3 feet (0.9) below the tailings interface. Both of these observations are best represented by boring TB-3. These measured fronts are in good agreement with predicted infiltration rates based on the subjacent soil's hydraulic properties (WESTEC 1991; PTI 1994) and an estimated water balance for the impoundment (SRK 1997), which project a solute front at a depth of 2 feet (0.6 m) after 1 year (Geomega 1997). The depths of the wetting and solute fronts were incorporated into fate and transport modeling to determine potential environmental impacts of the solute transport from the impoundment (Anderson et al. 1997).

The gravimetric water content of the tailings ranges between 5% and 19% (total porosity of the tailings is 30%) whereas the water content in the substrate ranges between 6% and 15% (average total porosity of the soils 25%). In situ moisture contents measured in Giroux Wash soils prior to construction of the tailings impoundment ranged between 4% and 15% (WESTEC, 1991). Hence, it appears that neither the tailings, nor the substrate soils, are near saturation, which limits tailings solution infiltration into the native material underlying the impoundment.

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